# Biomethane

## Status and Factors Affecting Market Development and Trade

This publication focusses on the status of biomethane (which includes upgraded biogas and bio-SNG) production, grid injection and use in different IEA countries. It also illustrates the options and needs for the development of biomethane supply strategies with the focus on improved trade. Further, an overview of expected future development of the biomethane sector is given.

As part of the study, results from a dedicated questionnaire were assessed to get an insight into the opportunities and barriers for biogas and biomethane in the market in a number of countries.

This study has been compiled as a joint effort by experts from the Task 37 and 40 of the IEA Bioenergy Implementing Agreement.

**A Joint Study by IEA Bioenergy Task 40 and Task 37**

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# Biomethane – status and factors affecting market development and trade

**Authors:**

Daniela Thrän (UFZ/DBFZ), Eric Billig (DBFZ)

Tobias Persson, Mattias Svensson (SGC),

Jaqueline Daniel-Gromke, Jens Ponitka, Michael Seiffert (DBFZ)

John Baldwin (CNG Services)

Lukas Kranzl, Fabian Schipfer, Julian Matzenberger (TU Wien)

Nathalie Devriendt (VITO)

Mathieu Dumont (RVO)

Jonas Dahl (DTI)

Günther Bochmann (BOKU, University of Natural Resources and Life Science, Vienna)

**Editors**

Martin Junginger, chairman of IEA Bioenergy Task 40

David Baxter, chairman of IEA Bioenergy Task 37,

**Of a Joint Study on behalf of IEA Bioenergy Task 40 and Task 37**

IEA Bioenergy



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# Abbreviation

| Abbreviation | Meaning |
|---|---|
| AFFSET | Agence française de sécurité sanitaire de l'environnement et du travail |
| BAT | Best Available Technology |
| bcm | billion cubic meters ($10^9$ m³) |
| Bio-SNG | Synthetic Natural Gas from biomass |
| BTEX | benzene, toluene, ethylbenzene and xylenes |
| CEN | Comité Européen de Normalisation |
| CHP | combined heat and power |
| CNG | compressed natural gas |
| EATS | exhaust after-treatment systems |
| EC | European Commission |
| EGR | exhaust gas recirculation |
| FICFB | fast internally circulating fluidised bed |
| FQD | Fuels Quality Directive |
| GBEB | Global Bioenergy Partnership |
| GHG | greenhouse gas |
| GWP | Global Warming Potential |
| HCN | Hydrogen cyanide |
| ICE | internal combustion engine |
| IEA | International Energy Agency |
| IEA-AMF | International Energy Agency – Advanced Motor Fuels |
| iLUC | indirect land use change |
| ISO | International Organisation for Standardization |
| LBG | liquefied biomethane |
| LCA | Life Cycle Assessment |
| LNG | liquefied natural gas |
| MN | methane number |
| MON | Motor Octane Number |
| NGV | Natural gas vehicle |
| NG | natural gas |
| NREAP | National Renewable Energy Action Plan |
| NWIP | New Work Item Proposal |
| OECD | Organisation for Economic Co-operation and Development |
| OEM | Original Equipment Manufacturer |
| PAH | Polycyclic Aromatic Hydrocarbons |
| PSA | pressure swing adsorption |
| RED | Renewable Energy Directive |
| RTO | regenerative thermal oxidation |
| SAE | Society of Automotive Engineering |
| SNG | Synthetic Natural Gas |
| SP | Technical Research Institute of Sweden |

# Glossary

**Biogas:** Biogas, sometimes called raw biogas, is the combustible product of the anaerobic digestion of different biomass substrates. It contains mainly methane ($CH_4$) (typically 50 – 70%) and carbon dioxide ($CO_2$).

**Biomethane from biogas upgrading:** Biomethane from upgraded biogas describes the production of biomethane by microbiological processes. The initial product is raw biogas which must be cleaned (normally called upgrading) to reach the high methane content

**Biomethane:** Biomethane is defined as methane produced from biomass (source: ISO DIS 15669, in preparation), with properties close to natural gas. It can be produced by thermochemical conversion (see bio-SNG) or biochemical conversion (see biomethane from biogas upgrading).

**Bio-SNG:** Bio-SNG stands for biological synthetic natural gas and is a methane rich gas. It is produced via gasification of lignin rich feedstock like wood followed by methanation.

**Gasification:** Gasification, as a part of the bio-SNG production, describes the conversion of woody, lignin-rich materials into a synthetic gas by using of a gasification medium e.g. steam or oxygen. The produced synthetic gas consists mainly of carbon monoxide, carbon dioxide, methane, hydrogen and vapor in different proportions.

**H-gas:** Natural gas quality specified by the Wobbe index. In these cases the gas is divided by the Wobbe index. H-gas stands for high-gas. The range (in Germany) for the Wobbe index is 12.8 to 15.7 kWh/m³. (DVGW 2000)

**L-gas:** Natural gas quality specified by the Wobbe index. L-gas stands for low-gas. The range (in Germany) for the Wobbe index is 10.5 to 13 kWh/m³. (DVGW 2000)

**Methanation:** Methanation is the conversion of the synthetic gas, which is produced during gasification, into a methane rich gas. Generally a catalyst, often nickel, is used for reaction. The product is a gas, which consist mainly of methane and carbon dioxide, similar to biogas.

**Siloxanes:** Are functional groups where two silicon atoms are connected via an oxygen atom. Depending on the substrate used to produce biogas and the process used for purification, biomethane can contain siloxanes. During combustion, siloxanes can be oxidized to silicon dioxide, an abrasive compound harmful for mechanical moving parts in e.g. engines and turbines.

**SNG:** SNG stands for synthetic natural gas and describes a methane rich gas. It is produced via gasification followed by methanation of carbon-rich feedstock such as coal.

**Wobbe index:** This index is an indicator of the quality of a fuel gas, measured from the heat produced by burning through a defined orifice under standard temperature and pressure conditions.

# Executive summary

In most IEA member countries, natural gas (NG) plays an import and particular increasing role in energy provision to meet the demand for heat, electricity and transport fuels. Hence, natural gas is an important all-round energy carrier with an already well-developed infrastructure in some countries such as gas grids, filling stations, road transport via heavy duty vehicles or marine transport via tanker in the form of compressed natural gas or liquefied natural gas. Nevertheless natural gas is a fossil based fuel and various countries have initiated the stepwise transition from a fossil resource base towards renewables due to concerns regarding greenhouse gas emissions, energy security and conservation of finite resources.

Biomethane, defined as methane produced from biomass with properties close to natural gas, is an interesting fuel to support the transition from fossil fuels to renewables and to achieve the greenhouse gas emission reduction targets in different ways. In principal, biomethane can be used for exactly the same applications as natural gas, if the final composition is in line with the different natural gas qualities on the market. Therefore, it can be used as a substitute for transport fuels, to produce combined heat and power (CHP), heat alone or serve as feedstock for the chemical sector. It can be transported and stored in the facilities and infrastructure available for natural gas. Biomethane can be produced by upgrading biogas or as so called bio-SNG from thermo-chemical conversion of lignocellulosic biomass or other forms of biomass.

**The aim of this study is to provide an up-to-date overview of the status of biomethane (which includes upgraded biogas and bio-SNG in this report) production, grid injection and use in different countries, and to illustrate the options and needs for the development of larger biomethane supply strategies.** The focus is on technical, economic and management-related hurdles to inject biomethane into the natural gas grid and to trade it transnationally. The study provides insights into the current status of technologies, technical requirements and sustainability indicators as well as cost of biomethane production and use in general and especially in selected countries. The study also assesses implementation strategies, market situations and market expectations in selected countries. Based on the findings in this report, proposals are given for actions to be taken to reduce barriers and to develop the market step by step.

The technical feasibility to produce biomethane from biogas on a large scale has been demonstrated over the last decade. Table 4-1 gives an overview of the biomethane production in selected IEA member countries. At the time of writing this report about 280 biogas upgrading plants were running in several countries with an overall production capacity of some 100.000 $Nm^3/h$. To inject biogas in the natural gas grid or to use it as a vehicle fuel, the raw biogas has to be upgraded and pressurised. Biogas upgrading includes increasing the energy density by separating carbon dioxide from methane. Furthermore, water, hydrogen sulphide and other contaminants are removed, sometimes before the upgrading process to avoid corrosion or other problems in downstream applications. Today, a range of technologies for $CO_2$-separation are on the market. It is difficult to specify the exact characteristics for an upgrading technology, since the design and operating conditions vary between the different manufacturers, sizes and applications. The key quality criteria for the upgrading technologies are the energy demand and the methane loss during upgrading.

The production of biomethane via thermo-chemical conversion is still in the pilot and demonstration stage, with no commercial market penetration so far.

**Table E-1:** Biomethane development in selected IEA bioenergy member countries in 2012 (Daniel-Gromke et al. 2013),(Dumont 2014), (Álamo 2013), (Strauch 2012), (Lampinen 2013), (Govasmark 2012), (Kang 2013), (Paulsson and Steinwig 2012), (Persson and Baxter 2014), (EBA 2013), (EBA 2012), (Grossen and Schmid 2012), (EPA 2013b), (biogas data 2013), (Thorson 2013), (Ministry of Environment 2012), (Rasmussen 2011), (Danish Energy Authority 2013), (DGC 2013), (NNFCC Biocentre 2013) (Note: excluding landfill gas plants)

| Country | Biogas Plants[1] | Biogas Upgrading Plants (Fed In) | Upgrading Capacity[2] in $Nm^3/h$ | Gas Filling Stations[3] | Gas Driven Vehicles[4] |
|---|---|---|---|---|---|
| Austria | 421 | 10 (7) | 2,000 | 203 | 7,065 |
| Belgium | 119 | 0 | 0 | 15 | 355 |
| Brazil | 16 [7] | n.d. | n.d. | 1,790 | 1,719,198 |
| Canada | ~ 50 [5] | 2 (n.d.) | 400 | 83 | 14,205 |
| Denmark | 137 | 1 (1) | 180[6] | 4 | 81 |
| Finland | 34 | 5 (2) | 959 | 18 | 1,300 |
| France | 256 | 3 (2) | 540[6] | 149 | 13,300 |
| Germany | 9,066 | 120 (118) | 72,000 | 904 | 95,162 |
| Ireland | 22 | 0 | 0 | 0 | 3 |
| Italy | 1,264 | 1 (0) | 540[6] | 903 | 746,470 |
| Luxembourg | 31 | 3 (3) | 894[6] | 7 | 261 |
| Norway | 44 | 5 (n.d) | n.d. | 23 | 353 |
| South Korea | 57 | 5 (n.d.) | 1,200[4] | 184 | 39,000 |
| Sweden | 187 | 53 (11) | 16,800[6] | 190 | 44,000 |
| Switzerland | 600 | 16 (16) | n.d. | 136 | 11,500 |
| The Netherlands | 211 | 16 (16) | 6.540[6] | 150 | 5,201 |
| U.K. | 265 | 3 (3) | 1,260[6] | 40 | 520 |
| USA | ~ 440 | 25 (n.d.) | n.d. | 1,035 | 112,000 |
| Total | >13,000 | 260 (>=179) | >100,000 | >5,800 | >2,800,000 |

n.d. – no data
[1] including waste water treatment plants, no landfill plants included
[2] referring to biomethane
[3] total (public and private)
[4] motorcar, public transport, truck; natural gas vehicles (NGV)s
[5] only biogas plants, no data for waste water treatment plants available
[6] assuming 60% $CH_4$ in the raw biogas
[7] no waste water treatment plants and no landfill plants included

The small-scale production of biomethane at many different locations is a new phenomenon, and requires additional efforts to adapt the regional infrastructure and to find adopted transport modes outside the natural gas grid. Biomethane may also play a significant role in future power-to-gas concepts by combination of renewable methane from excess energy, e.g. by providing the renewable carbon source (separated $CO_2$), so that hydrogen produced from excess electricity and the renewable carbon source can be converted to methane, thus the overall methane output can be increased.

Even if the technical and logistical requirements for biomethane production are in principle available today and in some areas already implemented on a local level, clear criteria for the biomethane quality (transnational) to be fed- into the gas grid and the end use application are necessary. Compared to conventional fuels, the level of standardization is sparse for gaseous fuels. The international ISO (International Organisation for Standardization) has issued a natural gas standard, ISO 13686:1998 "Natural gas - Quality designation" and a standard for compressed natural gas, ”ISO 15403 Natural gas – Natural gas for use as a compressed fuel for vehicles”. The normative part of both standards contains no levels or limits, but have informal parts included with information for suggested values for gas composition, i.e. from national standards or guidelines from France, Germany, the UK and the U.S. The absence of quantitative limits reflects the prevalent view of the gas industry that no precise gas quality can be specified, given the wide range of compositions of the raw gas obtained from underground. Up to recent years, the natural gas vehicle business has adjusted to this, international and national standardization focussing more on safety issues regarding vehicle cylinders, other gas-related components and refuelling stations. Regarding biomethane, there is a range of national standards in Europe for the injection of upgraded and purified biogas to the natural gas grid. Work on the international standardization of biomethane has been on-going since 2006. The specific challenge is to define standards which are attractive for the different potential end-user (gas grid owner, automotive industry, etc.) to enter the new market. Intensive discussions primarily concern sulphur and silicon content. Currently, two different standards for grid injection and automotive specification are under development at European level and might be passed by the end of 2015.

One key driver for the application of biomethane is the reduction of greenhouse gas emission (GHG) due to the substitution of fossil fuels. The emission reduction potentials depend on both plant design and operation, as well as the GHG accounting methodology. By following best practices, it is possible to achieve GHG savings of over 80% when compared to the fossil fuel alternative. Key parts in the production of biomethane that contribute to these GHG emissions include biomass feedstock cultivation (e.g. energy crops like maize) and different biogas upgrading technologies. Sustainability standards for biomass have been discussed and developed in different contexts during the last years. The most important approaches are the indicators from the Global Bioenergy Partnership (GBEP) and the demands from the European Directives on Renewable Energy and Fuel Quality. The EU sustainable criteria are only obligatory for biomethane when it is used as fuel for transport. It is so far not obligatory for biomethane if it is used in other fields, such as for CHP. Outside the EU (e.g. USA (U.S. Congress 2005)) biofuel sustainability criteria are established for liquid biofuels but do not refer to biomethane.

Compared to natural gas, the biomethane provision is linked to higher costs, at least on the short- and middle-term. To ensure a sustainable feedstock as well as a proper and transparent mass balance for the biomethane which is transported and traded via the natural gas grid, uniform and cross-border standards for biomethane composition and quality are necessary.

Today, the biomethane market is still at the very beginning. Different strategies, investment programmes, support schemes and utilisation concepts have been adopted in different countries and there are different stakeholder expectations. Due to the complex supply chain, see Figure E-1, there are different environmental, economic and administrative hurdles for the market introduction of biomethane. On the other hand, a survey of market expectations in five selected focus countries of IEA Tasks 37 and 40 showed that many stakeholders have quite strong expectations for market growth. Even if the response to the survey per country is not sufficient for a statistically sound analysis, it gave an insight in the trends and perceptions in the countries (Austria, Belgium, Germany, The Netherlands and Sweden).

Regarding the policy for biomethane, it can be concluded that a good framework is necessary to push biomethane development forward. Because of the challenging conditions of the post-economic crisis of 2008, biomethane needs political support and as a result of that financial support. This conclusion is the same for all the countries surveyed. Even in countries like Germany and Sweden that have strongly promoted biomethane, financial support is still an important factor. When asked if international trade should be developing, experts from Belgium, Germany and Sweden answered positively. Respondents from the Netherlands and Austria were more sceptical whether international trade could or should be established in the future. The main reason for doubt is that demand for biomethane in these countries is higher than the production, so there will be nothing left for export. The Swedish respondents reported that they hope to import biomethane to satisfy the increasing demand.

Market introduction strategies have to consider the complex provision chain (Figure E-1), which has to include the very different stakeholders.

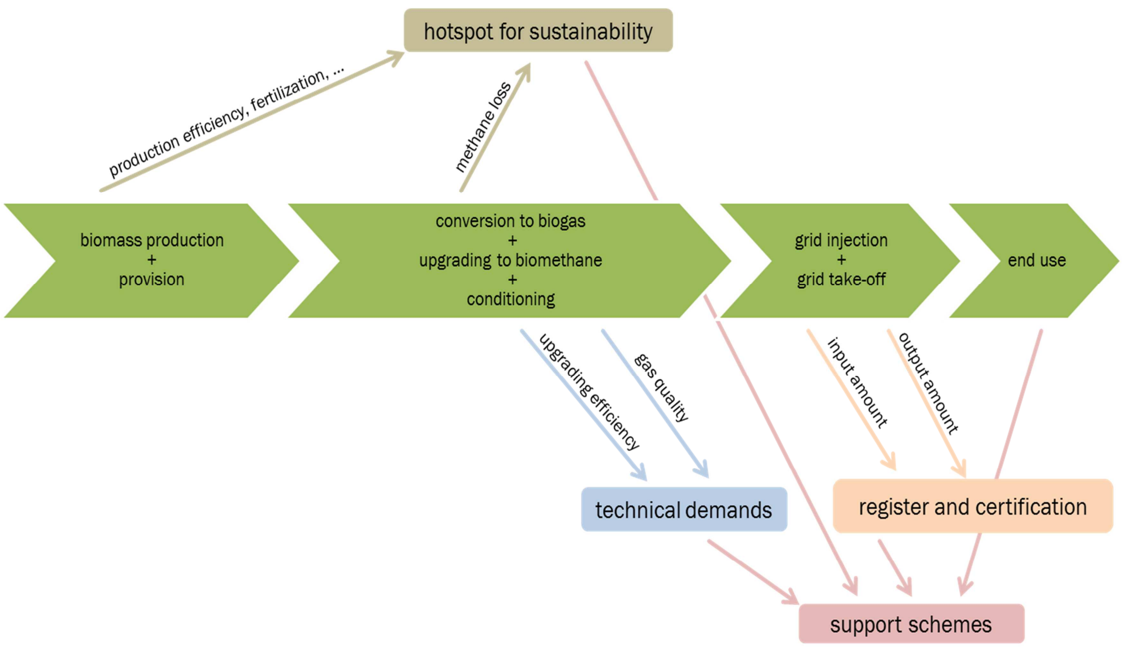


**Figure E-1.** Framework of the biomethane value chain

Promising markets are seen in those countries with dedicated biomethane strategies, targets and support schemes. Today there is a wide range of approaches, instruments and certificates established which can differ in technical demands on grid injection and end use, sustainability demands, support schemes and monitoring of the biomethane flows.

Given the political strategies and the presence of an extensive natural gas grid, a number of EU countries are becoming more active in the development of a biomethane market. There are on-going actions in the field of technical standardisation and sustainability certification, including mass balancing and tracing. Both are complex issues, but should provide instruments in the next one or two years to improve the situation with biomethane application and cross border trade. Several European countries have established national biomethane registers, which provide information on the amount and origin of the available biomethane qualities to support the market implementation. Furthermore, there is already a planned close cooperation between the national biomethane registers for better trade between six countries with the option of including more countries, see chapter 3.3.3. Relevant next steps for those registers are the development of a common terminology, tracing system and the definition of interfaces between the country specific quality demands while also enabling accounting and monitoring of the market. Additional problems for transnational trade arise from the different support schemes developed in the different countries. Two aspects are relevant here:

> (i) The part of the supply chain to which the financial policy support is applied: Currently in the different countries different products are supported (biomethane feed into the grid, electricity provided from biogas, biomethane provided at filling stations, etc.). From a national perspective this is reasonable due to different targets and strategies for biomethane, but for international cooperation there is the risk of confusion. For international trade a very clear tracking of flows is necessary in order to avoid double support or marketing (e.g. at the injection point in one country and at the delivery point in another country).
>
> (ii) Level of support: Today the specific level of support differs over a wide range (e.g. the feed-in-tariff for biomethane injected into the grid). If framework conditions for international trade are implemented it will be very easy to transport the biomethane via the gas grid to those countries giving the higher support or otherwise very favourable framework conditions, which may on the one hand accelerate market development, but on the other hand may also cause some national support systems to collapse.[1]

This has led to the conclusion that a more coherent EU-wide support structure between countries could make market development easier and reduce the complexity of the registry systems. To ensure a successful regulated and sustainable market, stable framework conditions are needed. Therefore, the following recommendations can be given for such a future biomethane market:

- Technical standards regarding for biomethane injection to the natural gas grid, which aims for standardised biomethane quality (in a defined range) regarding e.g. calorific value and purity.

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[1] Comparable experiences were made when single European countries implemented renewable electricity certificates at the beginning of the 21st. century, i.e. in the Netherlands large amounts of renewable electricity were imported as certificates to get a tax exemption. Within two years the Dutch government had to significantly change the tax exemption scheme and ultimately switch to a different support scheme altogether.

- Sustainability standards for all biomethane applications, but also with the possibility to trade sustainable biomethane between the countries.
- Certification and registries for a transparent national and international market of biomethane (e.g. no double support).
- Equal treatment of domestic and imported biomethane (certification, support/incentive, etc.).
- Support schemes need to be stable over the long term. From today's perspective, uniform regulation for regions connected by a single natural gas grid (e.g. Europe) seems to be an important pre-requisite for the development of international markets; this study did not investigate in detail what such an instrument could contain (e.g. a uniform biomethane grid injection tariff, a quote, etc.).
- Roadmaps for middle and long term biomethane targets in order to provide a guide for incentives and support schemes.

With regard to the complex provision chain of biomethane, different stakeholders in the field and the transnational natural gas grid (especially in Europe) it is easy to understand that framework conditions are difficult to achieve. Implementing the above recommendations should provide a good base for building a sustainable, fair, future-orientated and stable biomethane market. An overarching international framework of sustainability information (e.g. feedstock, origin, GHG emission from production and transport, etc.) for fossil and renewable energy carrier could also support the biomethane market, but goes beyond the scope of this study.
Outside the EU, only minor activities were observed, such as in the USA and South Korea, with less restriction than in the EU.

# 1. Introduction

## 1.1. Background

In most IEA member countries natural gas (NG) is an important resource for meeting the demand of heat, electricity and fuel. Natural gas is an important all-round energy carrier with an already well-developed infrastructure in some countries such as pipelines (natural gas grid, see the example of Europe in Figure 1-1) and filling stations as well as new developing infrastructure like road transport via heavy duty vehicles or marine transport via tanker in the form of compressed natural gas (CNG) or liquefied natural gas (LNG). Where there are existing pipelines NG is easy to transport and has comparably low environmental impacts (low-emission combustion, see chapter 3.2.2). Further expansion in usage is expected (IEA 2012).

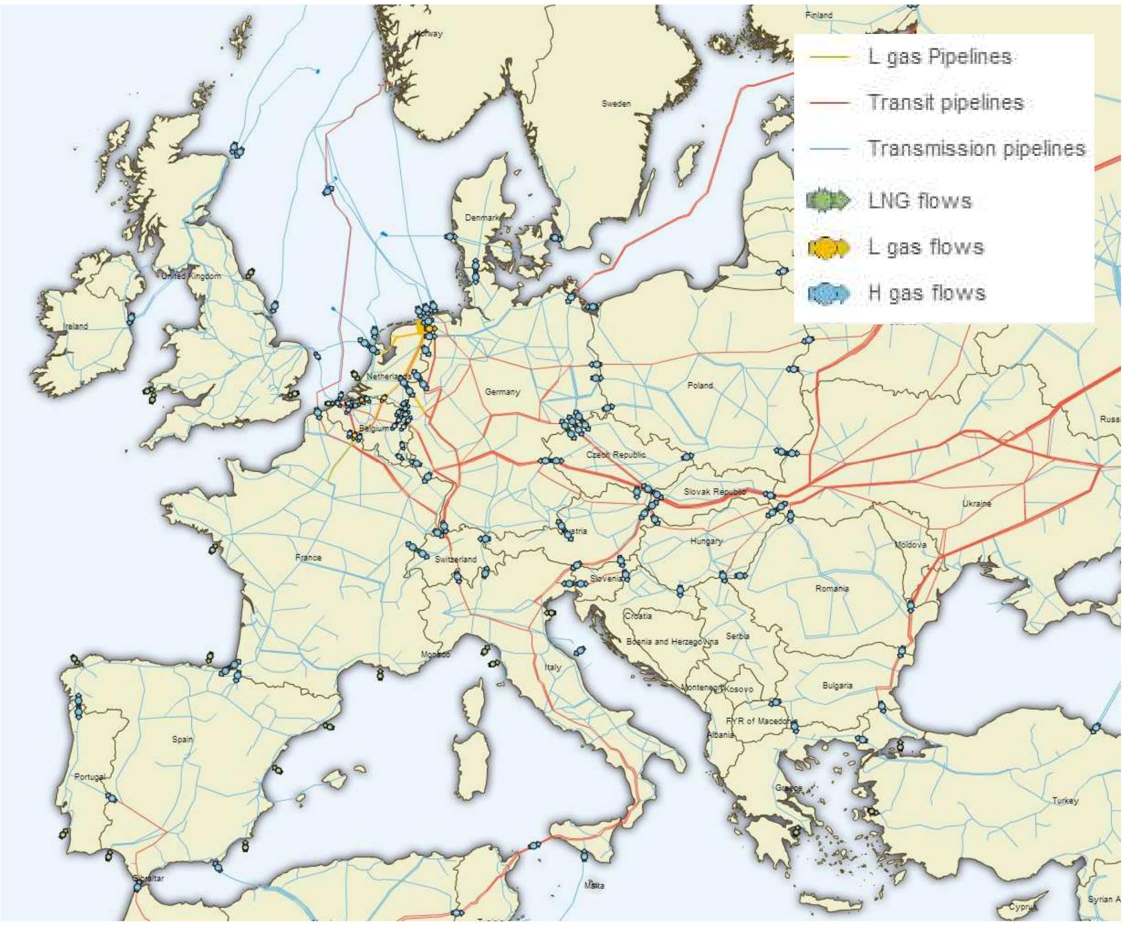


**Figure 1-1.** IEA, gas trade flows in Europe (OECD/IEA 2014). LNG: liquefied natural gas; H-gas and L-gas stand for certain natural gas qualities specified by the Wobbe index (see also glossary)

Over the past few decades, natural gas has become more important in different parts of the world. For example, most EU countries with limited own production (except for Denmark, the United Kingdom and the Netherlands) have been forced to increase their imports.

Overall, the OECD Europe[2] imported 265 billion cubic meters in 2010 and this is estimated to increase to 335 billion cubic meters by 2020 (IEA 2012). Other countries are expanding use of natural gas to fill the gaps for future energy demand (e.g. Japan, China) (IEA 2013a). The most important suppliers are Russia, the Middle East, Canada, Norway and North Africa. However, the United States of America are currently changing from a natural gas importer to a natural gas exporter because of the increasing shale gas recovery (IEA 2012). Various countries that have implemented or are currently implementing policy strategies (based on the Kyoto Protocol) on greenhouse gas emission reduction, energy security and protection of finite resources have initiated the stepwise transition from a fossil resource base towards renewables, such as the member states of the EU (European Union 2009a) and the USA (EPA 2013a). Some countries have set concrete targets for the substitution of natural gas (e.g. Germany and Luxemburg).

Biomethane is defined as methane produced from biomass (ISO 16559:2014), with properties close to natural gas. When produced by thermal conversion (e.g. gasification and methanation), the methane-rich product gas is normally referred to as biobased synthetic natural gas (bio-SNG), whereas when it is produced by biological processes, including landfills and waste water treatment, the initial product is raw biogas which must be cleaned (normally called upgrading) to reach the high methane content that is referred to as biomethane from biogas upgrading. Bio-SNG and biomethane from upgraded biogas are essentially chemically identical and must meet the same technical specification to be injected into natural gas pipelines.

Biomethane in principal can be used for exactly the same applications as natural gas, if the final composition is in line with the different natural gas qualities on the market (i.e. H-gas and L-gas). Therefore, it can be used as a substitute for liquid transport fuels, to produce combined heat and power (CHP), heat alone and serve as feedstock for the chemical sector. In contrast to liquid biofuels such as biodiesel and bioethanol, biomethane and natural gas are fully interchangeable from an end-user perspective. Biomethane can also play a significant role in future power-to-gas concepts by combination of renewable methane from excess electrical energy, e.g. by providing the renewable carbon source (separated $CO_2$), so that hydrogen from excess energy conversion can be used to increase the methane output of biogas process.

Due to the close relationship with the natural gas market, energy units for biomethane are usually given in $Nm^3$ or kWh (1 $Nm^3$ of biomethane typically contains 10 kWh primary energy, equivalent to 36 MJ).

## 1.2. Aim, scope and data sources of this study

The aim of this study is to provide an up-to-date overview of the status of biomethane (which includes biomethane obtained from biogas and bio-SNG from gasification-of biomass) production, grid injection and use in different countries, and to illustrate the options and needs for the development of biomethane supply strategies. The focus is on technical, economic and management-related hurdles to inject biomethane into the natural gas grid and to trade it transnationally. Therefore, the study provides insights on the current status

[2] OECD Europe: Austria, Belgium, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Luxembourg, Netherlands, Norway, Poland, Portugal, Slovak Republic, Slovenia, Spain, Sweden, Switzerland, Turkey and United Kingdom. For statistical reasons, this region also includes Israel.

of technologies, technical requirements and sustainability indicators as well as cost of biomethane production and use in general and especially in selected countries. The study also assesses implementation strategies, market situations and market expectations in selected countries. Based on the findings in this report, proposals are given for actions to be taken to reduce barriers and to develop the market step by step.

The study provides an overview on the technical demands on the provision of biomethane usable as a substitute for natural gas (chapter 2), the non-technical barriers and opportunities (chapter 3), market situation and expectation for biomethane in selected countries (chapter 4) and stepping stones towards market deployment and trade (chapter 5). Finally, conclusions are drawn with regard to necessary steps for the implementation of international markets.

This report was written for IEA Bioenergy Task 37 and Task 40. The sole responsibility for the content of the publication lies with the authors. It does not necessarily reflect the opinion of the IEA or the members of the IEA Bioenergy Implementing Agreement. IEA Bioenergy Task 37 and Task 40 have reviewed and approved this report, but are not responsible for any use that may be made of the information or opinions contained therein.

The study is based on open literature. Also, data have been collected from member countries of Task 37 and Task 40[3]. Given the large amount of biogas production in a number of EU countries, the study focusses on Europe, with detailed investigation of some countries (Austria, Belgium, the Netherlands, Sweden and Germany). However, it is evident that a number of countries in Asia and the Americas are rapidly increasing interest in biomethane production. An important source of information for this study was the EBA Biogas report 2013 and the "Overview of Biomethane markets …" reports of the green gas grid project as well as the Task 37 and Task 40 country reports. (EBA 2013), (GGG 2012)

# 2. Production technologies for biomethane

## 2.1. Overview on production pathways

Biomethane can be generated from various sources of biomass using two different processes: anaerobic fermentation and thermochemical gasification (Figure 2-1). They are characterised by using different feedstocks, technologies and different scales for conversion, while the energy yield, e.g. from energy crops per hectare arable land is similar. Biomethane can be produced from a wide range of feedstocks, so in general, the technical biomethane potential could be very high (source (Thrän et al. 2007)).

Anaerobic digestion and biogas upgrading has been successfully demonstrated. On a global level, about 277 biogas upgrading plants, connected to anaerobic digesters, were in operation in the end of 2012. Their geographical location can be seen in Figure 2-2. Biomethane can be transported and stored in the facilities and infrastructure available for natural gas. Some degree of pressurisation is needed for injection into NG pipelines.

Table 2-1 gives a general overview of the range of the components of biogas compared to natural gas.

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[3] Austria, Belgium, The Netherlands, Sweden, Germany, France, Switzerland, United Kingdom, Italy, Denmark, Ireland, Finland, Norway, United States of America, Canada, Brazil, Korea

Gasification and methanation of biomass to bio-SNG is still in the research and demonstration stage. Production of bio-SNG was demonstrated for the first time on a 2 MW-scale in Güssing/Austria using a fluidised bed gasifier and forest residues. The next step in the scale-up process (to 20 MW) is taking place in Sweden.

| | **Anaerobic Digestion and Upgrading** | **Gasification and Methanation** |
|---|---|---|
| |  |  |
| **Capacities** | Low to medium capacities 1 to 60 $MW_{CH4}$ | Medium to high capacities, 20 to 340 $MW_{CH4}$ |
| **Feedstocks** | Biogas substrates, mainly liquid manure, organic residue and silage (e.g. maize, grain, gras)<br>~ 8.000 t fresh matter per year and $MW_{CH4}$ | Biogenic ligneous fuels, like (residual) forest wood, industrial waste wood, short-rotation wood<br>~ 3.500 t fresh matter per year and $MW_{CH4}$ |
| **Area sp. yields** (energy crops) | 3.000 to 4.500 $m^3_N$/(ha a)<br>(e.g. maize silage) | 3.500 to 5.000 $m^3_N$/(ha a)<br>(short-rotation wood, e.g. willow) |

**Figure 2-1.** Provision routes of biomethane, adapted from (Thrän 2012)

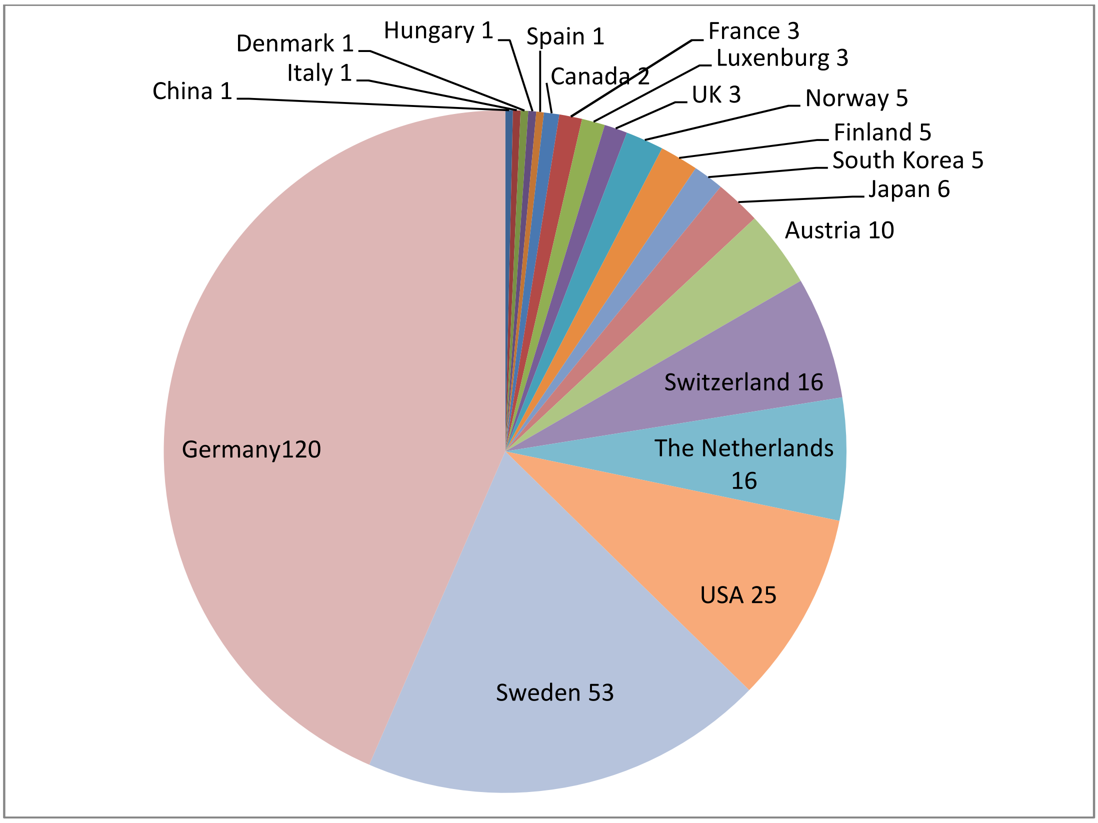


**Figure 2-2.** Location of 277 biogas upgrading plants, connected to anaerobic digesters, in operation at the end of 2012.

Biomethane can be transported and stored in the facilities and infrastructure available for natural gas. Some degree of pressurisation is needed for injection into NG pipelines.

**Table 2-1.** Properties of natural gas and raw biogas (DVGW 2000), (DVGW 2004), (Beil et al. 2011)

| **Substance** | **Biogas from anaerobic fermentation** | **Natural gas (H-gas quality)** |
|---|---|---|
| methane | 50 – 85 % | 83 – 98 % |
| carbon dioxide | 15 – 50 % | 0 – 1,4 % |
| nitrogen | 0 – 1 % | 0,6 – 2,7 % |
| oxygen | 0,01 – 1 % | - |
| hydrogen | traces | - |
| hydrogen sulfide | up to 4,000 ppmv | - |
| ammonia | traces | - |
| ethane | - | up to 11 % |
| propane | - | up to 3 % |
| siloxane | 0 – 5 mg/m$^3$ | - |
| Wobbe Index | 4.6 – 9.1 | 11.3 – 15.4 |

## 2.2. Technical options for biogas upgrading

To inject biogas in the NG grid or to use it as a vehicle fuel, the raw biogas has to be upgraded and pressurised. Biogas upgrading means that the carbon dioxide in the biogas is removed to increase the energy density. Furthermore, water, hydrogen sulphide and other contaminants are also removed (this step is commonly called gas cleaning), sometimes before the upgrading process to avoid corrosion or other problems in downstream applications.

There are different methods used for carbon dioxide removal. Absorptive and adsorptive processes can be distinguished as well as processes based on membrane filtration or cryogenic separation. The different technologies are described below and some performance information is summarised in Table 2-2.

In the **water and the organic physical scrubber** the biogas is pressurized (5-10 bar) and the carbon dioxide is dissolved in the water or a selective organic solvent. The biogas is upgraded and the dissolved carbon dioxide is released from the solvent in a desorption vessel at atmospheric pressure during air stripping.

In a **chemical scrubber**, the in water dissolved carbon dioxide (carbon acid) reacts with an added amine and thus can be separated from the gas stream. This process can be carried out at atmospheric pressure since it is a chemical reaction that drives the process. Heat is needed to reverse the reaction and release the carbon dioxide in a stripper vessel and restore the amine.

In a **pressure swing adsorption (PSA)** system, the raw biogas is pressurized (3-10 bar) and fed into an adsorption column filled with an adsorbent, such as carbon molecular sieves. Carbon dioxide is adsorbed by the bed material and the biomethane passes through. The carbon dioxide is desorbed from the adsorbent by reducing the pressure and using a purge gas (commonly biomethane).

In **membrane separation** the biogas is pressurized (5 – 20 bar) and fed into the membrane unit. The carbon dioxide, as well as other gas components, permeates through the membrane, whereas the methane is retained. The performance varies widely depending on the settings (e.g. pressure stages, loops) and the unique design adopted by each manufacturer.

**Cryogenic separation** is a developing technology with so far only one plant in operation according to the knowledge of the authors. Methane and carbon dioxide are separated by gradually cooling down the raw biogas. All compounds with higher condensation temperature than methane, such as water, hydrogen sulphide, siloxanes and nitrogen, can be separated in this process. Since this is still a developing technology it is not included in Table 2-2. In case of an increasing share of LNG in the market, e.g. for transport, cryogenic separation might be of growing importance because of the benefits to be gained by integration of $CH_4$ separation with liquefaction units for the $CH_4$.

In a water scrubber, hydrogen sulphide is commonly separated together with carbon dioxide. For the other technologies, an external $H_2S$ removal device is needed. Commonly, this is an activated carbon filter, but other technologies also exist on the market (Petersson 2013). Regarding siloxanes (derived from waste consumer products and especially prevalent in landfill gas), preliminary results suggest that they are effectively separated by most upgrading technologies (Arrhenius et al. 2011). However, more detailed research is needed for verification. More detailed information about the different technologies used for biogas upgrading can be found in the literature (Bauer et al. 2013a).

**Table 2-2.** Overview of the properties and the performance of the mature biogas upgrading technologies (Bauer et al. 2013a)

| **Parameter** | **Water scrubber** | **PSA** | **Membrane (2-4 stages)** | **Chemical scrubber (amine)** | **Organic physical scrubber** |
|---|---|---|---|---|---|
| $CH_4$ in product gas | 96 – 98 % | 96 – 98 % | 96 – 98 % | 96 - 99 % | 96 – 98 % |
| Availability | 95 - 98% | 95 – 98 % | 95 - 98% | 95 - 98% | 95 – 98 % |
| Annual maintenance cost (% of investment cost) | 2 - 3% | 2 – 3 % | 3 – 4 % | 2 – 3 % | 2 – 3 % |
| $H_2S$ removal | Yes | External | External | External/Yes | External |
| $H_2O$ removal | External | Yes | Yes | External | External |
| $N_2$ and $O_2$ separation | No | No/partly | Partly ($O_2$) | No | No |
| Electricity consumption (product gas > 4 bar(g)) (kWh/Nm³ raw biogas) | 0.2 – 0.3 | 0.2 – 0.3 | 0.2 – 0.3 | 0.10 – 0.15 | 0.2 – 0.3 |
| Heat (kWh/Nm³ raw biogas) | None | None | None | 0.5 – 0.6 | Internal |
| Pure $CO_2$ | No | Yes | Yes | Yes | No |

The first biogas upgrading plants were built in the 1980´s and a few more in the 1990´s, but it was not until 2006 that development really took off, especially in Germany. From then until today, more than 200 biogas upgrading plants have been built and taken into operation. Pressure swing adsorption (PSA) and water scrubber have had major parts of the market since the beginning. From 2009, chemical scrubbers (e.g. amine scrubber) have increased their market share. The latest developments indicate that the membrane technology will gain a larger market share in the coming years. The existing market share between the different technologies is shown in Figure 2-3.

Methane loss (normally called methane slip) from biogas upgrading is intensively discussed in some countries. Larger manufacturers guarantee methane losses below 0.5 - 2% in a new plant, and 0.1% for amine scrubbers. Some type of off-gas treatment is needed for all technologies, except for the amine scrubber, in markets such as Germany where only 0.2% of the methane is allowed to be released from the upgrading plant. However in other countries, such as Sweden, off-gas treatment is commonly not needed since larger methane emissions are allowed from the upgrading plant.

The electricity consumption for the different technologies is quite similar, usually between 0.2 and 0.3 kWh/Nm$^3$ raw biogas, except for the amine scrubber, which has electricity consumption around 0.10-0.15 kWh/Nm$^3$. The exact electricity consumption will depend on several parameters such as the size of the unit, the pressure in the system, the specific design and in some cases on the outdoor temperature (mainly physical scrubbers) and the methane concentration in the raw biogas (mainly PSA). The amine scrubber has an additional heat demand around 0.5-0.6 kWh/Nm$^3$ to facilitate the desorption of the carbon dioxide from the reagent (Bauer et al. 2013b). Specific investment costs for upgrading facilities significantly decrease up to a capacity of 500 Nm$^3$ raw biogas/h for all the different technologies (Bauer et al 2013a). For units above 500 Nm$^3$ raw biogas/h a cost range of 1.000 – 3.000 €/Nm$^3$ is found. Further development of the technology will decrease that level (GGG 2013).

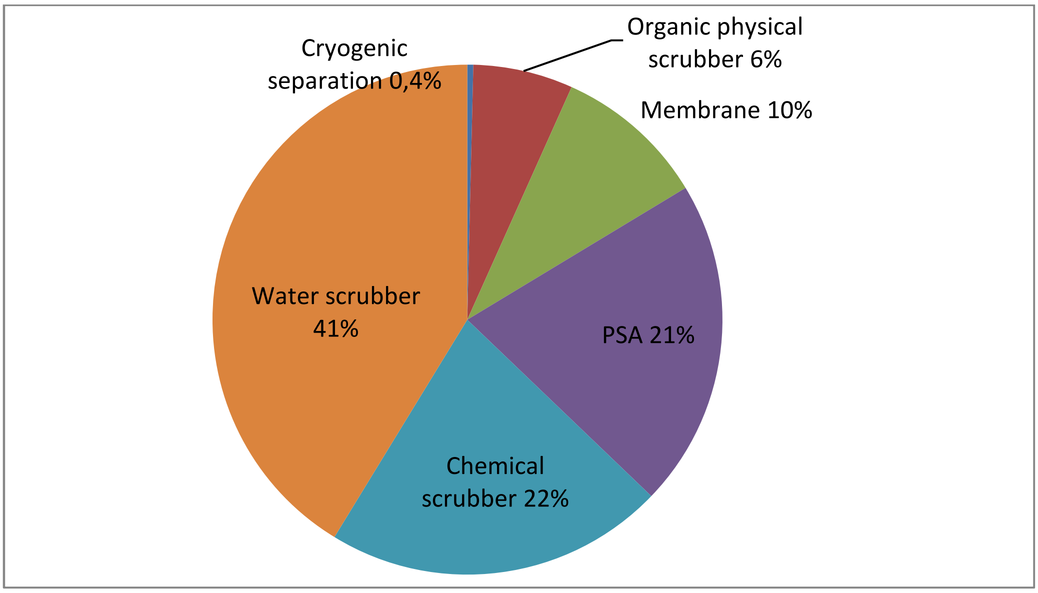


**Figure 2-3.** The market share 2012 of the different technologies used for biogas upgrading today according to the information collected by IEA Bioenergy Task 37.

The pressure of the biomethane after the biogas upgrading should be considered as well as the heat recovery potential when evaluating the overall economy of a biogas injection plant. The energy needed for possible additional pressurisation before injection into the grid will be higher if the operating pressure of the biogas upgrading unit is low. Annual service costs are commonly between 2 and 4% of the investment cost.

## 2.3. Technical options for raw SNG upgrading

The thermo-chemical production pathway of synthetic natural gas aims to convert solid biomass into gas with high methane content (approx. 95%). The conversion pathway from biomass to SNG can be subdivided into five process steps: (i) biomass pre-treatment, (ii) biomass gasification, (iii) raw gas cleaning, (iv) methanation and (v) raw-SNG upgrading. In the following, the technology of the raw-SNG upgrading will be described.

To feed Bio-SNG into the natural gas grid, it has to meet the quality requirements of the grid. Therefore, a final raw-SNG upgrading is necessary after methane formation (methanation) from the raw gas. Raw gas upgrading includes the separation of carbon dioxide, water and depending on the raw gas quality, other gas components (e.g. hydrogen). Therefore, besides the SNG composition and purity, the Wobbe index is of particular interest.

For all raw gas upgrading steps, several technologies are currently available on the market and in operation for coal gas treatment processes, natural gas treatment processes and biogas upgrading processes (see chapter 2.2). A relevant adsorption process for Bio-SNG production systems is pressure swing adsorption (PSA) for the adsorption of carbon dioxide, e.g. on an active carbon bed. However, due to specific aspects of their technical operation, different technologies may be more appropriate for small scale and large scale applications.

Depending on the upgrading technology, further drying could be necessary. In general, to achieve this, the gas is cooled down below the water dew point. For further drying, adsorptive and absorptive methods can be applied (Seiffert and Rönsch 2012).

## 2.4. Application of biomethane

The possible end-uses of biomethane do not differ from those for natural gas. Biomethane is chemically similar to a lean natural gas with lower levels of higher hydrocarbons. Therefore the Wobbe Index of biomethane injected to the NG pipeline may need to be adjusted by addition of liquefied petroleum gas (LPG). Biomethane is fully miscible in all proportions with its fossil counterpart, and fully interchangeable from an end-user perspective. This is not the case for liquid biofuels, such as biodiesel and bioethanol.

The preferred end-use of biomethane depends heavily on the framework conditions of the country where it is produced.

If electricity generation is favoured, the raw biogas is only upgraded to biomethane if the direct production of **power and heat** from biogas is not possible. In comparison to on-site conversion of biogas into electricity, the upgrading of biogas to biomethane affords much more flexible use of biomethane so that better utilisation of heat can be achieved. A recent trend has been for countries to provide subsidies to promote biogas upgrading for NG pipeline injection in cases where heat recovered after electricity generation is wasted due to lack of available market.

In this way, biomethane becomes similar to natural gas regarding its distribution and availability for all types of electricity generation end-uses. Examples of European countries where electricity generation from biogas dominates are: Germany, Spain and Austria. Examples of countries where grid injection schemes are becoming increasingly common are the Netherlands, Switzerland, Austria, United Kingdom and Germany.

Biomethane can also be used directly as **automotive fuel**, in which case it can be produced to the same compositional standard as pipeline NG, or it can be made to a higher specification for higher performance vehicles. Biomethane as a fuel was first applied for trucks during and after World War II in a number of European cities. It was relaunched as an automotive fuel in the early 1990's in Switzerland and Sweden and this kind of end-use has now spread all over the world, predominantly in Europe and the USA. By the end of 2013, biomethane was available as an automotive fuel in 13 European countries (Green Gas Grids). Policies such as tax reductions on clean vehicles and renewable fuel quota systems are important for the emergence and growth of this form of use. Sweden is the country in Europe where this utilisation route is dominating, due to the significantly lower tariff for green electricity (tenfold lower than Germany; quota system with market controlled pricing). Hard facts about biomethane utilisation as transport fuel are sparse. Three countries dominate in terms of volumes used: USA (600-1,000 GWh/a (2013), fourfold increase projected for 2014) Germany (150-500 GWh/a, (2013)), and finally Sweden, the only country, besides Iceland, where the biomethane utilisation for automotive purposes is larger than the one for natural gas (869 GWh/a biomethane out of a total 1,493 GWh/a (2013)). Other countries with statistics (2013) for biomethane are The Netherlands (ca 240 GWh/a), Switzerland (90-180 GWh/a), Austria (35 GWh/a), Norway (30 GWh/a), France (20 GWh/a), Iceland (20 GWh/a), Italy (15 GWh/a) and Finland (10 GWh/a). The United Kingdom is also using biomethane for automotive purposes, but no statistics are available. A very rough world estimate would be 2-3 TWh/a, rising rapidly up to 6 TWh/a if the projections for the US holds true.

As an automotive fuel, biomethane clearly outranks petrol with its motor octane number (MON) of 130, but only in a fully dedicated internal combustion engine (ICE) can this be fully exploited. In most cases, the gas is used in bi-fuel mode, so the spark ignited ICE is a compromise design, based upon the combustion constraints of both petrol and methane. In heavy duty applications, compression ignited diesel ICE's are still better compared to dedicated methane powered spark ignited ICE's. This is however gradually changing, in part through the application of advanced control strategies and exhaust gas recirculation (EGR). New research into fuel fed pre-chamber ignition is showing great promise. Emissions performance from heavy duty methane engines has recently been reviewed by IEA-AMF (Olofsson et al. 2014).

Compared to biomethane, natural gas has a wider range of fuel qualities. With the presence of higher hydrocarbons in the gaseous fuel the knocking propensity in ICE's increases. This is measured by the methane number (MN), where pure methane has an MN of 100, and pure hydrogen is given the MN of 0[4]. Lean natural gas and biomethane has MN's around 100, richer natural gas qualities, with high levels of higher hydrocarbons, decrease the MN down to levels around or below 70.

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[4] MN is by definition dimensionless. It is calculated by comparing the composition of the actual fuel used with data from testing of different ternary mixes of reference fuels made by AVL back in the 70's. There's no analytical solution, so dedicated software is needed to estimate the MN, with several commercial alternatives available on the market. See section 2.5 for further information.

In comparison to stationary electricity generating ICE's working at steady-state, the trace components in biomethane used as automotive fuel need to be controlled even further, due to the transient operation and stricter emission regulations of ICE's in automotive applications. Please refer to chapter 2.5 for more information.

Finally, **biomethane can be used as a feedstock** for the production of many different products (paints, plastics, detergents, etc.) in the specialty chemicals industry. There is a keenness to increase the renewable share in the products, provided costs are justified. However, to the best knowledge of the authors, no significant sales of biomethane as a feedstock to this sector are taking place today. The price levels are still too high, however customer expectations and increased availability of sustainably manufactured goods may increase the price tolerance of the industry in the future.

## 2.5. Technical standards for the use of biomethane as vehicle fuel, for grid injection and as LNG

Vehicle manufacturers, having identified natural gas as a major future alternative fuel, are developing more efficient gas engines, aiming for diesel-like performance in the heavy-duty segment. Together with the introduction of more strict emission regulations in the U.S. and Europe, the OEM's (Original Equipment Manufacturer) have therefore become more proactive in the standardization arena, since tighter specifications would facilitate their engine development work.

Simultaneously, biomethane, used directly as automotive fuel or being injected into the natural gas grid, has been identified by the European Commission as an important renewable fuel where missing standards hamper its market development. A mandate (M/475) was issued in 2010 "…for standards for biomethane for use in transport and injection in natural gas pipelines", the starting point for the current standardization work on biomethane within CEN (Comité Européen de Normalisation).

### 2.5.1. Current standards

The current international standard for CNG, issued in 2006 "ISO 15403 Natural gas – Natural gas for use as a compressed fuel for vehicles" is based largely on the American SAE J1616 from 1994. It is divided in two parts, where the first one is normative, but with no quantitative limits. Part 2, an informative technical report, was issued on request from the OEM's, which wanted more information published on suggestions for suitable limits for the different parameters.

The German national standard for CNG, "DIN 51624:2008-02 Kraftstoffe für Kraftfahrzeuge – Erdgas – Anforderungen und Prüfverfahren (Automotive fuels – Compressed natural gas – Requirements and test methods)" is one of the most strict standards issued to date, with limits of total sulfur, methane content and methane number that has the effect of excluding a large number of the European grid gas qualities. Outside Europe, the standard issued by the state of California (California Code of Regulations, 13 CCR § 2292.5 Specifications for Compressed Natural Gas) is used by several states in the US.

Regarding biomethane, there is a range of national standards in Europe for the injection of upgraded and purified biogas into the natural gas grid. An overview was published by

Marcogaz 2006[5]. A number of other countries have since then introduced standards, e.g. Belgium and the Czech Republic. Outside Europe there is the ”Rule 30“ standard issued by Southern California Gas Company. The Swedish standard SS 155438 ”Motor fuels - Biogas as fuel for high-speed Otto engines” (1999) is to date the only standard regulating the direct utilisation of biomethane as an automotive fuel. Another alternative outside the EU can be found in South Korea with similar conditions as in Sweden (Kang 2013).

### 2.5.2. On-going standardization work within CEN

Work on the international standardization of biomethane injection into the natural gas system has been ongoing since the Marcogaz report was issued. In Europe, work is organised by CEN in a joint technical committee (TC408) ”…for transport applications and injection in natural gas pipelines”. The work started late 2011. In addition to biomethane, natural gas used as an automotive fuel has also been included to the scope of the work. Working drafts of the standard, divided into two parts, where issued early 2014 (as seen in Figure 2-4). The one for injection of biomethane into the grid, prEN 16723-1, relies heavily upon the parallel standardization work in CEN/TC234/WG11 on natural gas quality (prEN 16726 Gas infrastructure — Quality of gas - Group H). Mandate M/475 from the European Commission stipulates that the parameters and limits adopted by prEN 16726 should be taken over and referred to by TC408. In contrast, the second part for automotive fuel, prEN 16723-2, is a stand-alone document.

As seen in Figure 2-4, for prEN 16723-2, there will be two gaseous fuel qualities defined, reflecting the current market situation with non-grid based sourcing solutions of CNG and LNG complementing the one of the grid, both renewable and fossil. The only differing parameter is methane number (MN), as defined by the MWM[6] method (similar to the original AVL[7] method). In local dedicated infrastructures, a more stringent minimum limit of MN 80 is adopted, while in the grid the limit implemented by prEN 16726 is adopted, MN 65. The majority of natural gas grids carry gas with a minimum of MN 70. If the current schedule holds, the two new standards prEN 16726, and prEN 16723 part 1 and 2, will be approved and published by the end of 2015.

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[5] Marcogaz (2006). “Injection of Gases from Non-Conventional Sources into Gas Networks”

[6] The MWM is an alternative method for the calculation of methane number. The raw data is the same as for the AVL method, but MWM developed its own algorithms. The company MWM has decided to make their algorithms public and free to use, through publication in the upcoming prEN 16726 on natural gas quality.

[7] The AVL is the original method for calculating the methane number. The raw data come from runs with different fuel compositions on a test engine back in the 1970’s. A description can be found in DIN 51624, Appendix B, “Berechnung der Methanzahl (MZ)”. Additional information also available in ISO 15403-1.

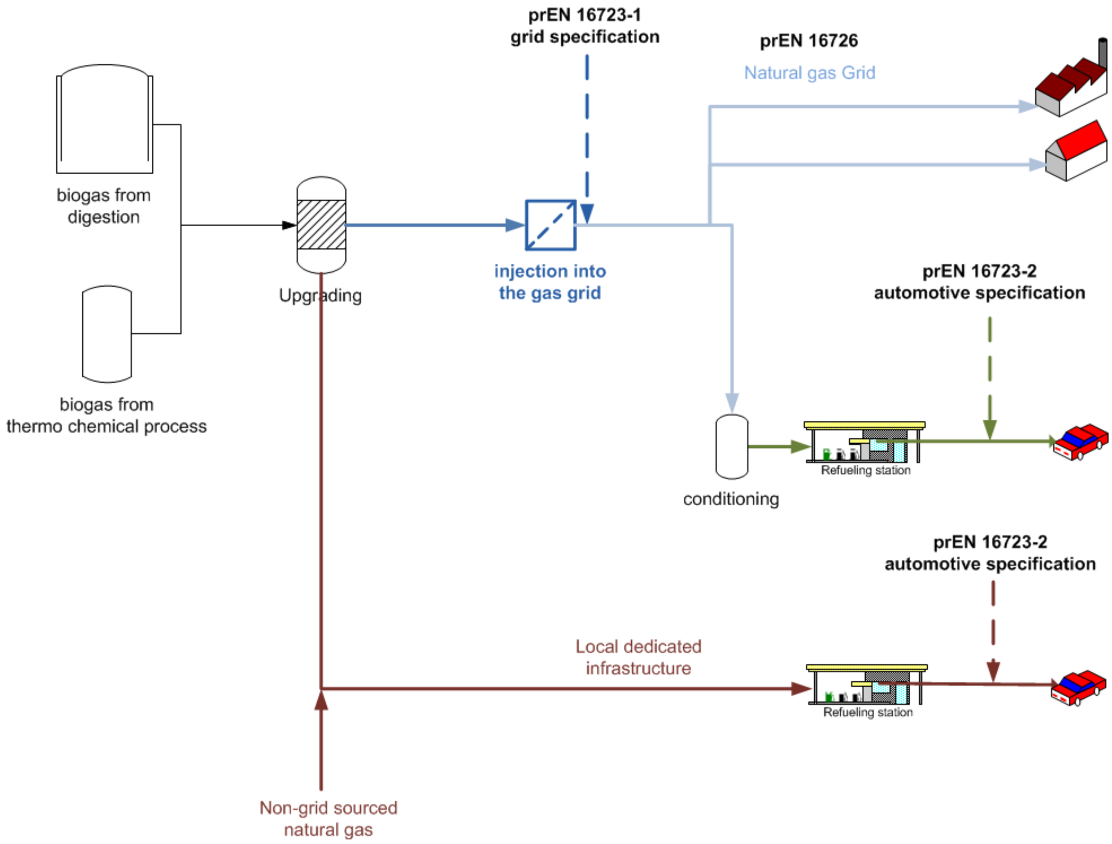


**Figure 2-4.** Schematic of the biomethane and natural gas transport system, showing in which points of the gas network the different standards of CEN/TC408 will apply; the point of entry for injection, and the point of use as automotive fuel. Source: CEN/TC408 working group.

### 2.5.3. Parameters of interest

The most discussed parameter in the two standard documents is *sulfur*. The automotive industry has a need for very low levels of sulfur in order to achieve durability in their exhaust after-treatment systems (EATS). The most prevalent source of sulfur is added for safety reasons; most of the odorization compounds used contains sulfur. In some countries, the odorant is added well above the wished for 10 ppmM sulfur level. The prEN 16726 puts a maximum limit of 20 mg/m$^3$, odorization excluded since it is a national issue. With refuelling station-based conditioning costs being prohibitive, it was impossible to implement a stricter sulfur level in the automotive fuel standard. However, it is stated that biomethane and LNG in most cases readily meet the 10 ppmV requirement.

The origin of *silicon* containing siloxanes in biogas is man-made silicon products and additives. Landfill gas and sewage gas thus have the highest silicon levels, with raw biogas levels of 10-20 mg/m$^3$, and peak levels above 100 mg/m$^3$ reported. The effect of siloxanes on appliances is cumulative, hinging on its precipitation during combustion as silica (silicon dioxide). The silica builds up on valves, cylinder walls and liners, causing abrasion and blockages. Downstream of the engine, switch-type oxygen sensors may withstand less than 0.1 mg Si/m$^3$ if wanting to avoid replacement during the lifetime of the car. Silica build-up in the EATS catalysts lead to cumulative and irreversible loss of degrading activity. Unfortunately, neither of the TC 408 parts of the standard include a limit because of the current lack of standardization of test methods.

For the injection standard, health risk is the most important criterion when choosing the limits. A special deterministic exposure model, devised by the French safety authority AFFSET (Agence française de sécurité sanitaire de l'environnement et du travail), was used to find the compounds that need to be limited. It models the kitchen use of a cooker and/or hob without dedicated exhaust gas extraction. Work is ongoing, with the parameters of *PAHs*, *HCN* and *chlorinated* and *fluorinated compounds* identified as being of interest. *Carbon monoxide, CO*, is already included in the working draft, with a suggested limit of 0.1 %. It is based on a worst case scenario with an unventilated room having a leaking pipe in close proximity to a sleeping person.

After health, the second most important criteria is the integrity of the pipelines. Besides levels for *water, hydrogen sulphide, ammonia* and *oxygen*, which are set to avoid corrosion, there is also a special need for stringent levels of oxygen and *hydrogen* if the gas is not conveyed in a dry system and if the gas is conveyed in proximity to underground storage systems. In prEN16726, oxygen is therefore stated with two levels, 0.0001 % and 1 %. The latter figure is also stipulated by the automotive fuel standard. Hydrogen, on the other hand, is not regulated in prEN 16726, because of the difficulty to find one or even two values which satisfy the large array of possible limits for different parts of the European gas grid. The automotive fuel standard has stipulated a maximum limit of 2 %, in order to protect the high-pressure storage cylinders from corrosion.

Avoiding liquid *water* at all temperatures and pressures gives protection from corrosion. The -8 ° C limit on the *water dew temperature* at maximum operating pressure stipulated by prEN 16726 is in most cases more than satisfactory. However, when decompression chilling takes place in natural gas vehicles, there is a risk for hydrocarbon hydrate formation in the fuel system, impairing drivability. Therefore, in the automotive fuel standard there are three classes of water dew points, -10 ° C, -20 ° C and -30 ° C at 200-bars, in order to allow for climate dependent adoption at national level. The risk of precipitation of higher hydrocarbons has been regulated by setting a *hydrocarbon dew temperature* limit of maximum -2 ° C for all pressures.

Drivability is also affected by entrained *compressor oil, mostly* originating from the refuelling station compressors. Just like with water, complete engine failure is not the result, but rather different degrees of reduced drivability, including engine stalling, and increased maintenance costs. Also, combustion of the oil in the engine leads to more particle formation, which invariably increases the carcinogenicity of the emissions. Presently, there is no standardized test method available for measuring compressor oil, but a method has recently been developed by SP Technical Research Institute of Sweden.

The issue of *microbial content* in biogas is not directly addressed in the TC408 standard drafts, but is mentioned in the comment for *dust impurities*. The use of a filter with a nominal mesh size of less than 1 µm is stated to remove most of the biogenic material. A Swedish study showed that levels of microorganisms are as high in natural gas as it is in biomethane, and that even if a potent pathogen would be present, the risk of suffocation surpasses the risk of contamination (Vinnerås et al. 2006). The standard drafts quote a Dutch study (Vlap and de Haan 2013) that showed that filters with an efficiency of at least 99.95 % (0.2 - 10 µm) are efficient enough to reduce the risks of microbiological contamination of the gas.

# 3. Frame condition, barriers and opportunities for biomethane production and use

This chapter considers framework conditions, barriers and opportunities for biomethane. Only biomethane via upgrading of biogas is considered because of the lack of implementation of the thermochemical path. Nevertheless, the majority of the conclusions should apply equally to biomethane produced from both biological and thermochemical pathways.
In section 3.1, the possibilities for biomethane transport are described and three practical examples are given (from Germany, Sweden, Brazil) how transport on a small scale can be realized. Further, an overview of storage possibilities, which can be implemented below- or above-ground, is included. In section 3.2, a detailed overview of the environmental demands for biomethane is provided. In section 3.3, sustainability standards are described, covering greenhouse gas emissions, value chains, important policy developments as well as the monitoring and reporting of sustainability issues. Finally, in section 3.4, overviews of the biomethane costs in comparison to natural gas as well as two practical examples for national biomethane markets are given

## 3.1. Gas distribution

Typically, natural gas grids have been designed to transport gas from large point sources to densely populated regions mainly in developed countries. The small-scale production of biomethane at many different locations is a new phenomenon, and requires additional efforts to adapt the regional infrastructure and to find transport modes outside the natural gas grid.
This section describes possible and necessary developments of a growing biomethane market:

- Road transport, local grids and joint upgrading facilities for small scale biogas production (for improved transportation)
- Storage systems for biomethane (for use according to demand)

Because of the different requirements in various countries, the following sub-chapters provide examples for Sweden, Germany and Brazil, but the main conclusions can be considered valid also for other countries with comparable condition.

### 3.1.1. Biomethane transport on the road and in local grids – some examples

**Biomethane transportation outside the grid – the Swedish case**
In Sweden, the gas grid coverage is limited and restricted to only one part of the country and grid expansion is limited by the low population density. For the use of biomethane as automotive fuel other solutions have to be used. Biomethane is mainly transported in compressed state in mobile storage units (see Figure 3-1) but also in liquefied state and in local gas grids. Sweden is today world-leading in both using biomethane as automotive fuel and in transporting it outside the gas grid.

**Road transport:** Under Swedish conditions for road transport, the best option for all volumes is transport in the compressed state up to distances of 200 km, while transport in the liquefied state can be an option for longer distances (Benjaminsson and Nilsson 2009). When trying to handle larger volumes of compressed vehicle gas by road transport, there can be logistical challenges that offset the economic advantage compared to transport in the liquefied state or by way of a local gas grid. This is one of the drivers behind the building of the first liquefied biomethane plant (LBG) in Sweden in Lidköping, where LBG is produced and packed for road transport.


**Figure 3-1.** Container used for transportation of compressed vehicle gas in Sweden. The container is filled with high pressure gas cylinders

**Local gas grids (micro grids):** There are a number of smaller local gas grids in several Swedish cities, and indeed in other countries like Brazil (see also in-practice example C below). These are commonly used to connect digesters situated a few kilometers apart from each other, typically at a waste water treatment plant and a food waste handling facility. The raw biogas is transported from one of the plants to the other and thereafter upgraded to biomethane in a joint facility. The produced biomethane is transported to the refueling stations through another gas pipe or by road. Rather large-scale local or even regional grids are being planned in Sweden, aiming to connect several larger industries with biomethane production plants and an LNG/LBG terminal at the coast. This may constitute both a risk and an opportunity: on the one hand, this could enable the import of (shale) gas, and thus lower the price of fossil natural gas, whereas on the other hand it may trigger new investments in the existing gas infrastructure (e.g. an extension of the distribution network) which may also be beneficial for biomethane.

**Centralized upgrading of biogas from small scale plants – some experiences**

The cost of upgrading biogas to biomethane basically depends on the size of the plant. Economics calculations show that the upgrading of biogas to biomethane can be profitable when at least 500 $Nm^3$ raw gas per hour can be used. However, from the economic point of view, even larger plants are of more interest. Currently, biogas plants with upgrading capacity of 1,400 $m^3$ raw gas per hour have been realized in Germany. Hence, under specific framework conditions the refitting of existing biogas plant by adding upgrading systems could be an option for larger facilities.

As the profitability of upgrading systems especially depends on the size, it would appear sensible to collect and upgrade raw gas from several biogas plant facilities at one large (biomethane) upgrading plant. A small number of such projects are already realized. For reasonable profitability on the one hand the amount of raw biogas has to be a significant amount, while on the other hand geographical conditions and local infrastructure are of importance. So biogas plants should be located close to each other, see the practice examples below.

Practice example A - Osterby (Germany):

In Osterby 2 biogas plants (approximately 3 km apart) are connected to an biomethane upgrading plant with a total installed capacity 700 $Nm^3/h$ raw gas yielding around 350 $Nm^3/h$ biomethane (Baur 2014). Farmers sell raw gas to “Landwärme”, the operator of the upgrading facility, which they partially own. According to Dena-study (DENA 2013a), invest cost was 3.2 million € (including all pipes and additional repowering facilities). For *Landwärme GmbH* refitting of the biogas plant for biomethane is a niche business; about 15 projects are currently in planning, thereof 7 - 8 plants have already been modified from on-site biogas utilisation to upgrading. Most projects are directed at sites where there is insufficient waste heat utilisation.

Practice example B - Biogas Brålanda (Sweden):

Biogas Brålanda is a small local gas grid in Sweden that connects four farms and one upgrading unit. The company Biogas Brålanda AB, which is responsible for upgrading and distribution, is jointly owned by Trollhättan Energi AB (an energy company from the nearby town Trollhättan) and Biogas Dalsland Economic Association (a farmer cooperative with 18 members). The investment in the grid was shared by Mellerud and Vänersborg municipalities together with Biogas Brålanda AB. Raw biogas is transported in the pipelines to the upgrading plant. From there, the biomethane vehicle fuel is sent in a pipeline to the tank fueling station in Brålanda. Here vehicle gas is put into larger tanks for distribution to a public filling station nearby or to other parts of the country. The biogas produced (1.7 million $m^3$) is enough to supply more than 1,800 ordinary cars. The total cost for the system of farm based biogas plants, grid with pipelines, upgrading plant and tank filling station is estimated to around 9.5 million €. More farm plants are planned and will be gradually connected to the grid that is sized to handle at least double the current production.

Practice example C – Brazil:

In the state Paraná on the Ajuricaba hydro basin in Brazil, 33 small scale family farms are producing biogas through anaerobic digestion of manure and other residues. Each of the 33 family farms injects raw biogas into a 22 km-long pipeline to a central position to produce either electricity and heat or to be upgraded to biomethane and used locally as a vehicle fuel. Through the anaerobic digestion process, the farmers also produce digestate that is used as a biofertilizer on their farms. (IEA 2013b)

### 3.1.2. Storage systems for biomethane

With the increasing contribution of (intermittent) renewable energy sources and the accompanying challenges of matching energy supply and demand, the topic “energy storage” has to be addressed. There is a wide range of energy storage solutions available, each with its own characteristics. In Figure 3-2, an overview of current available energy storage technologies is given. Storage capacities for natural gas are very large in comparison to electrical power storage, compressed air or water storage. The global storage capacity for natural gas is about 319 billion $m^3$ with more than 690 storage sites worldwide, The United States of America have the largest capacity in terms of the working gas volume for below ground storage with 121.4 billion $m^3$ (419 storages), followed by Russia with 95.6 billion $m^3$ (22 storages), Ukraine with 32.8 billion $m^3$ (13 storages) and Germany with 20.7 billion $m^3$ (50 storages). (LBEG 2013).

Storage concepts for biomethane can be divided (similar to natural gas storage) into above-ground and below-ground storage. These technologies differ significantly in terms of maturity, capacities as well as the future market potential. Against this background the relevant technologies today with significant storage volumes will be described briefly below.

Below ground storage technologies for natural gas (so called geological pore storage reservoirs) can be divided into (i) salt caverns, (ii) aquifers and (iii) depleted natural gas reservoirs. In the following table an overview of the typical characteristics of below ground gas storage technologies is given based on German conditions.

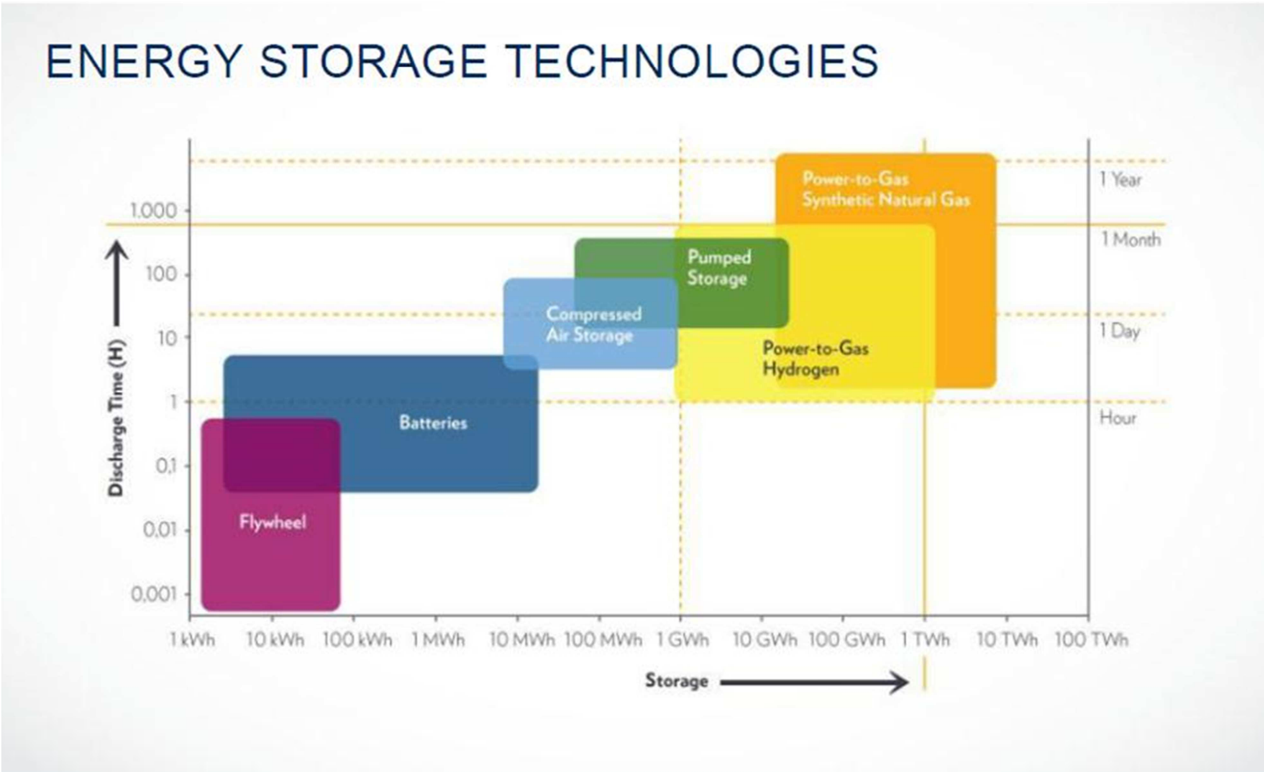


**Figure 3-2.** Energy storage technologies (Newton et al. 2013)

**Table 3-1.** Characteristics of geological pore storage reservoirs in Germany (Stronzik et al. 2008)

| | **salt cavern** | **Aquifer** | **depleted gas reservoir** |
|---|---|---|---|
| average volume in Germany (mil. m³) | 431 | 350 | 1,381 |
| feed-in and removal | High | Low | low |
| turnover ratio (per year) | 4.5 | 1 | 1 |

While depleted gas reservoirs are characterised by a high non-process gas volume, which lowers the turnover rate, aquifers have a high exploration demand to guarantee tightness of the storage system. Against this background, salt caverns have today the greatest potential to serve as below ground gas storages. Typical parameters within Germany are process gas volumes of more the 400,000 Nm³. A challenging aspect is that these types of storage concepts require a relatively long planning and construction phase in comparison to other concepts (from five up to ten years) (Acht 2012). Below-ground storage under those conditions for biomethane might be realised jointly with existing storage systems for NG.

Above-ground technologies for the storage of natural gas and biomethane can be divided into (i) spherical gas tanks and (ii) pipe concepts or pipe tanks. While spherical gas tanks are operated with a pressure of 8 bar, pipe tanks can be operated up to 100 bar. In terms of capacities spherical gas tanks, for instance in Germany, have a process gas volume (useable share of gas storage volume) of approx. 50,000 $Nm^3$. Similar is the capacity for pipe gas tanks without a compressing unit. With the integration of compressor the process gas volume can be increased up to 140,000 $Nm^3$ (on average) (Langner et al. 2013). Those volumes are interesting for the development of dedicated biomethane storage systems.

Besides the storage of natural gas or biomethane as gaseous fuel, currently several storage concepts for liquefied natural gas (LNG) are in development or use. LNG is generated by cooling natural gas to about -162°C (NaturalGas.org 2013). LNG can be stored for instance during long distance transport on vessels within tanks that have insulated walls. Nowadays, the direct liquefaction of biomethane in small units has been achieved in Sweden, Norway, the USA and the United Kingdom.

## 3.2. Environmental demands

### 3.2.1. Introduction

The production and use of biomethane has to support the overall goals for Greenhouse Gas (GHG) emission reduction, resource saving and be in line with the specific environmental demands in the different countries. As the carbon from biomethane is captured from the atmosphere during the growth of the plants, in principle this is a closed cycle, and thus when combusting biomethane, there is no net increase of GHG emissions. To ensure that GHG emissions are reduced by biomethane production, it is important that the GHG balance of production and delivery is favorable (Black et al. 2011). The life cycle assessment approach has been established for those assessments, considering direct and indirect effects from feedstock provision until the final utilisation of the biomethane (see chapter 3.2.3).

There are additional environmental aspects, like eutrophication, acidification, human health and ecotoxicology, which are also relevant, and can also be assessed through LCA, but not discussed in detail in this report. Especially the biomass feedstock production (when using dedicated crops) can result in problems such as pressure on biodiversity, use of scarce water resources, risks to food security or land degradation. Hence it is important that bioenergy production is managed sustainably (GBEP 2011).

### 3.2.2. Greenhouse Gas Emissions and the Value Chain of Biomethane

The generation of biomethane is a complex multi-stage process. At each stage of the supply chain GHG emissions arise from agricultural processes, energy consumption, fugitive emissions and other minor sources. Net GHG emissions can depend upon a number of factors as explained in detail in the biogas handbook (Wellinger et al. 2013).
Figure **3-3** displays the main process stages in the biomethane value chain with potential GHG emissions sources, main system inputs, energy and carbon flows.

**Biomass Production (Feedstock Supply)**
Biomass feedstocks used to produce biogas are diverse. Feedstocks can come from farms in the form of energy crops, by-products of industrial and agricultural processes such as animal slurries and manures, or waste materials such as sewage sludge and food waste. GHG emissions arising from biomass production therefore depend primarily on the biomass

source, its location, and the cultivation/collection method used. Effects of land use change through energy crop cultivation (for biomethane from biogas) and carbon accounting for forest biomass (for biomethane from SNG) are currently discussed on scientific and political levels (Council of the European Union, 2014), (Agostini et al., 2013). The findings might yet influence the assumption for GHG emissions from feedstock supply significantly.

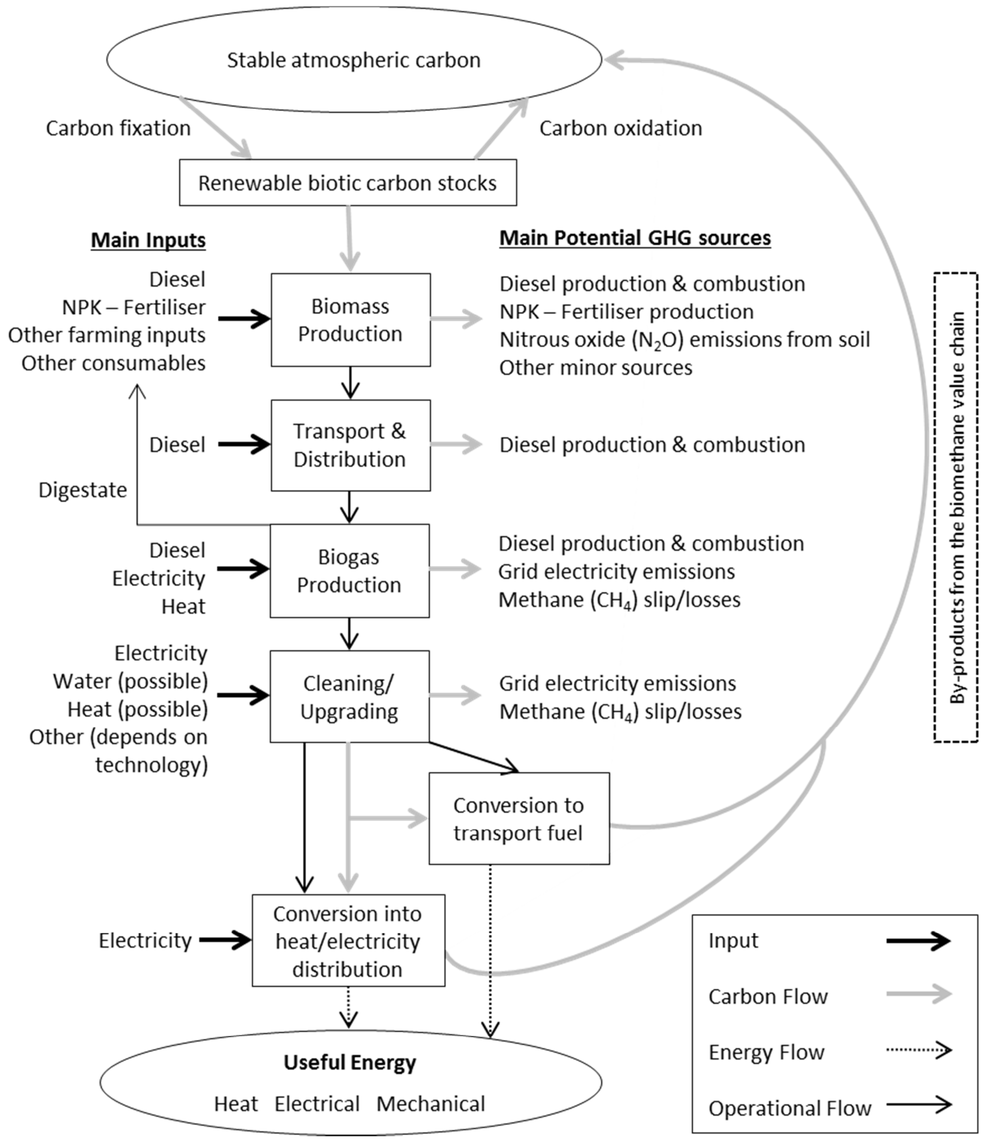


**Figure 3-3.** Flow chart for the calculation of GHG emissions for biomethane production (Adams et al., 2014)

**Transportation and Distribution of Biomass**

GHG emissions from transport and distribution are relatively minor in local arable systems (AEA, 2010). GHG emissions from transport arise primarily from the combustion of diesel, however the total contribution is usually less than 10% of the total supply chain GHG emissions (GGG, 2013a).

**Fugitive emissions**
Methane is a potent greenhouse gas (IPCC, 2007) with a global warming potential (GWP100) 34 times larger than carbon dioxide. For this reason, all reasonable precautions must be taken to minimize losses to the atmosphere. Emissions ('methane slip') from methane production installations occur if gas escapes into the atmosphere, either inadvertently due to poor design or operation, or intentionally for safety reasons. Emissions can potentially occur at all steps in the production and gas handling process as well as when handling residues. The case of biogas production has been widely assessed (e.g. GGG, 2013a), however, there is no published information for bio-SNG production.

**Biogas Upgrading**
Although a number of different technologies are available to fulfil the task of producing a biomethane stream of sufficient quality, a small percentage of methane is lost during the upgrade stage (Starr et al. 2012). This can vary considerably between the upgrading technologies chosen, although all equipment suppliers can provide off-gas treatment to deal with methane losses. Methane slip from upgrading biogas to biomethane can make a significant contribution towards the overall lifecycle greenhouse gas emissions. Biomethane is a greenhouse gas 36 times more potent than carbon dioxide. Therefore already small leakages can cause substantial reductions in the climate change mitigation potential.

**Biomethane feed-in**
Feeding biomethane into the natural gas grid is an efficient energy solution, even if the sites in which the gas is to be used are far away from the sites at which it is produced (Biogaspartner, 2011). For the purposes of injection, the gas must meet the quality specifications of the relevant legal provisions and may only deviate within the range of these quality standards (Biogaspartner, 2011), see chapter 2.5. When the gas grid does not have capacity or is not close, the biomethane can be transported on road via CNG tube trailers. This happens in Sweden (with limited gas grid), see chapter 3.1.1.

**End-use**
For conventional fossil fuels, the emissions arising from use are significant and contribute significantly to Global Warming Potential (GWP). In contrast, the combustion of biomethane will result in predominantly biogenic $CO_2$ and therefore contributes to more stable atmospheric carbon.

Despite potentially high GHG emissions by following best practice, it is possible to achieve GHG savings by biomethane of over 80% when compared to the fossil fuel alternative. Figure 3-4 shows that sources of GHG emissions vary depending on the process stage in the biomethane production. Key sources of GHG emissions include biomass feedstock cultivation (where purposely-grown energy crops are used) and biogas upgrading. Emissions may be significantly reduced with the application of BAT (Best Available Technology). Substantial emission savings can also be made through the recycling of organic nutrients (in digestate use) and following sustainable farming practices.

### 3.2.3. Life Cycle Assessment of Biomethane application

**LCA Methodology**
Life Cycle Assessment (LCA) is a methodology for assessing environmental impacts and resource consumption of goods and services. This method allows every component of biomethane production to be assessed in terms of GHG emissions, emissions to air, water & soil, and resource depletion, therefore helping to evaluate the sustainability of the entire

process from feedstock production to biomethane injection, i.e. over the 'life-cycle of the production of 1MJ (~0,278 kWh) of biomethane'. LCA is structured, comprehensive and internationally standardised which follows a systematic and phased approach (ISO, 2006). In the case of biomethane production a full LCA needs to include both direct and indirect emissions. Many of these emissions are indirect to the biogas production and use phase. A methodology to calculate the GHG emissions has been developed by the European Commission (EC) in the Fuels Quality Directive (FQD)) and in the Renewable Energy Directive (RED) for biofuels and bioliquids for transport, electricity, heating as well as cooling. The aim is to provide numbers for GHG savings as one sustainability criterion (see chapter 3.3). The RED methodology does not incorporate the emissions associated with the manufacture of the machinery and equipment used in bioenergy production and supply. Also, it does not incorporate the $CO_2$ emission credit resulting from substituting the recycled nutrients contained in the digestate for commercial fertilizers. However the RED gives a precise guideline. Regarding life cycle assessment with a focus on Europe, it is much more practicable to use the RED instead of the ISO 14040.

**Default values for biomethane application as a transport fuel**

The RED Annex V presents typical and default values for the GHG emissions savings for a range of biofuels compared to fossil diesel and gasoline, see chapter 3.3.2. The RED Annex V shows that in the field of transport fuels biomethane offers some of the highest GHG savings when compared to other liquid biofuel options. Biomethane from municipal organic waste has a default value for GHG saving compared to the fossil fuel comparator of 73% and 82% when produced from dry manure (Directive 2009/28/EC). In comparison, rape seed biodiesel has 38% and sunflower biodiesel 51% (Directive 2009/28/EC).

In the UK, the Government has developed a tool which calculates GHG emissions for different bioenergy systems. The 'Biomass Carbon Calculator' follows the RED methodology and has a range of default values for commonly used feedstocks for biomethane production (GGG, 2013). These include silage grass, whole crop maize, organic whole crop maize, whole crop wheat, sugar beet, wet manure, and dry manure. Using these default values it is possible to compare GHG emissions from each of the biomethane production pathways by assessing each life cycle stage. Figure 3-4 shows the percentage contribution for each of the five main stages of the biomethane value chain (i.e. cultivation & harvesting, transport & distribution, production of biogas, biomethane upgrade, and biomethane injection). It can be seen that crop growth account for at least 50% of GHG emissions for each pathway using crops for biomethane. However this does not account for the use of digestate and therefore assumes high inorganic fertiliser input. Biomethane upgrading is also an important stage for each pathway due to the assumptions made around methane slip and electricity consumed.

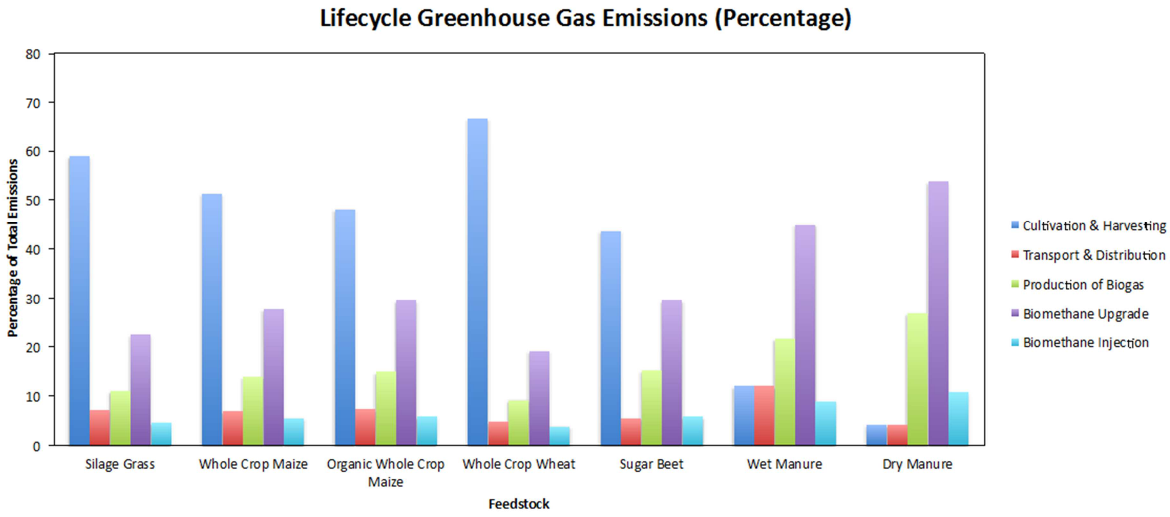


**Figure 3-4.** Percentage Lifecycle Emissions by Feedstock, calculated by using the UK Biomass Carbon Calculator Model (GGG, 2013a)

### 3.2.4. Policy Developments

European Directives currently include criteria on GHG saving thresholds. Emissions associated with indirect land use change (iLUC) do not yet have to be reported. While both Directives (RED and FQD) did include an obligation to review the impact of indirect land use change on greenhouse gas emissions associated with biofuels no formal changes have been adopted so far. Proposals for amendment to the Fuel Quality Directive (FQD) 98/70/EC are demanding at least a 60% saving against the GHG threshold for biofuels production processes starting operation after 1$^{st}$ January 2018. It is also proposed that members will now also be obliged to include indirect land use change (iLUC) factors in reporting by fuel suppliers. The US and Canadian markets are moving, driven in particular by transport use and Green Gas Certificates mode.

### 3.2.5. Concluding Remarks

This chapter has described the main possible sources of GHG emissions associated with the biomethane production value chain. Significant variations are possible which arise from both the plant design and operation, and the GHG accounting methodology. By following best practice it is possible to achieve GHG savings of over 80% when compared to the fossil fuel alternative (GGG, 2013). Sources of GHG emissions respective savings vary depending on the process stage in biomethane production as well as the reference system regarding the end-use. Biomethane may directly or indirectly substitute different fossil fuels, depending on its end-use, and environmental benefits in general will probably be largest if biomethane substitutes coal (at least in terms of avoided GHG emissions). Nevertheless, high GHG savings can also be achieved by substitution of NG or oil in the heat and CHP sector as well as a substitute liquid and gaseous fuels in the transportation sector.

Key sources of GHG emissions include biomass feedstock cultivation (where purposely grown energy crops are used) and biogas upgrading. Emissions may be significantly reduced with the application of BAT (Best Available Technology).

## 3.3. Sustainability standards for biomethane

Sustainability standards for biomass have been discussed and developed in different arena over recent years. The most important approaches are the indicators from the Global Bioenergy Partnership (GBEP) and the demands from the European Directives on Renewable Energy and Fuel Quality. Outside Europe biofuel sustainability criteria are established (e.g. USA (U.S. Congress 2005)) but do not refer to specifically biomethane, so there are not considered in the following.

### 3.3.1. GBEP criteria

The Global Bioenergy Partnership (GBEP) developed 24 sustainability indicators which can be subdivided into environmental, social and economic indicators. The indicators should guarantee sustainable production and use of biomass independently from biomass type and origin. Although a high sustainable standard in biomass production and usage is required, in most cases the indicators (Table 3-2) are not directly, or not all of them, implemented. The EU and the member states are anxious to strengthen the sustainable standards for biomass in Europe which leads among other to the EU 2009/28/EC directive and the resulting applicable law in the member states.

**Table 3-2.** Sustainability indicators by GBEP (GBEP 2011)

| Environment | Social | Economic |
|---|---|---|
| life-cycle GHG emissions | allocation and tenure of land for new bioenergy production | productivity |
| soil quality | price and supply of a national food basket | net energy balance |
| harvest levels of wood resources | change in income | gross value added |
| emissions of non-GHG air pollutants, including air toxics | jobs in the bioenergy sector | change in consumption of fossil fuels and traditional use of biomass |
| water use and efficiency | change in unpaid time spent by women and children collecting biomass | training and re-qualification of the workforce |
| water quality | bioenergy used to expand access to modern energy services | energy diversity |
| biological diversity in the landscape | change in mortality and burden of disease attributable to indoor smoke | infrastructure and logistics for distribution of bioenergy |
| land use and land-use change related to bioenergy feedstock production | incidence of occupational injury, illness and fatalities | capacity and flexibility of use of bioenergy |

### 3.3.2. Criteria from the EU directives

The Renewable Energy Directive, RED (Directive 2009/28/EC) establishes in Article 17, 18, 19 and Annex V sustainability criteria for biofuels and bioliquids[8] (EC, 2009). The sustainability criteria aim to promote biomethane production in a sustainable form. According to the EU directive respective the national law, the biomethane sustainable criteria can be summarised as follows (European Union 2009a):

- No biomass from biodiverse areas, nature protection or similar areas for biomethane as fuel is allowed, including primary forest and highly biodiverse grassland. Exception can be made in case of evidence is provided that the production of raw material did not interfere with those nature protecting purposes.
- Biofuels, like biomethane, should be promoted in a way to encourage greater agricultural productivity and the use of degraded land.
- The greenhouse gas emission saving shall be at least 35% compared to fossil reference. From the beginning of 2017 they shall be at least 50% and from the beginning of 2018 they shall achieve at least 60% greenhouse gas emission saving.
- Biofuels shall not made from raw materials from land with high carbon stock[9]. Further, biofuels shall not be made from raw materials from peatland unless no negative harm is provided regarding drainage.
- Agricultural raw materials for biofuel production have to fulfil requirements in part A and point 9 of Annex II in Council Regulation (EC) No. 73/2009.

The requirements in Council Regulation (EC) No. 73/2009 consider the relationship between agriculture and the environment. These include e.g. the conservation of natural habitat and of flora and fauna, protection of groundwater and soil against pollution and soil. (European Union 2009b)

The EU sustainable criteria are only **obligatory for biomethane when it is used as fuel for transport**. It is so far **not obligatory for biomethane when it is used in other fields like for CHP**.

As solid biomass is not mentioned in the EU directives, it is not subjected to any sustainable standard yet. However, in some countries, like the Netherlands, more detailed sustainable standards are implemented or in planning, including solid biomass. Other national ambitions for sustainability are for example the Renewable Fuel Standard program (RFS) in the USA or the government response for sustainability criteria for biomass in the U.K., which also deals with solid biomass as feedstock (DECC 2013).

The sustainability standards affect the production and use of biomethane in the different countries as well as the trade between these countries.

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[8] In this context Biofuels means ‘liquid or gaseous fuel for transport produced from biomass’ and Bioliquids means ‘liquids fuel for energy purposes other than for transport, including electricity and heating and cooling, produced from biomass’.

[9] In case of converting land with high stocks of carbon in its soil for cultivating of biomass, the resulting negative greenhouse gas impact should therefore be accounted for calculation of greenhouse gas emission saving.

### 3.3.3. Monitoring and reporting of sustainability issues

The European Commission (EC) can assess existing voluntary schemes for monitoring sustainability in order to facilitate the biofuel market. To secure a sustainable provision, the EC already recognised 17 sustainability schemes for biofuels. Additionally the member states are also able to use their own voluntary schemes if proofs of the EC's requirements are given. (EC 2011), (GGG 2013a)

Therefore, the common biofuels (bio diesel and bio ethanol) are already constantly monitored and registered. Biomethane as a comparable new fuel is still in the market penetration stage (depending on country). To secure the correct mass/energy trade as well as sustainable standards for biomethane, the relevant data (substrate, plant size, technology …) has to be submitted to monitoring institutions and respective registers. Not every EU member has already implemented a registration institute. So far, the following registers are implemented in Europe:

- Germany: Nabisy (sustainable biomass system) and Biogasregister
- The Netherlands: Vertogas
- Denmark: Energinet.dk
- France: Gaz Réseau Distribution France (GrdF)
- Switzerland: Verband der Schweizerischen Gasindustrie (VSG)
- U.K.: Green Gas certification scheme
- Austria: AGC Biomethan Register Austria
- Sweden: biomethane is registered due to the tax exemption, additionally statistics has started to keep track of CNG (biomethane and natural gas)
- Italy: GSE S.p.A. (registration for biomethane planed)

At present, six European biogas registers (DE, A, DK, U.K., F, CH) are planning close cooperation for improved reporting of sustainability parameters and particularly for a better trade between these countries. The aim is compatibility between the registers and recognition of guarantees of origin for biomethane. Further registers are likely to follow (DENA 2013b). In addition to the issue of sustainability of biomethane, the collaboration aims at better traceability. The use of different mass balance systems during cross boarder trades lead to a difficult mass determination or lead to possible uncertainties.

One of the problems to be solved is, that according to the RED (European Union 2009a), a mass balance system has to be implemented in the member states to guarantee compliance with the sustainability criteria. This includes traceability on a mass balance level, where consignments and their sustainability information remain intact. Currently, it is not clear if transport of biomethane via the NG grid is suitable or not because of the blending of biomethane with natural gas. So, for example in Sweden, the conclusion is that the transport has to be done by truck, vessel or train to meet the RED requirements. This hinders Sweden in their attempt to play a major rule in the emerging European biomethane trade, as a biomethane importer (Jozsa 2014).

In addition to the already existing sustainability criteria and regulations, a further directive for deploying of alternative fuels infrastructure in the European Union is in progress. The directive aims to standardize the interface of refuelling of alternative fuels (such as biomethane) to promote sustainable fuels in the EU. (European Union 2013).

## 3.4. Cost of biomethane production

### 3.4.1. Biomethane via upgraded biogas

To assess the costs of the production and injection of biomethane, a clear understanding of the constellation of these costs in terms of their components is necessary. In summary, the final cost can be distinguished between the biogas production cost, the upgrading cost and the cost for distribution (e.g. grid injection).

Costs for the production of biogas and therefore also for the biomethane are influenced by highly varying prices for feedstocks. Urban (Urban et al. 2009) discusses two different base cases: a feedstock mixture of 90% manure and 10% maize silage and a feedstock mixture of 10% manure and 90% maize silage. While manure can be a freely available resource, especially for smaller systems up to 500 $Nm^3/h$ a feedstock price for maize silage of 35 €/t was identified by Urban (Urban et al. 2009). Based on a market assessment in the years of 2007 and 2008, Urban estimate the specific feedstock costs for two cases with 1.8 and 3.6 €cent/kWh for Germany, the Netherlands, Sweden and Canada regarding the net calorific value of the produced gas[10]. In Hornbacher (HEI 2006), the production of raw biogas using maize silage and a small content of manure was considered using a feedstock price of 25 €/t for maize silage. This results in specific feedstock deployment costs of 2.2 €cent/kWh for the produced biogas in the mentioned study. All values are illustrated in Figure 3-5 and transferred to $€_{2013}$cent/kWh to provide comparability.

The actual production costs of raw biogas mainly depend on economic parameters e.g. investment-, operation- and maintenance including storage of raw materials and raw biogas. Upgrading costs can be computed with the Biomethane Calculator from Mitner (Mitner et al. 2012) which was developed in the IEE project BioMethane Regions to address the costs from various upgrading technologies under different conditions. In this tool, upgrading costs for gas-permeation, pressurised swing adsorption, pressurised water scrubbing and amine scrubbing under different conditions are included. Depending on the raw biogas composition and the volumetric flow, upgrading costs between 1.5 and 2.0 $€_{2013}$cent/kWh can be observed, including desulphurisation, water and $CO_2$ separation. Urban (Urban et al. 2009) give average upgrading costs of 1.7 €cent/kWh for comparable cases. These values consider technology specific methane losses as well as higher sulphur content in raw biogas produced from the manure based feedstock mix. Figure 3-5 compares the total specific biogas upgrading costs stated in this paragraph with the higher value (5.2 $€_{2013}$cent/kWh due to economy of scale and technological learning effects) from Hornbacher (HEI 2006) and outlines the composition of these costs for the values computed with the Biomethane Calculator from Mitner (Mitner et al. 2012).

For the injection of biomethane into the natural gas grid the following cost components exist:

- Transportation from the upgrading unit to the gas grid is calculated to be performed in a low pressure pipe,
- pressurisation,
- odorisation,
- conditioning and necessary measurements are typically done in the gas transfer station located at the transfer point.

[10] All cost values in this chapter specified for the net calorific value of produced gas

Injection costs of four different settings proposed in Urban (Urban et al. 2009) have been recalculated and compared with the original values from literature. The 500 $Nm^3$/h-case[11] investigates a biomethane production plant located directly next to a pipeline system at 16 bar pressure; the second doubles the volumetric flow used in the first case and includes a low pressure pipeline with the length of 1 km to inject the product into a system at a pressure of 45 bar; and the third case doubles the volumetric flow of case 2 including a low pressure pipeline with the length of 5 km to inject the product into a system at a pressure of 70 bar. By calculating the four upgrading technologies mentioned in the previous paragraph, an average total specific biomethane injection cost of 0.6 €$_{2013}$cent/kWh can be computed. For the same cases Urban (Urban et al. 2009) states injection costs averaged to 0.2 €$_{2013}$cent/kWh supposing that 100 % of the costs for pressurisation and 50 % of the costs for the transportation are provided by the grid operator. Depending on the local gas quality, conditioning by adding liquid gas (propane and/or butane) could be necessary. The addition of 1 % propane related to the biomethane flow increases the injection costs by an average of 1.0 €cent/kWh. Total specific injection costs from literature and specific costs for the different injection steps computed with the Biomethane Calculator from Mitner (Mitner et al. 2012) can be found in Figure 3-5.

Upgrading and injection costs computed with the Biomethane Calculator from Mitner (Mitner et al. 2012) were extended with specific raw biogas production costs from Urban (Urban et al. 2009). The resulting specific biomethane costs are illustrated in Figure 3-5 and compared with values from Urban (Urban et al. 2009) and Hornbacher (HEI 2006). An average specific biomethane deployment cost of 8.7 €$_{2013}$cent/kWh can be observed for 18 different constellations based on a maize silage dominating mixture. An average specific biomethane deployment cost of 7.0 €$_{2013}$cent/kWh was calculated for four different constellations based on a manure dominating. Deviations from this value for different technologies are small and also the gap between the computed values for the maize silage options for the 500 $Nm^3$/h-case and the 2,000 $Nm^3$/h-case is of minor importance[12] in relation to the entire biomethane deployment costs.

An average natural gas price of 3.7 €cent/kWh for industrial[13] use for the year 2012 was plotted (Eurostat Database 2013) as a red vertical line. This illustration highlights that the examined biomethane deployment options are far away from being economically viable on this market if no use from support schemes is made. The green shading indicates the range between 4 and 6 €$_{2013}$cent/kWh and shows the natural gas price increase of 20% and 60% between 2010 and 2030 for the ambitious climate scenario and the reference scenario from Sebi (Sebi et al. 2013). An average value of 3.4 €$_{2013}$cent/kWh for industrial use for the year 2010 was used for this estimation (Eurostat Database 2013). In order to be able to derive conclusions about the future competitiveness of biomethane against natural gas, scenario calculations for the production, upgrading and grid injection would be necessary. Among others, such a calculation would have to include feedstock price development, energy supply cost scenarios and technological learning curves which is out of scope of this chapter.

[11] With regards to the volumetric flow of raw biogas

[12] Average value of 8.5 and 7.8 €cent/kWh for different upgrading technologies for the 500 $Nm^3$/h-case and the 2,000 $Nm^3$/h-case based on maize silage dominating feedstock mixture

[13] Group I3: 10.000GJ<consume<100.000 GJ

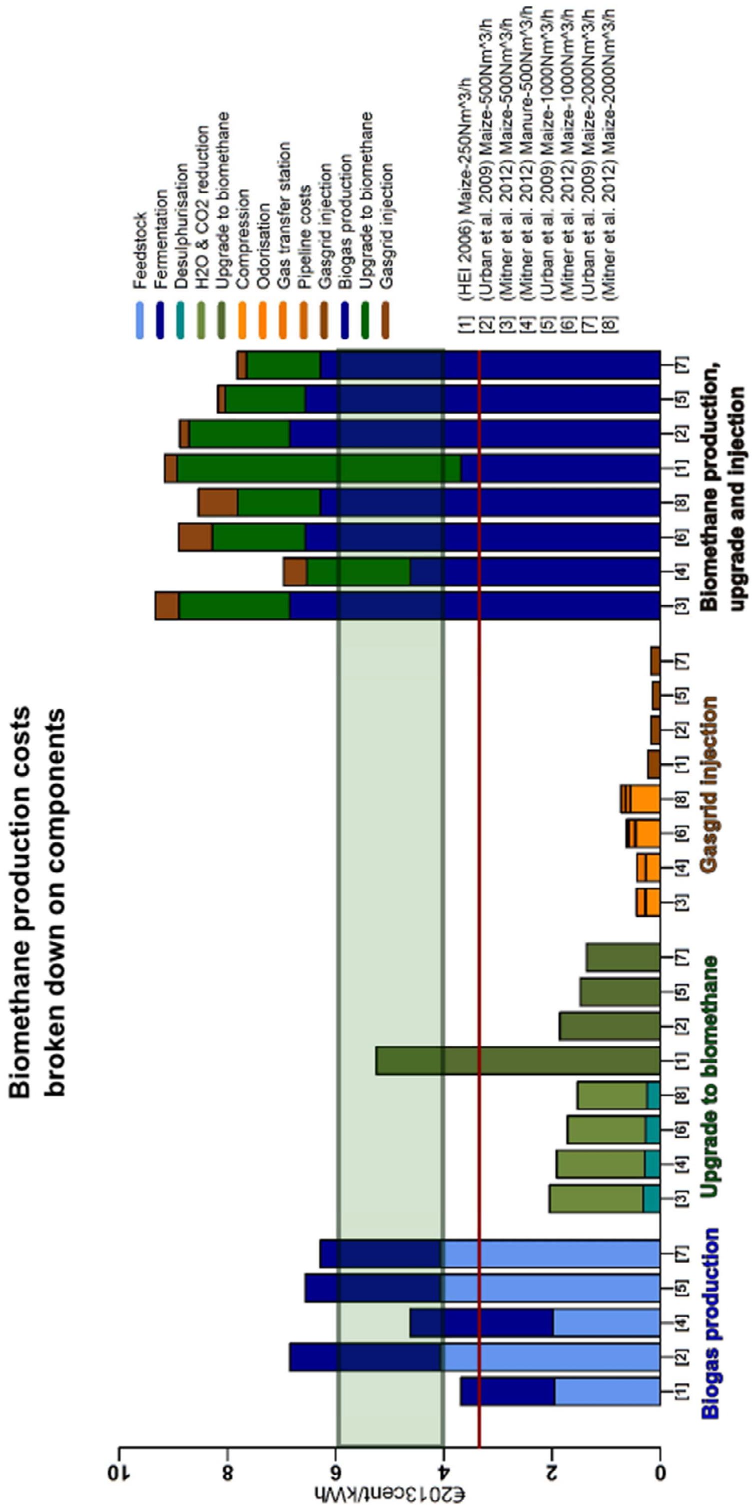


**Figure 3-5.** Averaged specific biomethane deployment costs acquired from literature ((HEI 2006), (Urban et al. 2009)) and own calculations (Mitner et al. 2012) broken down into components: The vertical red line shows the reference European average natural gas price of 2012 (Eurostat Database 2013) and the green shaded part gives a natural gas price range for 2030 (Sebi et al. 2013)). The tick marks indicate the respective literature, feedstock and size of the biomethane production.

Specific biomethane deployment costs were obtained from literature and own calculations. Raw biogas production was found to be the largest component of the total cost for 22 of the 23 cases investigated. For all cases specific injection costs vary between 0.1 and 0.7 $€_{2013}$cent/kWh and represent the lowest cost component. Specific biogas upgrading costs are averaged to 1.7 $€_{2013}$cent/kWh for 22 of 23 cases (excluding the numbers of Hornbacher (HEI 2006)). Specific raw biogas production costs based on a feedstock mixture dominated by maize silage result with an average value of 6.5 $€_{2013}$cent/kWh. The manure dominated feedstock mixture results in an average value of 4.6 €cent/kWh. Hornbacher (HEI 2006) shows another cost structure because of the relatively low feedstock costs but negative effects of economies of scale and technological learning compared to the other cases. On the one hand the stated natural gas price of 3.7 €cent/kWh for industrial use shows the need for support schemes if biomethane injection is to be economically attractive. This position can be strengthened by natural gas price increments stated by Sebi (Sebi et al. 2013) for the period 2010-2030 of about 20% and 60% for the "ambitious climate" and the reference scenarios, respectively (compare Figure 3-5). On the other hand, the possible advantage of the utilisation of waste is outlined with the example of a manure dominated feedstock mixture. Any more thorough assessment of biomethane deployment costs would have to include a much wider range of feedstocks, incuding waste and residues and taking into account any additional costs due to necessary pre-treatment of the feedstocks as well as costs associated with separation and disposal or utilisation of the digestate.

### 3.4.2. Biomethane via gasification and methanation

At the time of writing this report, biomethane via gasification and methanation was still under development and no commercial plant was in existence (see chapter 2.3). As a consequence no validated cost data were available. So far, all costs are based on simulations and forecasts of the technology. One exception is the planed GoBiGas plant in Gothenburg, Sweden which was in the commissioning phase in mid-2014. If biomethane is produced via the thermochemical path different process steps are required than via the upgrading of biogas.

In general, investment costs for thermochemical biomethane installations will be higher due to the much bigger capacities in comparison to the biomethane from digestion and upgrading, see Figure 2-1. For example the investment cost for the GoBiGas plant (20 $MW_{bio\text{-}SNG}$) are 168 million € (Held 2013), the cost for four other simulated plants (22 - 500 $MW_{bio\text{-}SNG}$) range between 42 and 550 million € (Müller-Langer 2011), (Carbo et al. 2011). According to various publications the resulting specific production costs lie between 4.8 – 12.7 €cent/$kWh_{bio\text{-}SNG}$ (Müller-Langer 2011), (Simell et al. 2014), (Heyne 2013), (Carbo et al. 2011).

The cost data seem to suggest similar costs biomethane production via the biogas and upgrading route and via the gasification and methanation (Figure 3-5). Once the thermochemical gasification and methanation process has matured, real costs should emerge and then an objective comparison of the costs of the respective processes should be possible.

## 3.5. A practical example of a biomethane market - Germany

Due to the novelty of biomethane and large number of stakeholders involved, the biomethane value chain is a complex system of feedstock provision, biogas production and upgrading, natural gas grid feed-in, trade of biomethane and numerous end use options.

Relevant groups of stakeholders involved in the biomethane process chain include biogas feedstock providers (farmers, waste management), plant operators/ owners, professional associations and business consultancy, investors, plant manufacturers and maintenance companies, network operators, energy supply companies, biomethane traders and final consumers (or consumer associations) ((dena 2011a) (Schuck et al. 2009; Thrän et al. 2012)). Other important stakeholders are land owners, construction companies, approval authorities and the general public (residents, public administrations, local politics).

Multiple barriers and risks for stakeholders are expected that hinder investments, building of plants and biomethane production and use. Germany therefore set ambitious targets. A survey was conducted within the project "Climate effects of biomethane" to identify the most common barriers and risks.

A large number (270) of stakeholders (manufacturers, planning, investors, certification, end users, politicians, environmental agencies) were identified and asked to participate in a questionnaire (n=56, response rate 21 %) to evaluate the multiple barriers and risks from their point of view (see (Ponitka 2013)) and to provide their ideas and possible solutions.

**Potential limiting factors for biomethane**

There are numerous projects, studies and further activities[14] describing and analysing opportunities, potential barriers, limiting factors and risks of biomethane. The broad range[15] of limiting factors influence specific sections of the biomethane value chain. These include controllable risks for the business segment or the specific location or not manageable risks (external risks, market development, weather conditions, regulations or laws) for the entire industry (Berenz et al. 2008; Schmuderer 2008).

In the field of '*agriculture and feedstock provision*' questions are often asked concerning the acceptance of energetic use of feedstocks (Brohmann et al. 2008) (BMELV 2009). Long term agricultural feedstock provision because of an incentivized demand is susceptible to availability of land in general (Hermeling and Wölfing 2011). Biogas plants are commonly located on farms where there is little economic advantages to invest in biogas upgrading (Urban 2010). Relatively large biomethane plants expose themselves to the risks of security of feedstock supply. A limiting factor can also be limitations of digestate recycling back to the farmland (Reinhold 2011).

From the German perspective, the planning and operation of biomethane projects includes major uncertainties and higher costs because of:

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[14] (e.g. „Bio-methane Regions" (EU); GreenGasGrids (EU); BMBF-Verbundprojekt „Biogaseinspeisung" (Fraunhofer UMSICHT 2009); Biogaseinspeisung (dena 2011b), „BIOMON", Biogaspartner (www.biogaspartner.de), Biogasregister (http://www.biogasregister.de), Biogas monitoring of the Federal Network Agency (BNetzA 2011); BMK – Biomethankuratorium; Memorandum „Initiative Erdgasmobilität" (dena 2011c))

[15] (Hooper and Li 1996; Stachowitz 2005; Madlener and Zweifel 2006; UBA 2006; Brohmann 2007; Mez 2007; McCormick and Kåberger 2007; Altrock et al. 2008; Berenz et al. 2008; BMU 2008; Brohmann et al. 2008; Keil et al. 2008; Markard 2008; Schmuderer 2008; BMELV 2009; Fraunhofer UMSICHT 2009; Kommission für Anlagensicherheit 2009; Postel et al. 2009; Schiffers et al. 2009; Schuck et al. 2009; Urban et al. 2009; Petersson and Wellinger 2009; dena 2010; Urban 2010; BauGB 2011; Bundesnetzagentur 2011; DBFZ 2011; dena 2011a; European Commission 2011; FNR e.V. 2011; Hermeling and Wölfing 2011; Reinhold 2011; dena 2011c; dena 2011d; Berger 2011)

- uncertain feedstock procurement and feedstock prices
- delays in approval procedures from licensing authorities
- delays due to protests by residents (Schuck et al. 2009), (Brohmann et al. 2008; DBFZ 2011)
- extensive planning needs (clarification of gas grid access, security of biomethane marketing)
- large biomethane plants are not privileged in approval procedures according to German laws (§35 (BauGB 2011))
- no direct feed-in tariffs[16] for biomethane (indirect market attractiveness in Germany by incentives in the electricity provision (Renewable Energies Act - EEG), quota assessment in the biofuel sector and the eligibility of biomethane in the heat market)

A '*lack of information*'**,** especially for the costs and chances of biogas upgrading as an option for the future of biogas, can be stated (Madlener and Zweifel 2006; Brohmann et al. 2008; Schuck et al. 2009), (Urban et al. 2009).

In addition to insufficient capacity or capacity bottlenecks of the gas pipelines (Urban 2010) there are complicated regulations for '*biomethane feed-in*'. Potentially there is a risk of a refusal of gas grid connection or of biomethane feed-in for a range of technical reasons (§17 (EnWG 2012), §33 (GasNZV 2010)).

In terms of physical biomethane trading (as opposed to virtual trading) at an international level, one key barrier is gas quality requirements with subsequent risk of refusal (Schiffers et al. 2009) in case of non-compliance with e.g. EASEE-gas obligations. Another risk for the operation of gas grids could be increasing gas grid utilisation fees due to allocation of biomethane feed-in costs (Urban 2010).

Nevertheless, there is increasing demand for biomethane production. Especially the current low sales respective poor markets in Germany for biomethane (dena 2010; DBFZ 2011) leads to increasing economic risks for producers and trading companies. In the transport sector a low user comfort of natural gas and biomethane (few vehicles and limited infrastructure) have an inhibitory effect (dena 2011d). Another constraint in the fuel sector in the European Union is the higher expenditure due to necessary certification verification (Biokraft-NachV 2009) to be able to count for the biofuel quota (§ 37a (BImSchG 2011).

For the field of '*environmental concerns'* negative impacts like intensification of agriculture, risks of hazardous incidents (Stachowitz 2005) (UBA 2006) (FNR e.V. 2011) are expected.

In general the '*low level of profitability*' and uncertainty about the '*economic efficiency'* of biomethane in relation to established sources of income influence decision-making. Also, limiting factor in decision-making are existing '*knowledge deficits'* (Schmuderer 2008) or '*lack of information'* (Brohmann et al. 2008; Schmuderer 2008) and the '*complexity'* of the technology and the market (Fraunhofer UMSICHT 2009). The uncertain '*legal framework'* and changes to the underlying political conditions e.g. amendments of the Renewable Energy Act during the planning process or changes in tax advantages for biomethane as motor fuel (DBFZ 2011) are also limiting factors (Hermeling and Wölfing 2011).

[16] For comparison, some countries (e. g. Netherlands "Stimulering Duurzame Energie Scheme") provide a feed-in tariff for biomethane.

**Limiting factors from a stakeholder point of view**

These potential limiting factors were evaluated by German actors and stakeholders via a questionnaire in 2012 (Ponitka 2013). The analyses of the results (n=56) showed that:

- the majority of the respondents see an opportunity for biomethane in the future (2020) energy system,
- the future competitiveness of biomethane is judged to be high/very high, especially for fuel production and electricity generation.

In contrast to the good future prospects for biomethane the main problems for the majority of the respondents are due to (from higher to lower importance):

- low economic efficiency,
- lack of consistent and changing political support,
- problems of increasing cost of feedstock,
- the complexity of biomethane and especially of biomethane trade,
- low demand for biomethane especially as fuel,
- low acceptance and fear of intensification of agriculture and
- limited benefits of biomethane for the end user.

In the case of the German biomethane market, based on the questionnaire, it can be summarised that questions of the '*economic viability*' of biomethane projects in connection with stable '*political framework*' conditions are the most relevant factors for individual decision-making. The importance of a '*reliable framework*', for example through *clear legal requirements* and adequate regulation and '*support measures'*, both for biomethane provision and end use markets, cannot be overemphasized.

# 4. Expectations of future development

## 4.1. Current capacities of biomethane production

In the IEA Bioenergy member countries, the development of biomethane production and use is at varying stages. Depending on e.g. infrastructure, national supporting systems and energy prices, different levels of production and use of biomethane have been achieved. In Germany and Sweden, the number of plant and production capacity of biogas upgrading plants is high. In countries like e.g. Ireland or Italy, no biogas upgrading to biomethane is implemented yet. Although no biomethane production in Italy is implemented, it possesses a high potential. Brazil and Italy are by far the countries with the most natural gas fuelled cars in the IEA member countries, with together over 2.4 million cars (Álamo 2013). There are also a lot of gas-fuelled cars in the USA, Germany and Sweden. However, the ratio of gas fuelled cars to gas filling station is not consistent. For example, in Italy and Germany roughly the same number of filling stations exist, but there are 8 times more NGVs in Italy than in Germany, see also Table 4-1. So, a limited number of filling stations cannot be the only factor for the development of a gas driven fleet. Hence, the transport sector can be seen as an excellent entry market for biomethane and with huge potential.

Table 4-1 gives an overview of the biomethane production in selected IEA member states, in this study named focus and overview countries.

**Table 4-1.** Biomethane development in selected IEA Bioenergy member countries in 2012 (Daniel-Gromke et al. 2013),(Dumont 2014), (Álamo 2013), (Strauch 2012), (Lampinen 2013), (Govasmark 2012), (Kang 2013), (Paulsson and Steinwig 2012), (Persson and Baxter 2014), (EBA 2013), (EBA 2012), (Grossen and Schmid 2012), (EPA 2013b), (biogas data 2013), (Thorson 2013), (Ministry of Environment 2012), (Rasmussen 2011), (Danish Energy Authority 2013), (DGC 2013), (NNFCC Biocentre 2013) (Note: excluding landfill gas plants)

| Country | Biogas Plants[1] | Biogas Upgrading Plants (Fed In) | Upgrading Capacity[2] In $Nm^3/h$ | Gas Filling Stations[3] | Gas Driven Vehicles[4] |
|---|---|---|---|---|---|
| Austria | 421 | 10 (7) | 2,000 | 203 | 7,065 |
| Belgium | 119 | 0 | 0 | 15 | 355 |
| Brazil | 16 [7] | n.d. | n.d. | 1,790 | 1,719,198 |
| Canada | ~ 50 [5] | 2 (n.d.) | 400 | 83 | 14,205 |
| Denmark | 137 | 1 (1) | 180[6] | 4 | 81 |
| Finland | 34 | 5 (2) | 959 | 18 | 1,300 |
| France | 256 | 3 (2) | 540[6] | 149 | 13,300 |
| Germany | 9,066 | 120 (118) | 72,000 | 904 | 95,162 |
| Ireland | 22 | 0 | 0 | 0 | 3 |
| Italy | 1264 | 1 (0) | 540[6] | 903 | 746,470 |
| Luxembourg | 31 | 3 (3) | 894[6] | 7 | 261 |
| Norway | 44 | 5 (n.d) | n.d. | 23 | 353 |
| South Korea | 57 | 5 (n.d.) | 1,200[4] | 184 | 39,000 |
| Sweden | 187 | 53 (11) | 16,800[6] | 190 | 44,000 |
| Switzerland | 600 | 16 (16) | n.d. | 136 | 11,500 |
| The Netherlands | 211 | 16 (16) | 6.540[6] | 150 | 5,201 |
| U.K. | 265 | 3 (3) | 1,260[6] | 40 | 520 |
| USA | ~ 440 | 25 (n.d.) | n.d. | 1,035 | 112,000 |
| Total | >13,000 | 260 (>=179) | >100,000 | >5,800 | >2,800,000 |

n.d. – no data
[1] including waste water treatment plants, no landfill plants included
[2] referring to biomethane
[3] total (public and private)
[4] motorcar, public transport, truck; NGVs
[5] only biogas plants, no data for waste water treatment plants available
[6] assuming 60% $CH_4$ in the raw biogas
[7] no waste water treatment plants and no landfill plants included

## 4.2. Support schemes and voluntary targets

Not all IEA Bioenergy member countries have support schemes or incentive programmes for biomethane. The countries which have already implemented, or are planning to implement such programmes use different approaches. The following paragraphs provide a short overview of the possibilities. Further detailed information can be found in the literature (GGG 2013b), (EBA 2013), (GGG 2012).

**Tax exemption**
Biomethane can be exempted from a tax or be subject to a reduced tax rate compared to fossil fuels (e.g. natural gas). This is one of the most common support schemes, and is applied e.g. in Austria, Germany, Sweden, Switzerland and Slovakia.

**Feed-in tariff for electricity**
If biomethane is used for electricity or CHP production, a feed-in tariff and partially also an additional biomethane bonus for biogas upgrading is granted. This is applied e.g. in Germany, Italy, Denmark, Slovakia and U.K.

**Direct feed-in tariff for biomethane**
Similar to the feed-in tariff for electricity, injection in the natural gas grid or direct delivery to a fuel station can be supported by a feed-in tariff for biomethane. This is applied in France, Denmark and the U.K. as well as in the Netherlands, where a feed-in subsidy covering the difference between production costs and income is implemented (biogaspartner 2014).

**Feed-in tariff for heat**
Similar to the feed-in tariff for electricity, the provision of biomethane for heat can be supported with a feed-in tariff on top of the gas price. This support scheme is applied in the U.K. and Denmark. The Danish support scheme is, however, still waiting for approval from the EC.

**Investment incentive**
A biogas or biomethane plant can be supported by a reduced interest rate for a loan or a fixed share of the investment cost. This is applied e.g. in Austria, Sweden, Denmark, Hungary, Slovakia and Poland.

**Fee for avoided network tariffs**
If biomethane is injected directly into the gas grid, it is assumed that this leads to lower costs than the use of natural gas, which typically has to be transported over significantly longer distances to the end-user, causing e.g. more costs for the operation of the pressure stages. These cost savings can lead to a direct incentive for biomethane. So far, this is applied in Germany with 0.7 €cent/kWh for the first 10 years of operation.

**Biofuel quota**
Countries can set fixed targets or quotas for a certain amount of biofuels in the vehicle petrol and diesel as well as gas, if used for transport. To achieve these quotas, biomethane can be traded virtually, and therefore may benefit from a high demand. This is applied e.g. in Germany, the Netherlands and U.K.

**Renewable energy quota (Trade of certificates of origin)**
A country can set an obligatory share of electricity production by renewable energies for the suppliers of electricity. These shares can be met by own renewable energy plants or by purchase of certificates for example from biomethane. Poland, Sweden, Norway and U.K. are some of the countries which implemented such a system.

To push the market deployment of biomethane, and therefore substitution of natural gas by a sustainable alternative, some countries have set (additionally to support schemes) voluntary targets for a biomethane share in the energy sector. This is especially common in the European Union countries, due to their general targets for renewable energies. Some of those voluntary targets and commitments are shortly described in the following:

- **France:** Biomethane is recognised as an attractive new renewable form of energy, and stimulated e.g. by feed-in tariff and a national working group. So far targets for biogas are defined in the French National Renewable Energy Action Plan (NREAP) (2010) but not yet for biomethane. (GGG 2013b)

- **Germany:** In Germany, targets of 6 billion m³ biomethane production by 2020 and 10 billion m³ by 2030 injection in the national gas grid have been set. (GasNZV 2012)
- **Hungary:** Hungary set targets for biomethane for the years 2016 – 2020 in their NREAP. Compared to other measures, these targets are quite low. (GGG 2013b)
- **Luxembourg:** At the end of 2011, Luxembourg passed a law which guarantees a fixed compensation for 10 million cubic meters biomethane per year. Within this limit, 3 – 4 standard upgrading plants with a capacity of 350 m³/h could be supported. (Recueil de Legislation Luxembourg 2011), (Koop and Morris 2012)
- **The Netherlands:** The ambitions of the Netherlands to increase the amount of renewable energy are expressed in the NREAP. It is planned that the amount of energy from the feed-in of biomethane into the natural gas grid should increase to 6.7 TWh in 2020, from around 1 TWh today, to meet the required share of renewable energy (Koppejan et al. 2009).
- **Denmark:** With the Danish energy agreement of 12 March 2012, a new support model and new subsidiary schemes for production and use of biogas were adopted in Denmark. One objective in this agreement is the deployment of biogas for other areas than production of CHP and thereby the facilitation of feeding, distributing and selling upgraded biogas (BNG) in the existing natural gas grid system has explicit focus. The agreement is supported by subsidy schemes for the upgrading as well as for the use of the gas for CHP, transport and industrial purposes. The current production of biogas in Denmark is 4 PJ, compared to an estimated total potential of 40 PJ. There are currently no explicit targets on how much of this should be upgraded and fed to the grid. However, in case the market will not show "significant growth" in 2014, there are political thoughts on issuing purchase of obligation for the Danish CHP plants (Energinet.dk, 2014).
- **Slovakia:** Targets for biomethane are implemented, but the financial incentives are not sufficient to stimulate rapid deployment. (GGG 2013b)
- **United Kingdom:** The UK is forecasting 1.5 TWh of biomethane in 2015, rising to 7 TWh in 2020 and 15 TWh in 2030. This is a significant contribution, but there is still a long way to go since the total demand for natural gas is estimated to be over 600 TWh in 2030. By 2015 biomethane will be recognised for support if it is used for renewable heating. (GGG 2013b).

In other countries, voluntary targets are under discussion, e.g.:

- in **Austria,** the Energy Strategy Austria envisages biogas to contribute to the renewable energy targets by delivering electricity or biofuel. The focus lies on upgrading biogas to biomethane with two options. The first option is the addition of 20% of biomethane to natural gas to reach 200,000 cars by 2020. The second option is increasing the amount of biogas produced to 10% of the gas demand, which corresponds to 8 TWh in Austria. Concrete targets have not yet been set.
- in **Belgium,** the research organisation VITO calculated the theoretical potential of biomethane production in the region Flanders to be ca. 330 mio m³, the equivalent of ca. 2% of the yearly non-industrial consumption of natural gas. This could be taken to deliver a part of the extra biofuels needed by 2020. In 2013, a system with both obligations for blending in gasoline and diesel and tax reduction was prolonged till 2019. Biomethane is not (yet) included in the current policy on biofuels for transport.
- **Sweden** has the governmental aim to have a fossil-independent transportation sector by 2030. A public inquiry is currently open (August 2014) to show how fossil free transportation can be reached in 2050 and the results are expected to be important for the future governmental support for biomethane production in

Sweden. The potential to produce biomethane from both biogas from anaerobic digestion and gasification until 2030 is estimated to be 10-20 TWh of biomethane if the conditions are right (Dahlgren et al. 2013).

From this, it is evident that biomethane markets are currently established in a number of EU countries with significant growth in the period 2010 – 2020. Between countries, there are differences in the quality of the targets and also in the intended main markets for biomethane:

- heating (UK)
- electricity with district heating (Germany)
- vehicle fuel (Sweden, Germany, Austria)

In conclusion, the country-specific situation is determined by the national political framework conditions which differ significantly between the countries. Nevertheless, there may be similar expectations of the stakeholders in different countries for the long term development of biogas and biomethane. Therefore a specific questionnaire has been developed and sent out to IEA Bioenergy Task 37 and 40 members (see chapter 5).

# 5. Stepping stones towards market deployment for bio-methane

Parallel to the analysis and collection of available information for this study, a specific questionnaire was developed and distributed in the focus countries to get deeper insights into the chances and barriers for biogas and biomethane as perceived by the different stakeholders. The detailed results are provided in the annex, the key findings are described in the following section.

## 5.1. Aim and response of the questionnaire

In 2013, a questionnaire was sent out relevant stakeholders through the different members of IEA Bioenergy Task 37 and Task 40. The questionnaire contained 23 questions divided over the following topics:

- market & trade
- policy
- certification & standards
- barriers:
    - economic barriers
    - policy barriers
    - operational barriers
    - trade barriers
    - social and environmental barriers

99 responses to the questionnaire, which was sent out in November 2013, were received. Figure 5-1 shows the distribution of the respondents over countries, Figure 5-2 shows the share of responses received for the different stakeholder categories.

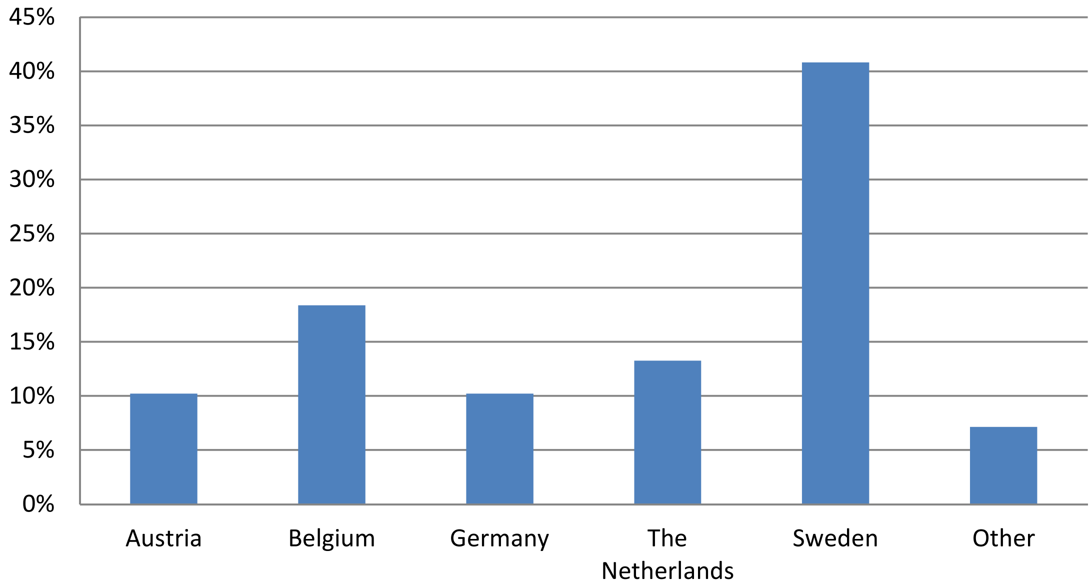


**Figure 5-1.** Country respondents to the survey

From Austria, 11 questionnaires were received from the different stakeholders, mainly policy makers, researchers and others (Energy Agency, Association, Biogas Register). In the survey, this needs to be taken into account when interpreting the results of Austria.

There were 18 Belgian respondents for the survey, with some respondents having multiple roles. All stakeholders are represented in the survey, with a strong representation of researchers.

10 completed surveys were received from Germany. The identification of the respondents is given in the Fig. 5-2 below. As can be seen, the different stakeholders in the value chain are represented but, as for Belgium, there is also a strong representation of the research community.

13 completed surveys were received from the Netherlands. All stakeholders are represented, the constructors are strongly represented and in the category ‘other’, consultants, project developers, policy related and public private partnerships respondents answered.

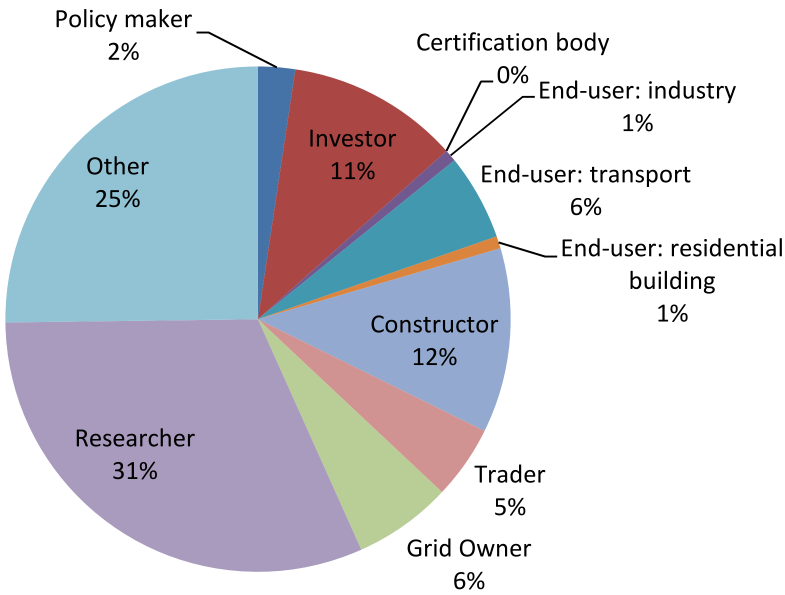


**Figure 5-2.** Identification of the respondents of the survey

The highest feedback came from Sweden with 40 responses. Also here, the research community was strongly represented. In the category 'other', consultants were strongly represented, but also farmers, producers of biomethane, sales and distribution partners and associations.

7 surveys from countries other than the focus countries were received: 1 from Norway, 1 from Denmark, 1 from UK, 3 from the USA and 1 from the European Commission.

## 5.2. Summary on stepping stones towards a biomethane market

The response to the survey per country is not enough for a scientific statistical analysis, but due to the fact that it was well-targeted towards experts on biomethane, it is considered to give a good insight into the trends and perceptions of each focus country.

Regarding the policy for biomethane, it can be concluded that a good **framework** is necessary to push the biomethane development forward. It is apparent that even in countries like Germany and Sweden that have already pushed biomethane forward, this is still an important point of attention.

As shown in appendix A 1 in more detail, four out of five countries focus on biomethane with the intended end-use for electricity and heat; only Sweden focusses on transport use. When asked for additional policy, the German and Austrian respondents would like to follow the Swedish example and ask for more support in the transport sector. Sweden itself would see some help for the facilities, the same for the Dutch respondents. Belgium (at the beginning of the development) is still focussed on injection into the gas grid.

Because of the (lack of) economic feasibility in the current market, biomethane needs **political support** and of course associated **financial support**. This conclusion was the same for all the countries.

The countries studied are in different phases of the development of the market: Belgium is standing at the start of the development. Austrian respondents perceive themselves as a premature market. The development to a mature market is for the Austrian respondents depending on the political support for biomethane. Germany, The Netherlands and Sweden have already a more developed and mature market. Despite this, respondents of those three countries still believe that there is still **room for growth**.

Next to a good policy framework, another important stepping stone for the development of a biomethane market is **good information flow** to the stakeholders and to the public. This possible barrier is evident in all the of the five focus countries. Another European barrier that can be seen in the responses was the shortage of feedstock and volatile feedstock prices. For the German and Austrian stakeholders, also the fear for environmental harms from agricultural intensification caused by increased demand of biogas crops was a possible barrier, this is not perceived in the other three countries.

When asked if **international trade** could occur in the future, respondents from Belgium, Germany and Sweden answered **positively**. Respondents from the Netherlands and Austria were less certain if international trade could be a fact in the future. The main argument for doubt is that the demand for biomethane in these countries is higher than the production, so there will be nothing left for international trade. The Swedish respondents describe the desire to import biomethane to satisfy the increasing demand.

# 6. Conclusions and Recommendation

Biomethane is an attractive fuel to support the transition of the fossil resource base and the climate protection targets in different ways. While the technical availability was shown for biomethane from biogas, the provision of biomethane via thermochemical conversion is still at the demonstration stage. The thermochemical conversion process is a highly complex process with no market penetration so far. In contrast to the biochemical conversion process, it is has to be implemented on a much larger scale with the resulting hurdles of logistic and technology.

In regions with good natural gas infrastructure, the great opportunity of biomethane is the relatively easy integration into the existing energy system (e.g. use for heat, electricity or as a transport fuel). Also, by injecting biomethane into the grid, production and consumption can be spatially decoupled. This logistical option is in principle available today, but clear demands for the biomethane quality (transnational) to be fed into the gas grid are necessary. Technical standards for biomethane from biogas are currently under development on a European level. The specific challenge is to define standards which are attractive for the different potential end-user (gas grid owner, automotive industry, etc.) to enter the new market.

The use of biomethane to replace natural gas can lead to significant reduction of greenhouse gases. It has been shown that significant variations are possible which arise from both the plant design and operation, and the GHG accounting methodology. By following best practice, it is possible to achieve GHG savings of over 80% when compared to the fossil fuel alternative. Sources of GHG emissions savings vary, depending on the process for biomethane production. The assumption on the fossil fuel replaced (e.g. coal, oil or NG in the heat and CHP sector or liquid and gaseous fuels in the transport sector) is important, because the GHG saving potential depends strongly on this choice. Key sources of GHG emissions include biomass feedstock cultivation (where purposely grown energy crops are used) and biogas upgrading. Emissions may be significantly reduced with the application of BAT (Best Available Technology). On the other hand, the biomethane provision is linked to higher costs compared to natural gas in the short- and mid-term. Therefore, standards are necessary which ensure sustainable feedstock production as well as a proper and transparent methodology to determine the mass balance for biomethane transported and traded via the natural gas grid.

Market introduction strategies have to consider the complex provision chain (Figure 6-1), which has to include widely different stakeholders. Promising markets are seen in those countries with dedicated biomethane strategies, targets and support schemes. Today, there is a wide range of approaches, instruments and certificates established which can differ in:

- sustainability demands of the biomethane provision (feedstock information and technical information on the conversion unit)
- technical demands of grid injection (gas quality information)
- technical demands for end use (gas quality information)
- support schemes (what kind of support and where in the chain)
- monitoring of the biomethane flows (registration in the relevant countries)

With regard to political strategies and access of the natural gas grid, Europe is becoming more active in the development of a biomethane market. Some countries have drawn up a biomethane strategy and implemented support schemes (e.g. Sweden, Switzerland, Germany, Denmark, United Kingdom, Italy), see chapter 4.2. Ongoing actions are in the field of technical standardisation and sustainability certification. Both are complex issues, but might provide instruments in the next one or two years to improve the situation with regard to biomethane use and cross border trade:

- Technical standards need to be implemented on an international level, especially for biomethane use in cars. The major problem here is that those standards have not been agreed yet for NG due to different interest of the stakeholder in this sector. With biomethane as an additional fuel, it currently seems that the opportunities to agree on a common standard have been increased.
- On European level, sustainability demands for biomethane need to be made compatible with the specific supply chains and transport options. This increases the demand to provide default values and appropriate reference systems for different biomethane applications, but also calculation methods to make sure that – even in a mass balance system – biomethane can be transported via the natural gas grid, similar to sustainably certified palm oil for biodiesel, which can be transported in a tank vessel together with conventional palm oil without violating the mass balance system.

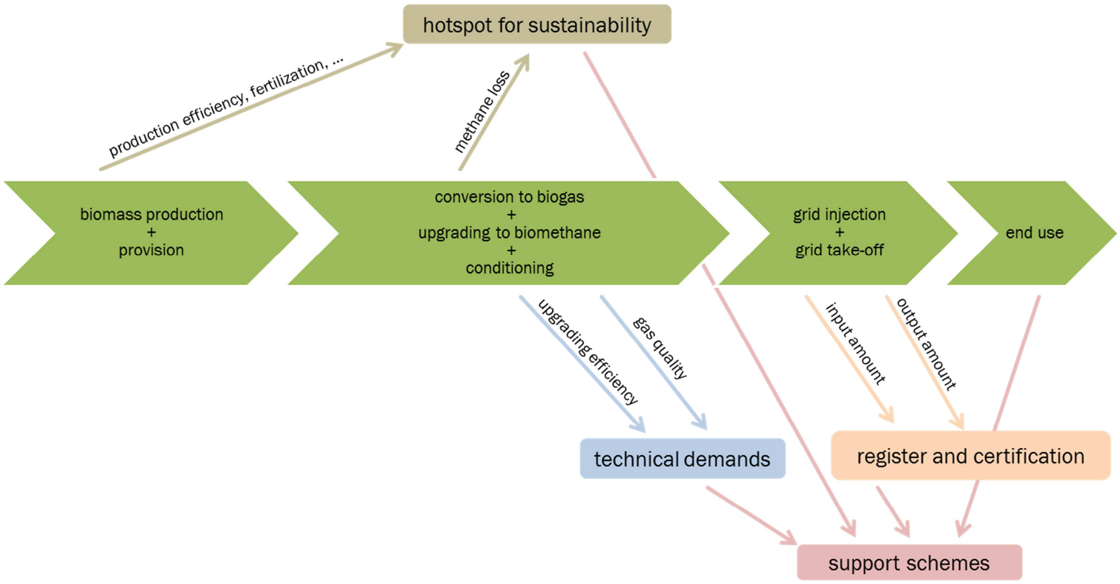


**Figure 6-1.** Framework of the biomethane value chain

So far, biogas upgrading is mainly undertaken in Europe. Outside the EU, only minor activities in e.g. the USA and South Korea are observed.

In the investigated focus countries, there is a strong expectation for a growing market. One reason can be seen in the financial support, which has been implemented in those countries, and which is seen as a major driver for the market implementation. National biomethane markets are also seen as the promising starting point for an expanding international biomethane trade. Furthermore, there is already a planned close cooperation between the national biomethane registers for better trade between the participating countries, with the option of including more countries. Relevant next steps for those registers are the development of a common terminology, tracing system and the definition of interfaces between the country-specific quality demands but also accounting and monitoring of the market. In the case of the German biomethane market, based on the questionnaire, it can be summarised that questions of the **economic viability** of biomethane projects in connection with stable **political framework** conditions are the most relevant factors for individual decision-making. The importance of a **reliable framework**, for example through **clear legal requirements** and adequate regulation and **support measures**, both for biomethane provision and end use markets, cannot be overemphasised.
Additional problems for transnational trade arise from the different support schemes developed in the different countries. Two aspects are relevant here:

**(i)** **To which point of the supply chain is the support connected**: Currently, in the countries investigated, different products are supported (biomethane fed into the grid, electricity provided from biogas, biomethane provided at filling stations…). From a national perspective, this is reasonable due to different targets and strategies how biomethane is included, but for international cooperation, there is risk of confusion. For international trade, a strong and clear tracking of flows is necessary, to avoid double support or marketing (e.g. at the injection point in one country and at the delivery point in another country).

**(ii)** **Level of support**: Today, the specific level of support differs widely (i.e. the feed-in-tariff for biomethane injected into the grid). If a framework for international trade is implemented, it will be relatively easy to transport biomethane via the gas grid to those countries where higher support is given, or otherwise very favourable conditions exist. This could on the one hand accelerate market development, but on the other hand may also cause the national support system to collapse.[17]

This leads to the conclusion that more coherent support conditions between countries could make the market development of biomethane easier and reduce the complexity of the registry systems.

**Recommendations:**

Summing up the current status on biomethane, this report shows that in some countries there are clear trends for biomethane market growth. To ensure a regulated and sustainable market, stable framework conditions are needed. Therefore, the following recommendations can be given for a future biomethane market:

- Development and implementation of widely-accepted technical standards regarding uniform biomethane injection to the natural gas grid, which aims to a standardised biomethane quality (in a given range) with respect to e.g. calorific value and degree of purity.
- Sustainability standards for all kinds of biomethane application, but also with the possibility to trade sustainable biomethane between countries.
- Certification and registries for a transparent national and international market of biomethane (e.g. no double support).
- Equal treatment of domestic and imported biomethane (certification, support/incentive, …)
- Support schemes with regard of reliable and long term conditions. From today's perspective a single, uniform regulation region connected by one natural gas grid (i.e. Europe) seems to be an important milestone for the development of international markets; this study did not investigate in detail how such an instrument could look like (e.g. a uniform biomethane grid injection tariff. A quota, etc.).
- Roadmaps for mid- and long-terms targets in order to clearly define the incentive.

With regard to the complex provision chain of biomethane, different stakeholder in the field and the transnational natural gas grid (especially in Europe) it is easy to understand that those framework conditions are difficult to achieve. Implementing these recommendations should provide a good base for sustainable, fair, future-orientated and stable biomethane market development. An overarching international framework of sustainability information (e.g. feedstock, origin, GHG emission from production and transport, etc.) for fossil and renewable energy carriers could support the biomethane market too, but goes beyond the scope of this study.

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[17] Comparable experiences were made when single European countries implemented renewable electricity certificates at the beginning of the 21.century, e.g. in the Netherlands large amounts of renewable electricity were imported as certificates to get a tax exemption. Within two years, the Dutch government had to significantly change the tax exemption scheme, and ultimately switch to a different support scheme altogether.

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# APPENDIX
# Detailed questionnaire results

*Nathalie Devriendt*

## A 1 Policy for biomethane

### A 1.1 Austria

The respondents were asked if there is a policy in place in their country. For Austria 63% answered positive, 37% answered negative. The Austrian respondents indicate that financial support for electricity and heat is the focus at the moment, but with the comment that the support is mostly for electricity and not for heat. Also financial support for injection is given. It is important to see in the figure below that also some respondents feel that there is a framework but no financial support in place.

This last indication relates also to the fact that the Austrian respondents feel that the current policies do not stimulate the market (83%), only 17% thinks there is enough policy to support the market.

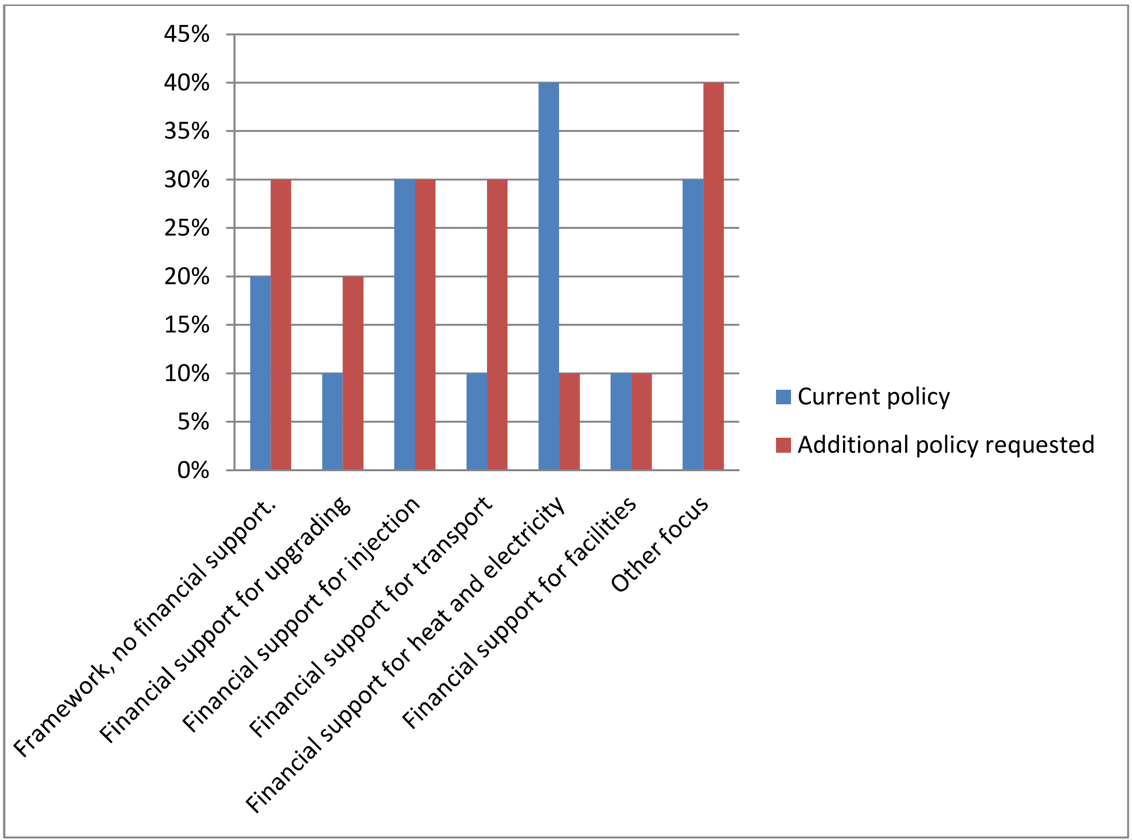


**Figure A-1.** Current and additional policy requested for biomethane following Austrian respondents

Suggestions for additional policy measures are also given in Figure A-1. Important to notice is that almost 30% of the respondents feel that there is greater need for a framework for biomethane, this can be seen as the starting point for a biomethane policy framework, not sufficiently present in Austria.

Additional support is also asked for the use as transport fuel and for injection. Other suggestions for policies are to go for a national obligation in fuel sources e.g. natural gas.
Political barriers perceived by the Austrian respondents can be seen in the following figure. All 3 barriers given by the survey for all countries are agreed on by the Austrian respondents:

- Too many barriers in regulatory approval
- Need for more political support for developing the market
- Uncertainties of biomethane within the national policy framework.

The need for more political support received the highest score.

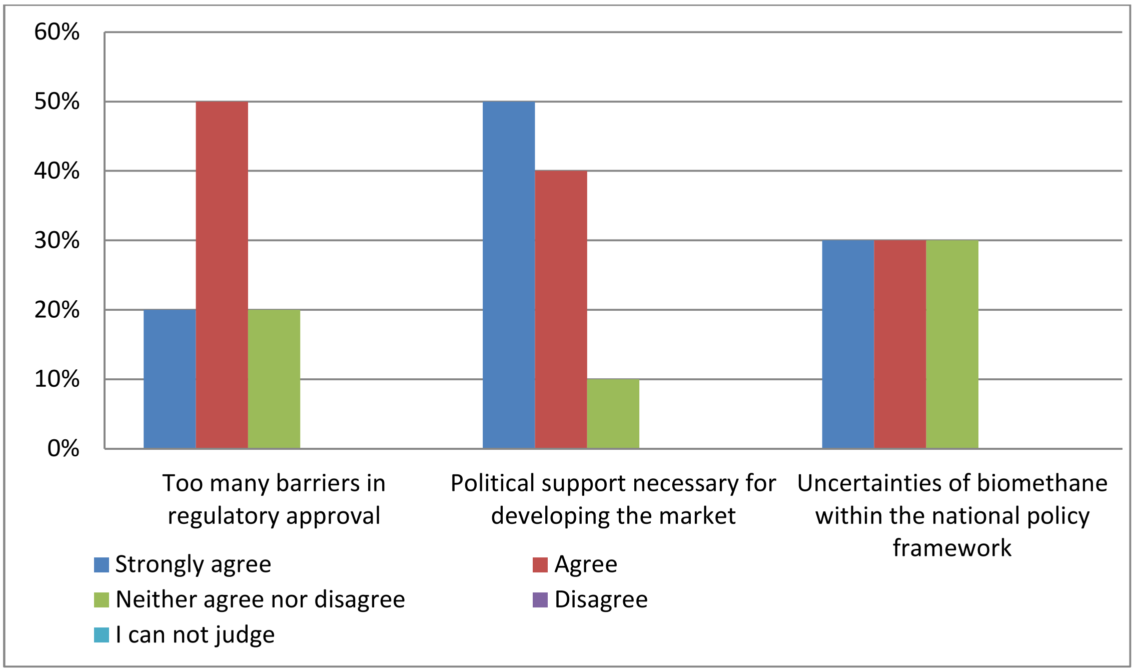


**Figure A-2.** Possible policy barriers following the Austrian respondents.

## A 1.2 Belgium

61% of the Belgian respondents answered that there is no policy in place, 39% say that there is a policy in place. The reason for the different views expressed could be the fact that policies differ according to the region. All respondents agree on the fact that the policy in place does not stimulate the market.

The policy in place in Belgian comprises a framework for biomethane, support for electricity and heat and for injection.

As seen for Austria, Belgian respondents still feel that many barriers exist in regulatory approval, that (more) political support is necessary to stimulate the market and that there are still many uncertainties in the current framework.

Additional policy requested by the Belgian respondents is first of all support for injection, followed by support for upgrading and support for transport and for facilities. Here again, it is clearly evident that Belgian respondents are asking for a better framework for biomethane.

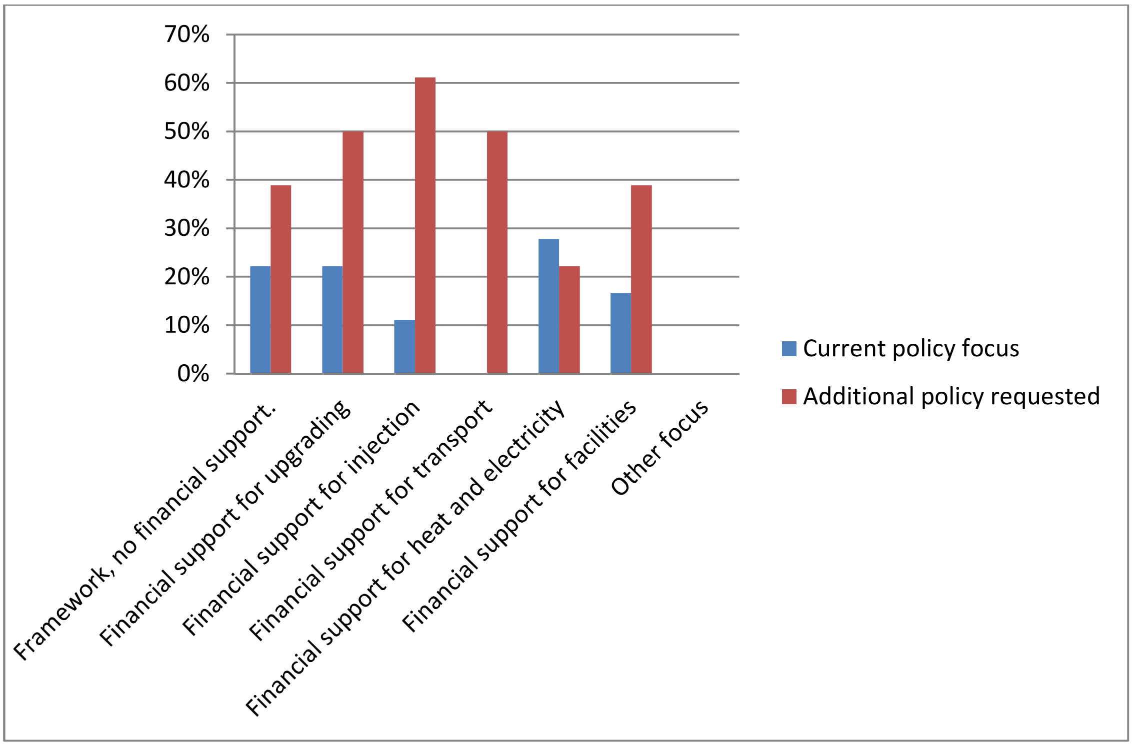


**Figure A-3.** Current focus biomethane policy following Belgian respondents

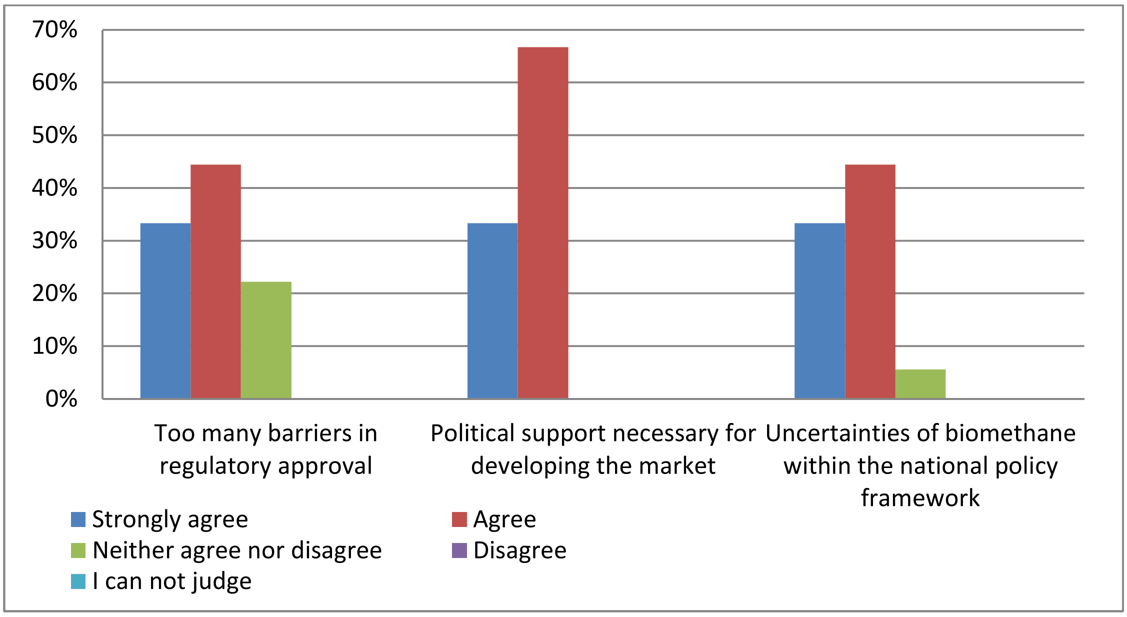


**Figure A-4**. Possible policy barriers following Belgian respondents

## A 1.3 Germany

For Germany the respondents give a clear view on their policy status: all respondents agree that there is at the moment a policy in place in Germany and 90% agrees that this is sufficient to stimulate the market. Their current focus for biomethane is on the electricity and heat markets.

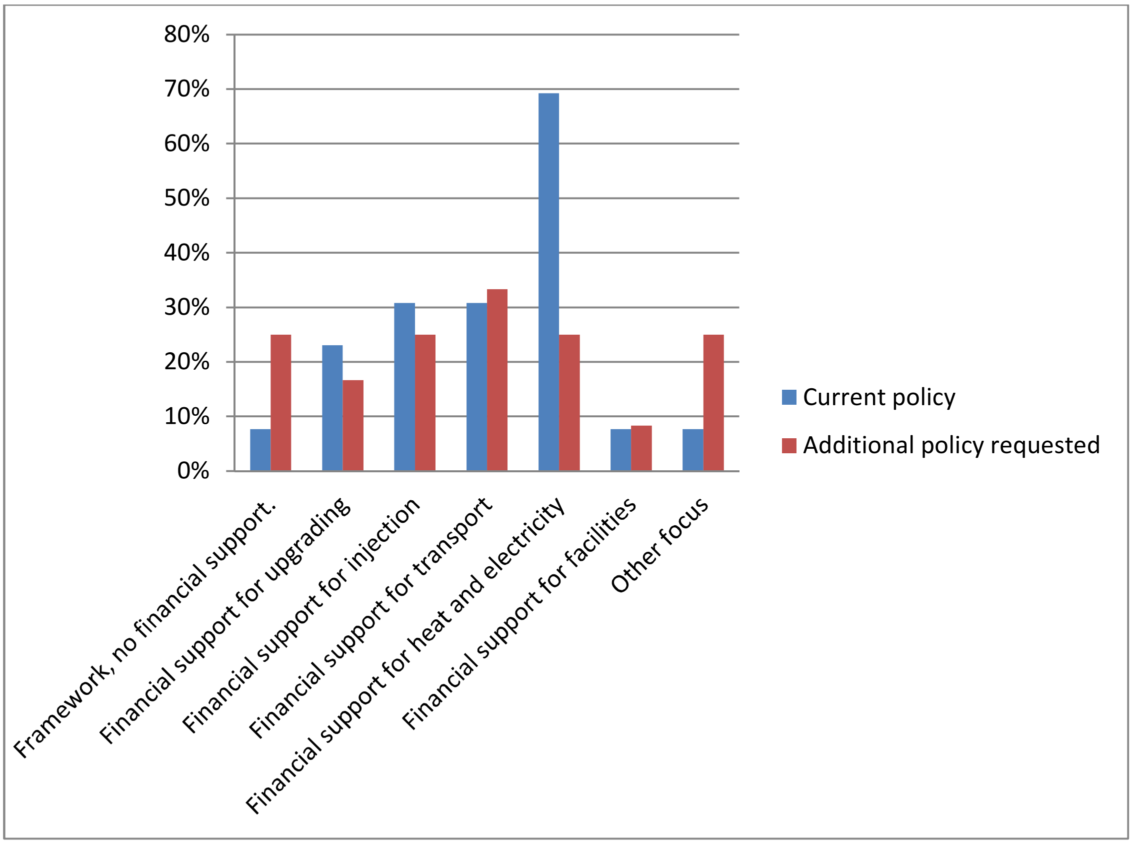


**Figure A-5.** Biomethane policy following German respondents

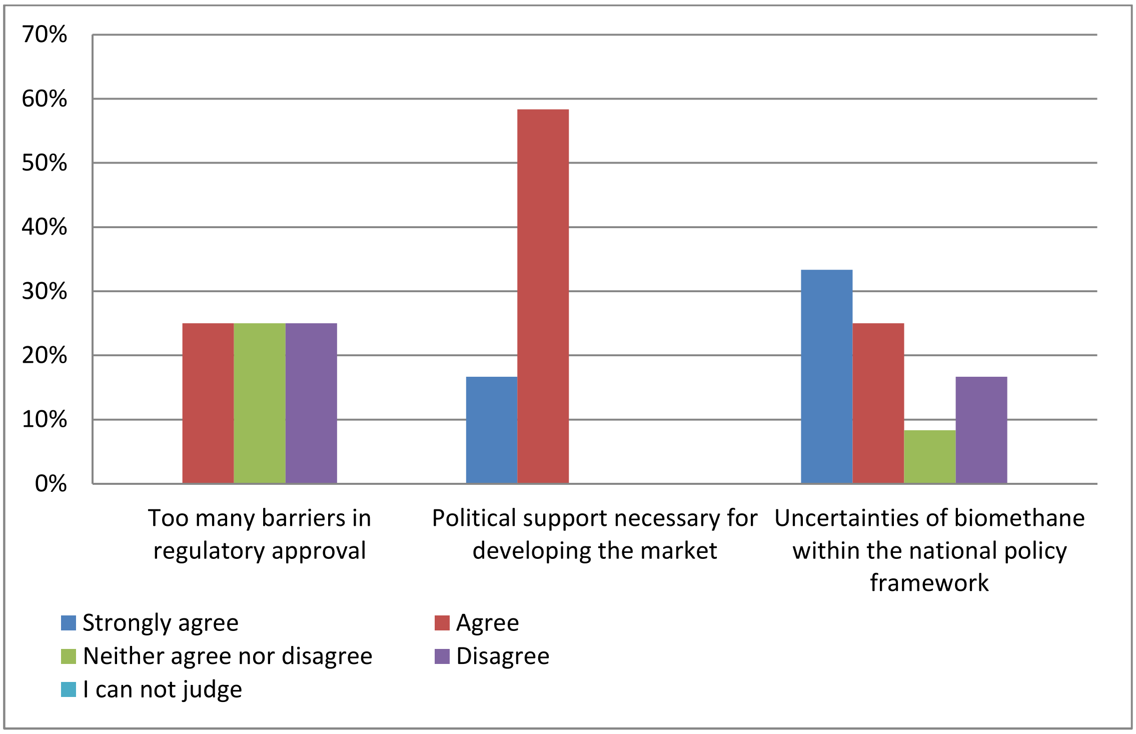


**Figure A-6.** Possible policy barriers following German respondents

The German respondents also stress that political support is a key factor for stimulating a biomethane market. A more scattered response is given to the question if there are still too many regulatory barriers and to the question if there are still uncertainties in the policy framework, see Figure A-6. Possible policy barriers following German respondents

In spite of a mature policy for biomethane, there is still a request for additional policy in Germany. 30% of the respondents would like to see some support for the use of biomethane for transport. Also the political framework can still be improved, combined with the comments that are given in the survey this could be related to long term stability that is asked for in a sustainable way. One suggestion also takes biomethane a step beyond the energy market and it is suggested to give support for the chemical industry for using biomethane.

## A 1.4 The Netherlands

69% of the Dutch respondents state that there is a biomethane policy in place, 31 % do not agree with that. Of the 69%, 61% think this policy stimulates the biomethane market.
The focus of the current Dutch biomethane policy is on the injection of the biomethane and the financial support for heat and electricity. According to the other respondents there is no specific biomethane policy in place, but the biomethane is embedded in the general renewable energy policy.

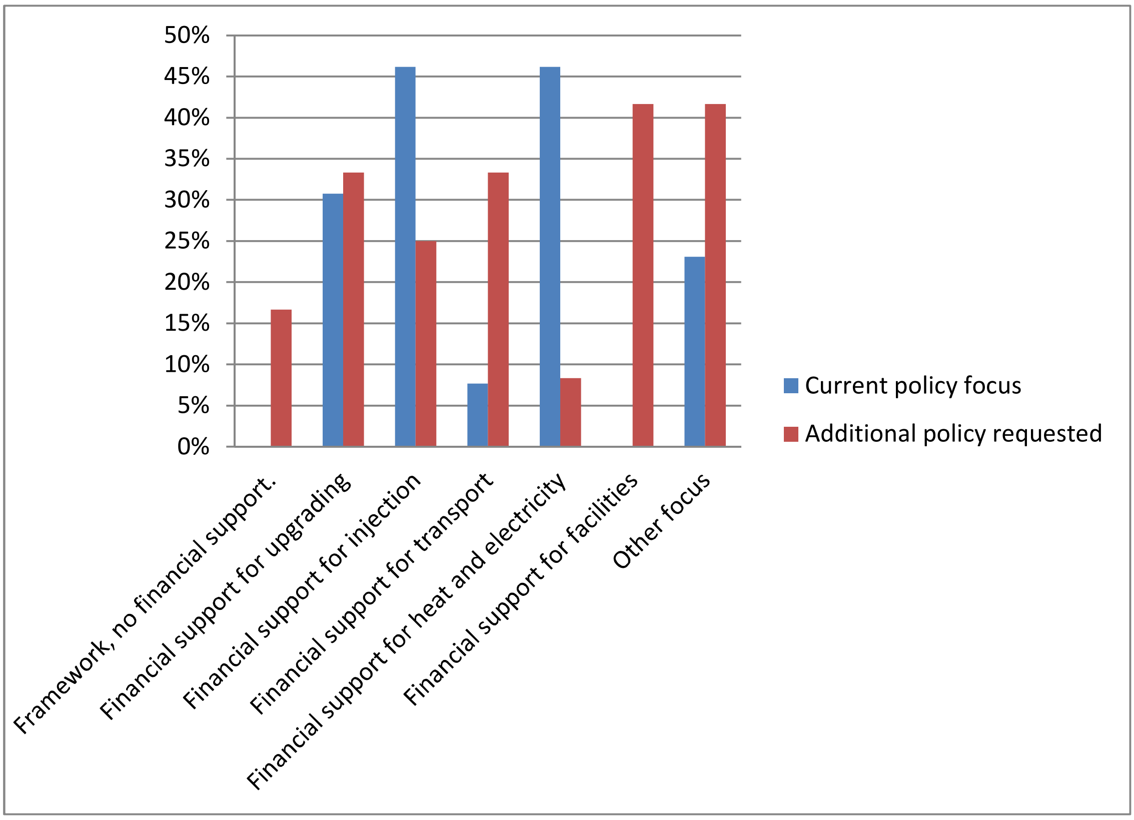


**Figure A-7.** Biomethane policy following the Dutch respondents

When asked to identify policy barriers, a mixed view is given by the stakeholders. Following the answers, regulatory barriers are not a main problem in the Netherlands. Political support is necessary for the majority but there is some disagreement with that statement. Also, uncertainties within the national policy framework are for some still a barrier but not for all.

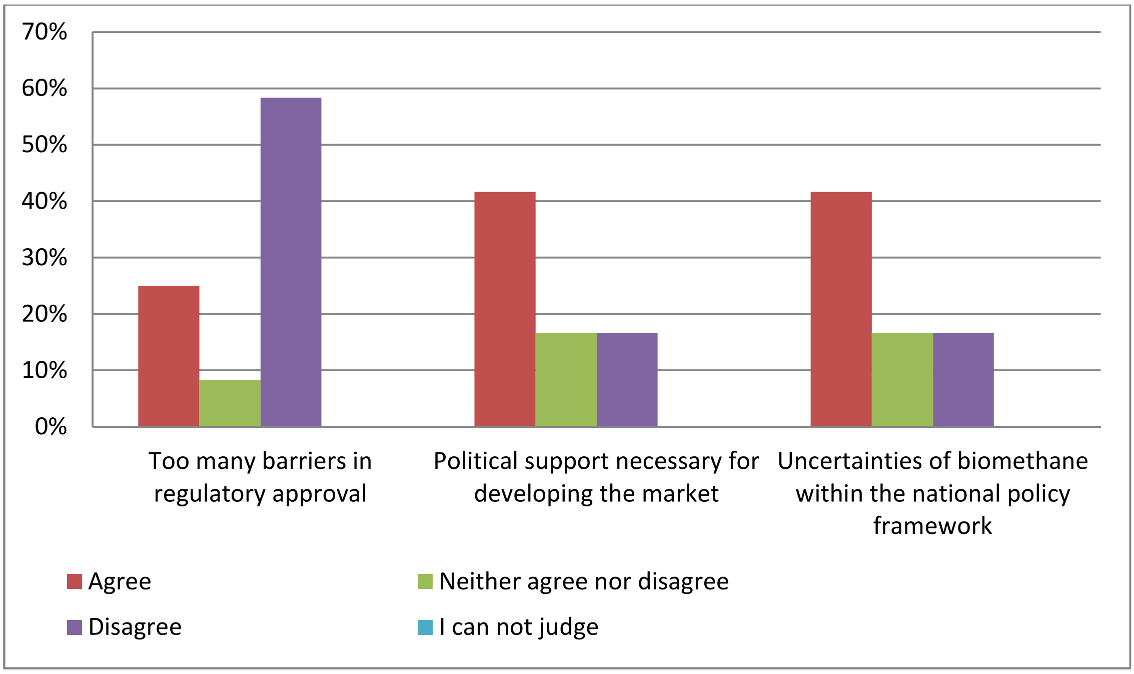


**Figure A-8.** Possible policy barriers following the Dutch respondents

When asked for additional policy in the Netherlands, the following suggestion was made: financial support for the facilities itself. Other needs proposed by the respondents are as follows:

- Conflicting rules and regulations e.g. government permit policies, hamper the development of biomethane, solutions are needed.
- Smart combination of the suggested policies
- Stable political framework
- Financial hedging to stimulate financing by banks

## A 1.5 Sweden

64% Of the Swedish respondents answers that there is a biomethane policy in place but only 56% of them think this is sufficient to stimulate the biomethane market.

The current focus of the biomethane policy in Sweden is on financial support for transport use. The financial support is not in the format of a subsidy, but given as a tax exemption. Other policy in place related to biomethane is financial support for farm scale installations, on waste treatment and on substrate production.

Also for the Swedish market it is clear that political support is necessary for developing the biomethane market. For most of the respondents uncertainties in the framework act still as a barrier. On barriers of derived from regulatory approval, more respondents agree than disagree.
Additional policy is requested by the respondents for financing the facilities, followed by financial support for transport. This is a bit surprising because the current focus is already on transport.

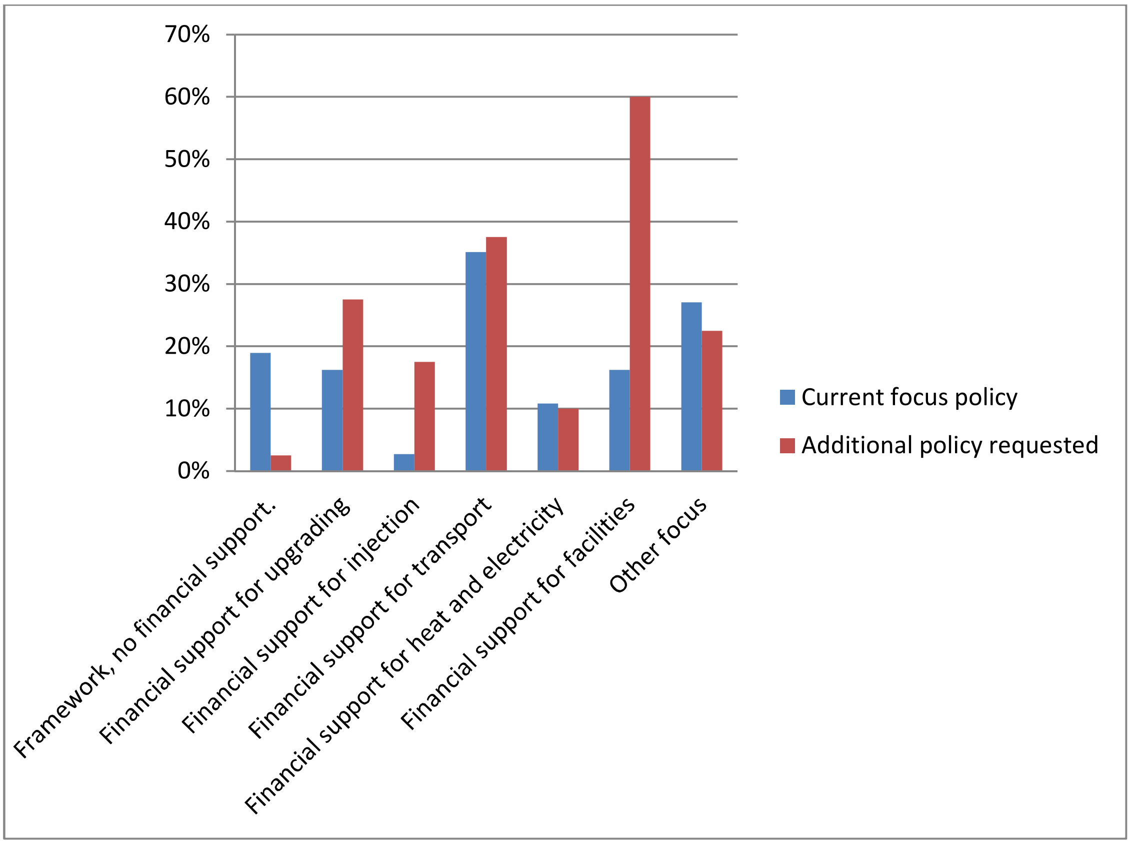


**Figure A-9.** Biomethane policy following Swedish respondents

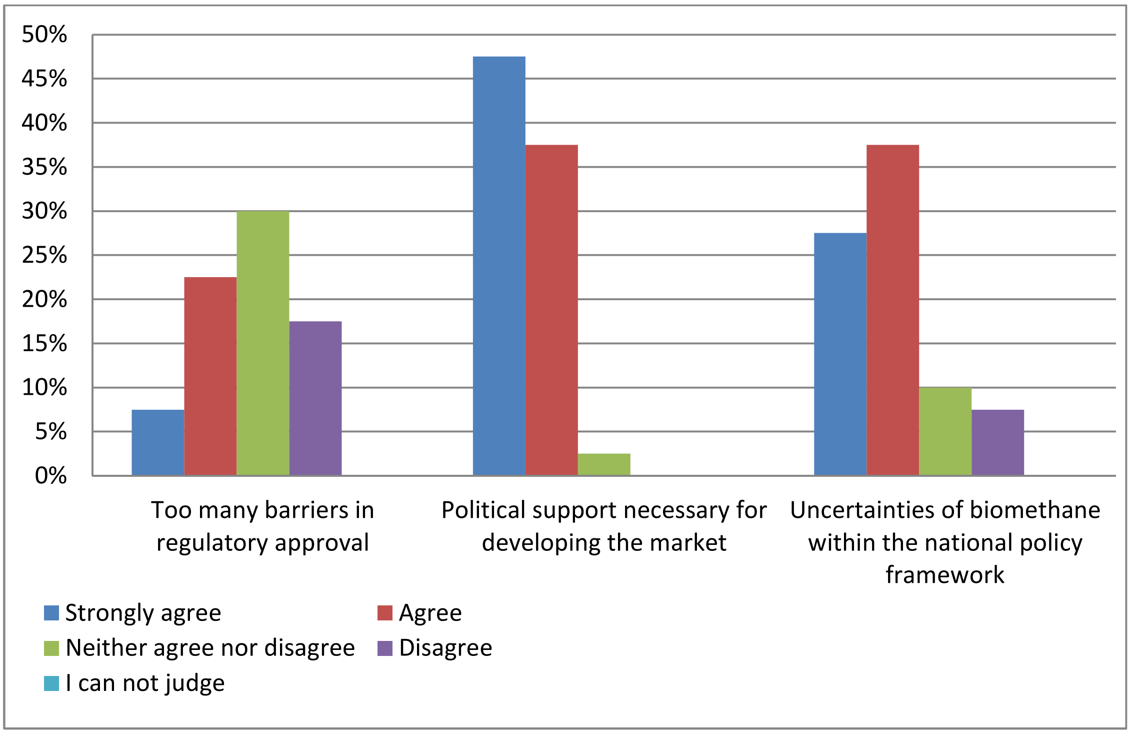


**Figure A-10.** Possible policy barriers following Swedish respondents

## A 2 Stakeholder expectations for biomethane markets
## A 2.1 Austria

For Austria all respondents agreed that a premature market is established in their country. When asked about progress of the market 30% expressed the opinion that the market will grow in the future, 60% expects a stabilisation of the market and 10% expects a decrease of the market. The most used argument that could influence the market in either direction is the political will/policy in Austria. According to respondents the current incentive given by the government is not enough to push the biomethane market into the direction of, for example, transport.

The respondents were asked to give the main drivers for biomethane, multiple answers were possible. In Figure A-11 it can be seen that the main driver for biomethane is the wide range of possible end-uses (60%), followed by the fact that biomethane is ideal for injection to the gas grid. Other drivers pointed out by some respondents include the fact that green electricity tariffs may be exhausted for biogas installations and they might be encouraged to switch to subsidised biomethane production. Another driver given was that biomethane stimulates the utilisation of residues.

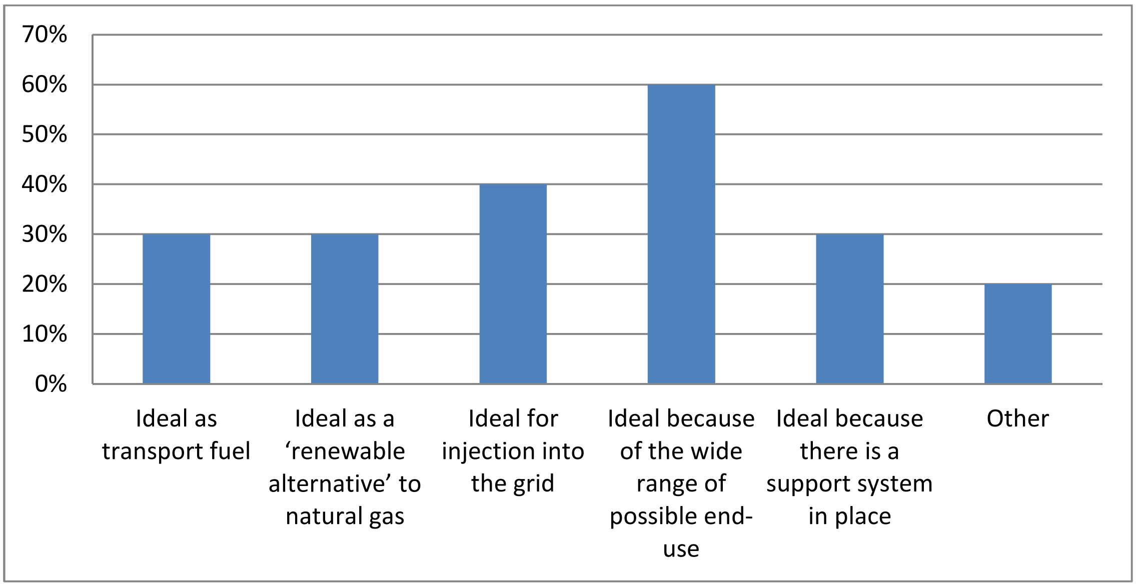


**Figure A-11.** Drivers biomethane following Austrian respondents

According to Austrian respondents high investment costs and increasing feedstock prices are the main economic barriers. The statement that biomethane projects have low profitability prompted diverse opinions. The fact that CNG-CHP's are more profitable than biomethane received a neutral reaction.

For the operational barriers a mixed impression is given by the Austrian stakeholders. On the fact that uncertain feedstock availability is a barrier, more people (strongly) agree (60%) but 30% also do not agree that this as a barrier. The planning process is for some people still a barrier but not for the majority. Similar impressions are formed for uncertainties in efficiencies and availabilities for the operating plant and for possible problems with fermentation residues.

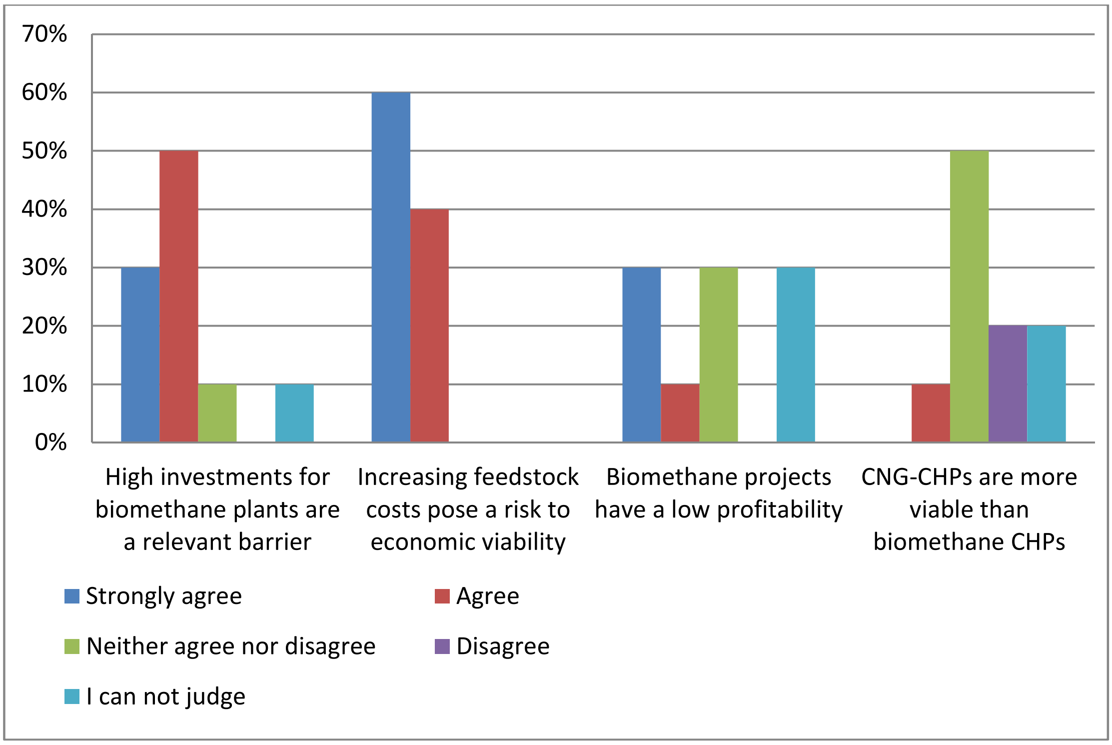


**Figure A-12. Possible economic barriers following Austrian respondents**

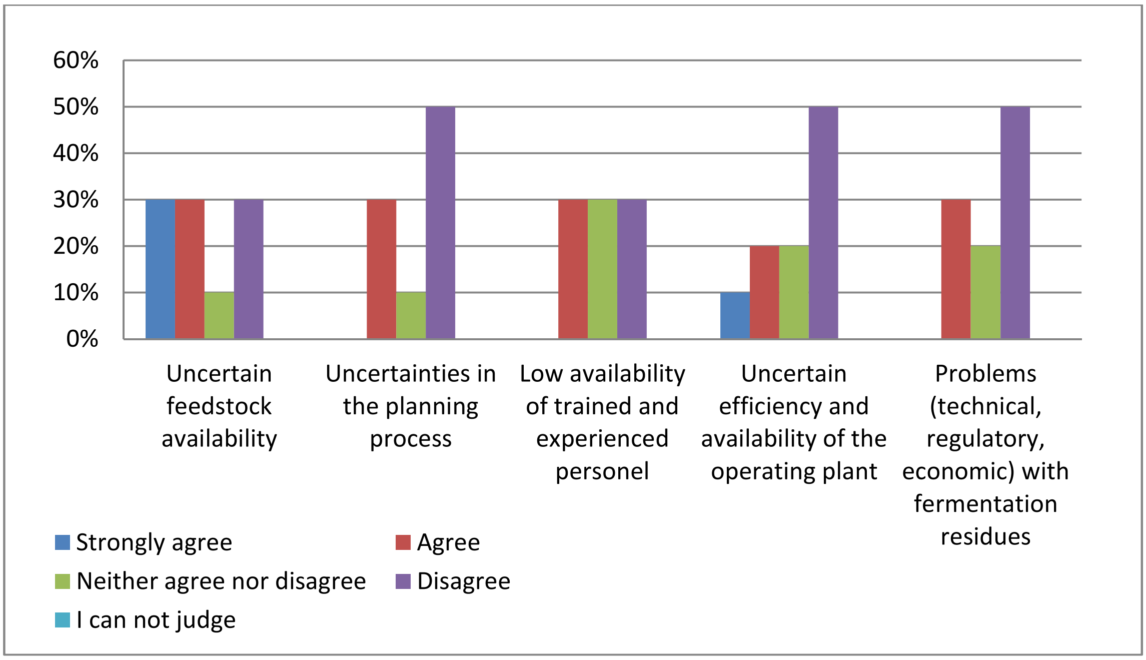


**Figure A-13. Possible operational barriers following Austria respondents**

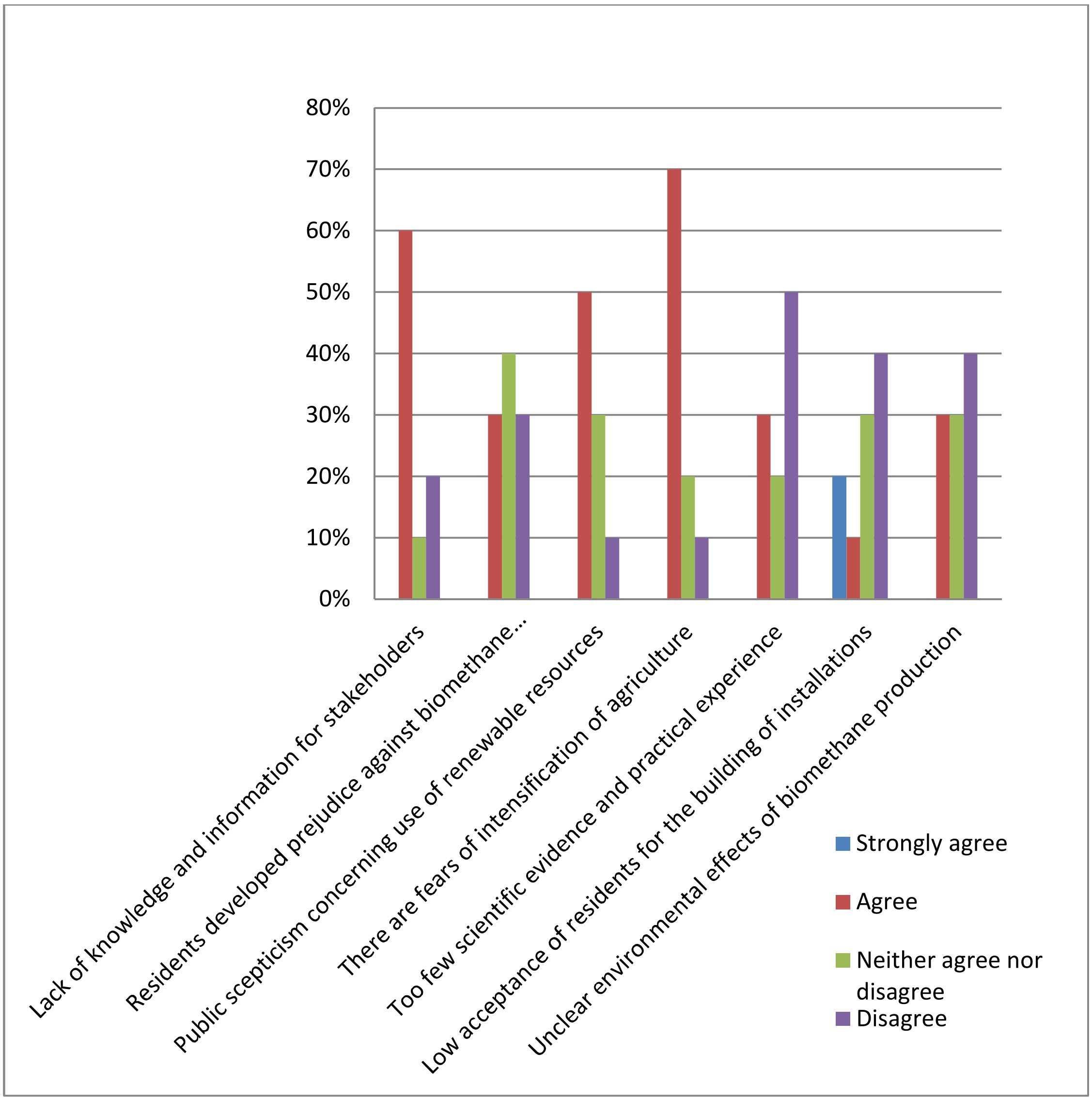


**Figure A-14. Possible social and environmental barriers following Austrian respondents**

The statement concerning the stakeholders, tells us that a lack of information is seen as a barrier. Regarding the public opinion, prejudgement against biomethane is apparent following some respondents but most do not agree or have no strong opinion. Acceptance of building the installations is by most respondents not considered a barrier, although 20% do see it as a strong barrier and 10% agree on this statement. There is more agreement on the fact that biomethane is also suffering from public scepticism concerning the use of renewables in general. The fear of intensification of agriculture is a huge concern following the Austrian respondents (70% agrees). Enough scientific evidence and practical experience is available according to respondents. Most respondents disagreed or were neutral concerning possible unclear environmental impacts.

## A 2.2 Belgium

In Belgium 69% of the respondents believe that a growing biomethane market will be established. 89% of the respondents say that there is no biomethane market in Belgium at the moment. Surprisingly 31% of the respondents answered that the market will stay at his current level, meaning no biomethane market will be developed. 11% says that there is a premature market in Belgium.

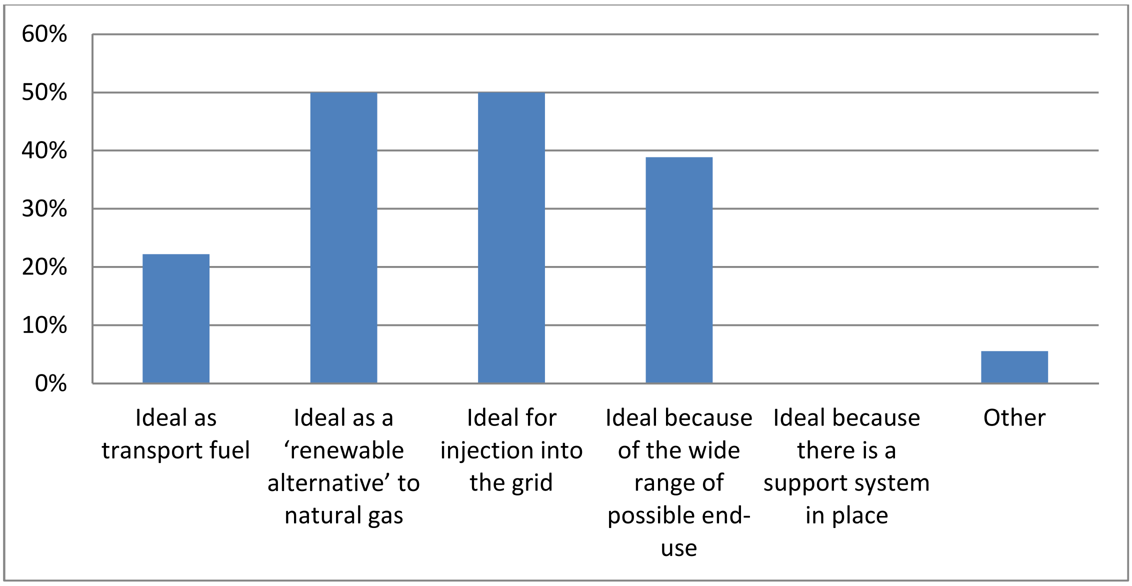


**Figure A-15.** Drivers biomethane following Belgian respondents

The Belgian respondents see biomethane mostly as a renewable alternative to natural gas and ideal for injection into the gas grid, followed by the driver that biomethane is ideal because the wide range of possible end-uses. Biomethane as transport fuel is perceived as a driver but only by 20% of respondents.

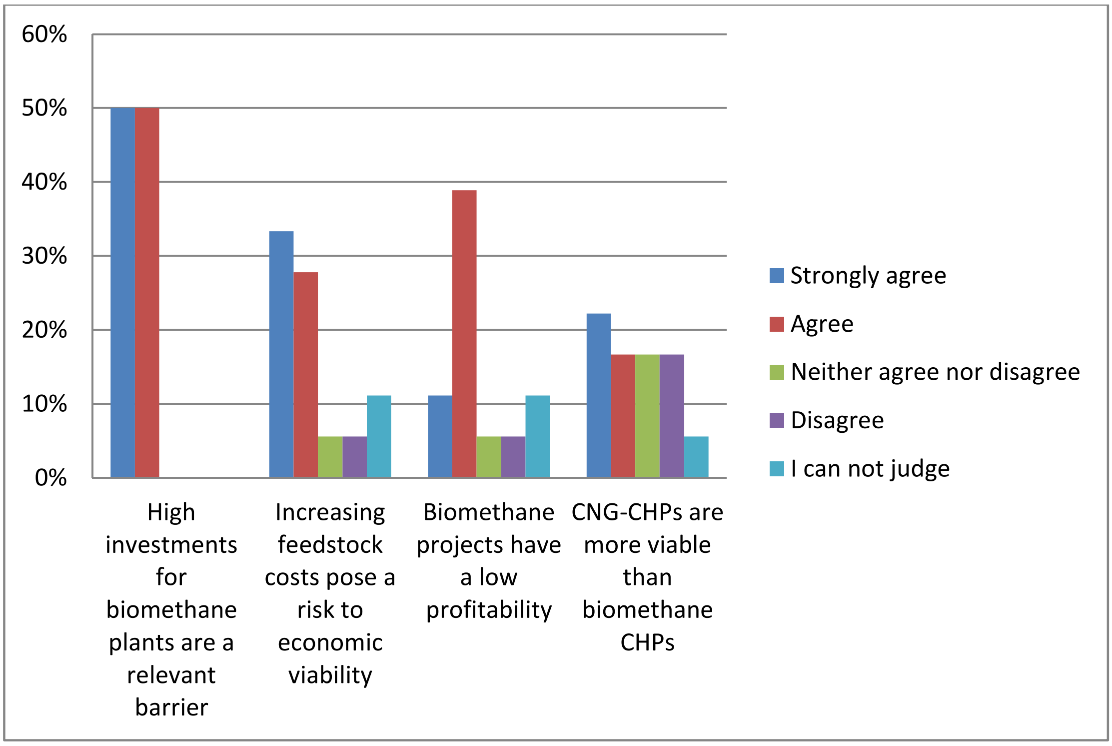


**Figure A-16.** Possible economic barriers following Belgian respondents

There is strong agreement from the Belgian respondents that the high investment cost, increasing feedstock price and low profitability are important economic barriers in the country. A scattered response was received on the statement that CNG-CHP's are more viable than biomethane CHPs.

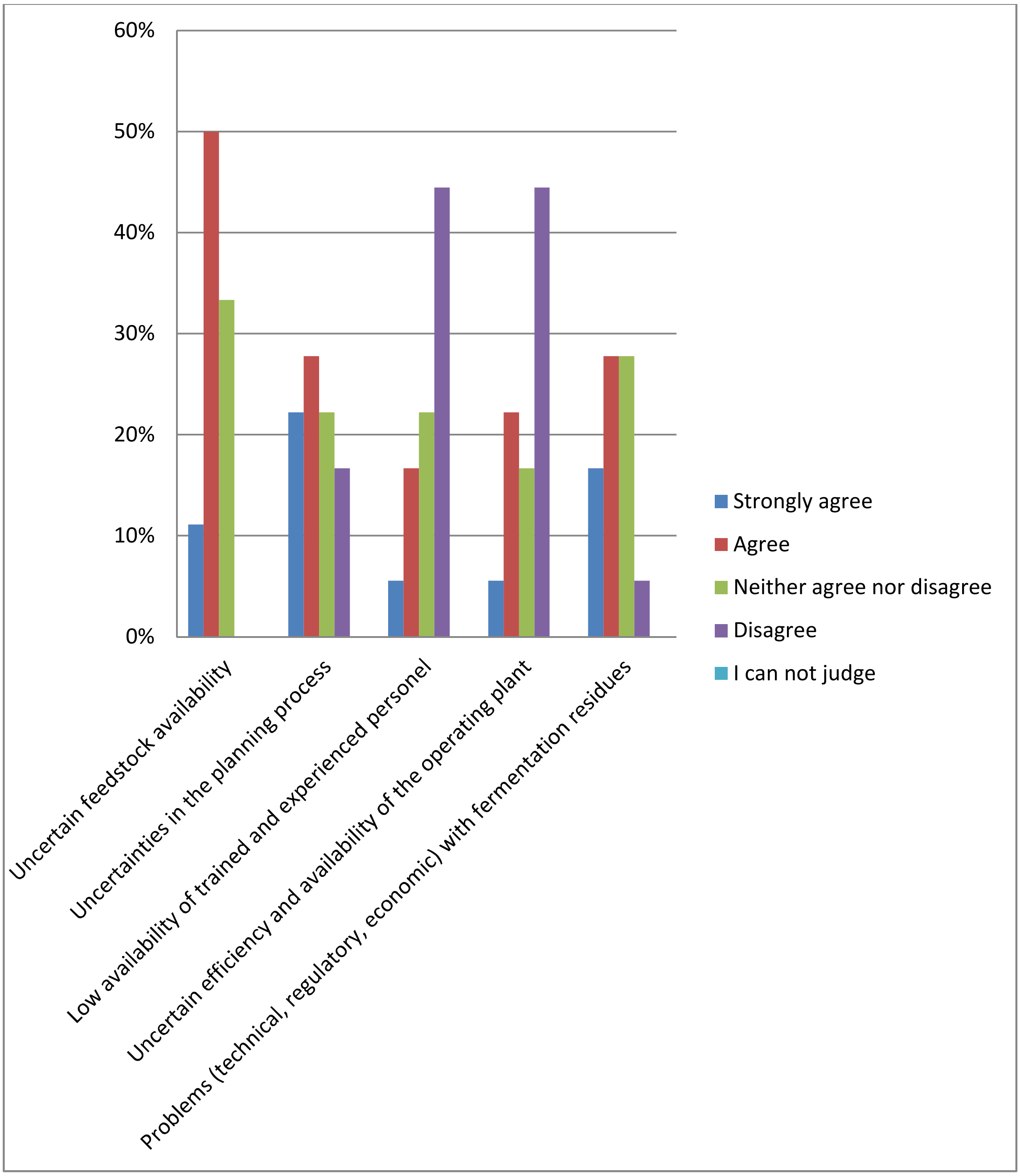


**Figure A-17.** Possible operational barriers following the Belgian respondents

For the operational barriers more scattered answers are given by the Belgian respondents. Most agree or are neutral on the statement that feedstock availability is an issue. Regarding the planning process some see it as a barrier, others disagree with this statement. The availability of trained and experienced personnel is not perceived as a barrier by most respondents. Also the efficiency and the availability of the operating plant are not perceived as barriers. Problems with fermentation residues on the other hand could be a barrier.

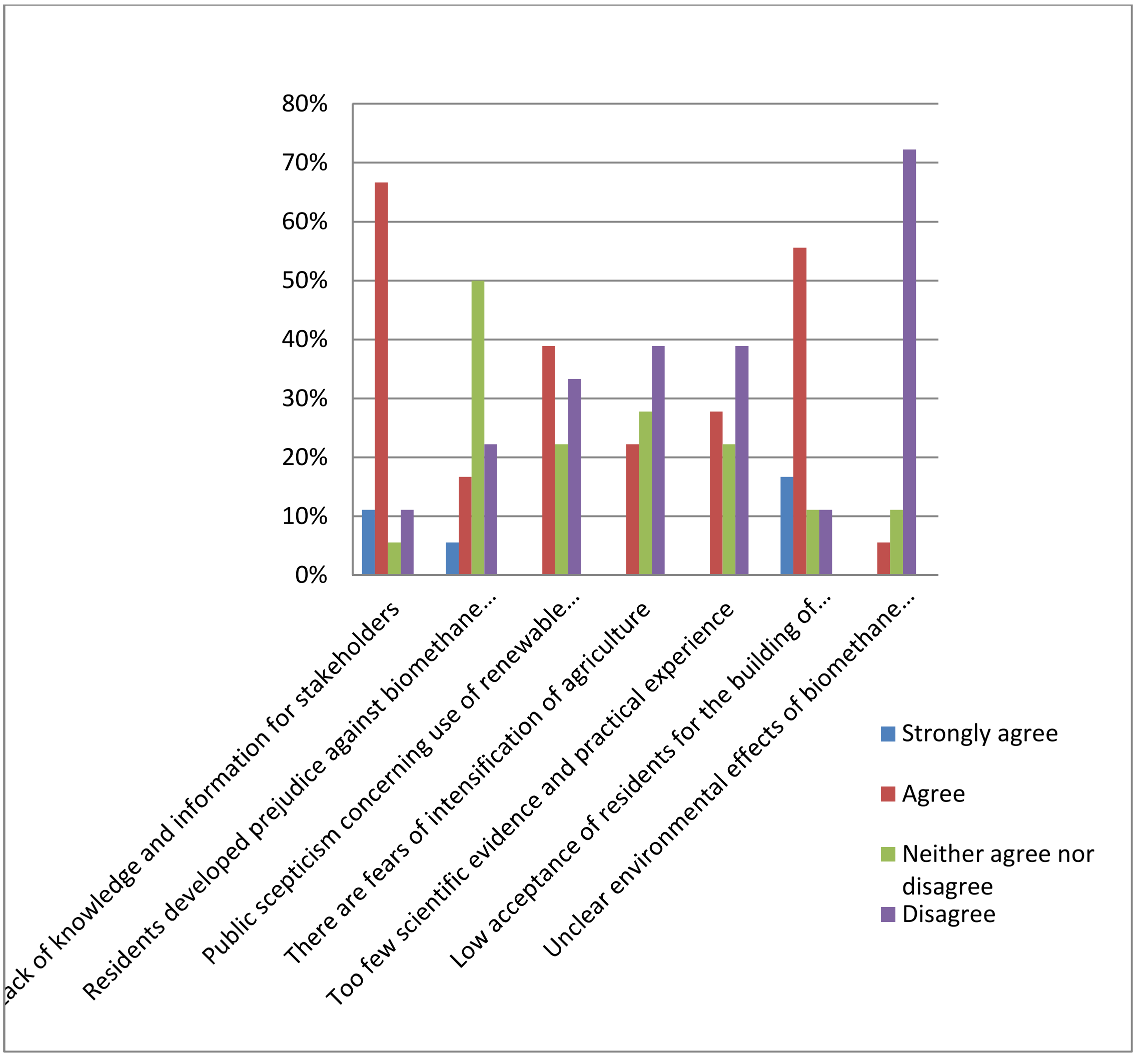


**Figure A-18.** Possible social and environmental barriers following Belgian respondents

The results for the social and environmental barriers tells us that informing the public is not yet done and is necessary, this is reflected in the high agreement on the statement that there is lack of knowledge and information for stakeholders and that there is a low acceptance by residents for building production installations. The fact that renewable energy is suffering from public scepticism received a mixed response. In Belgium there is no big fear of the intensification of agriculture in comparison with Austria. The scientific evidence and practical experience is not perceived as a big barrier. Strong disagreement was expressed for the statement that the environmental effects are unclear for biomethane.

## A 2.3 Germany

80% of the German respondents perceive biomethane production as mature, 20% as premature. In relation to that, 45% of the German respondents think that the biomethane market will grow in the future. 55% expects stabilisation of the market.

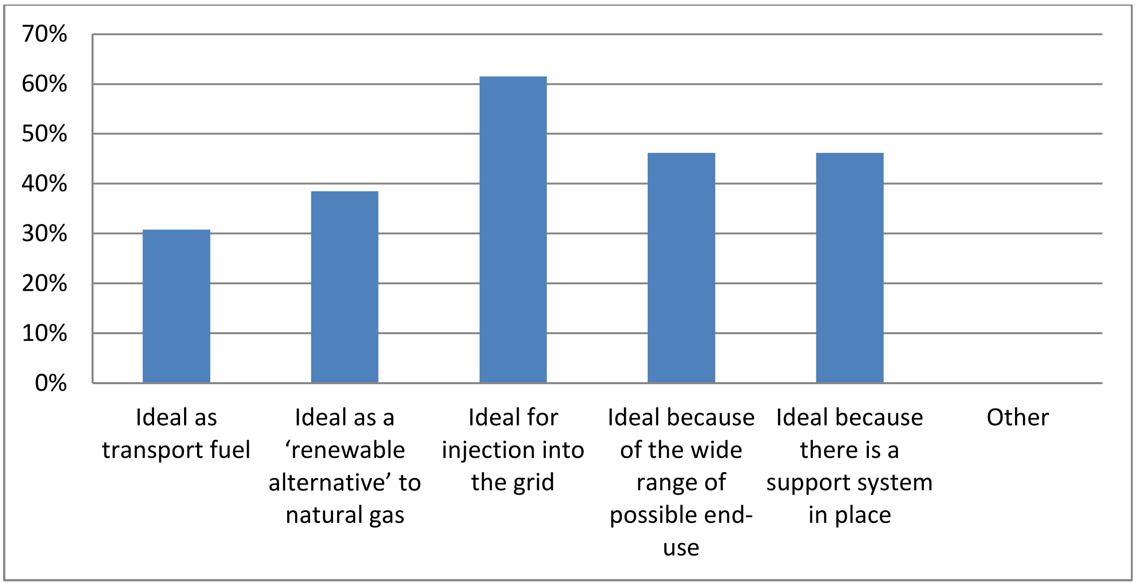


**Figure A-19.** Driver for biomethane following German respondents

Biomethane receives the highest score for the driver that biomethane is ideal for injection on the grid, followed by the driver that it is ideal for a wide range of possible end-uses and the fact that there is a support system in place. Transport fuel is perceived a driver but received the lowest score.

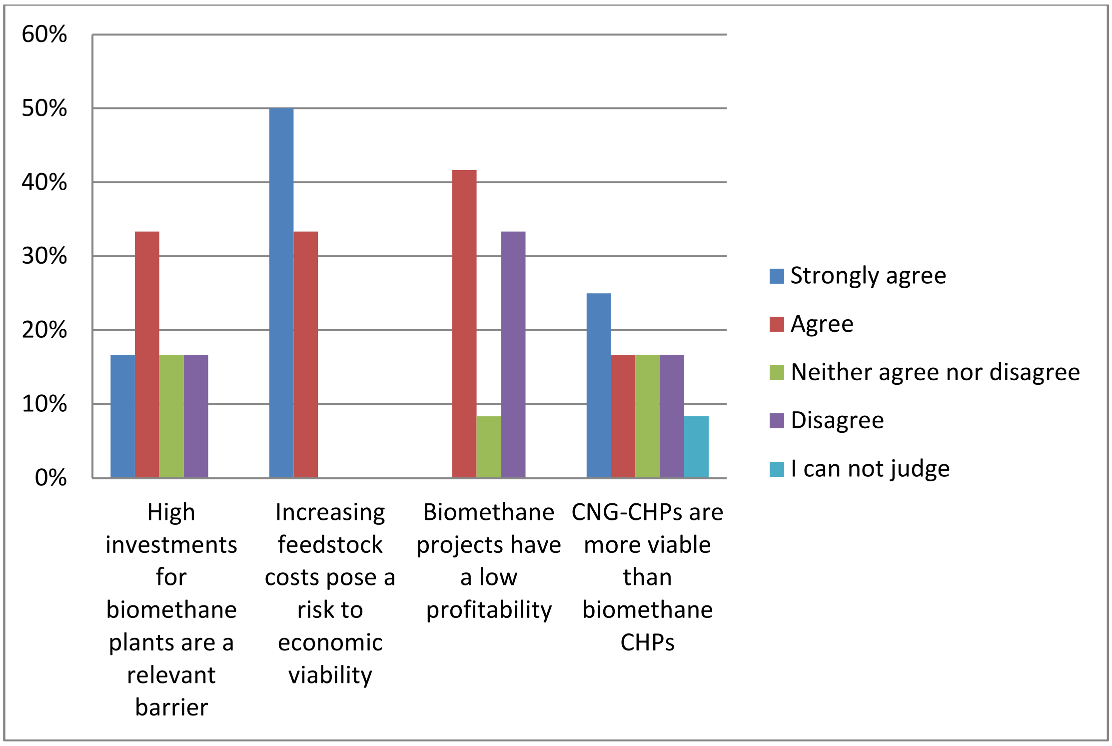


**Figure A-20.** Possible economic barriers following German respondents

High feedstock price is an economic barrier that also for Germany is perceived as a barrier, as for Austria and Belgium. The high investment cost received mixed opinions, from strongly agree to disagree. The statement concerning low profitability also received a mixed response. This was also the case for the comparison with CNG-CHPs. A possible reason for this scattered view is that in Germany support mechanisms are in place which influences the economic situation of biomethane installations.

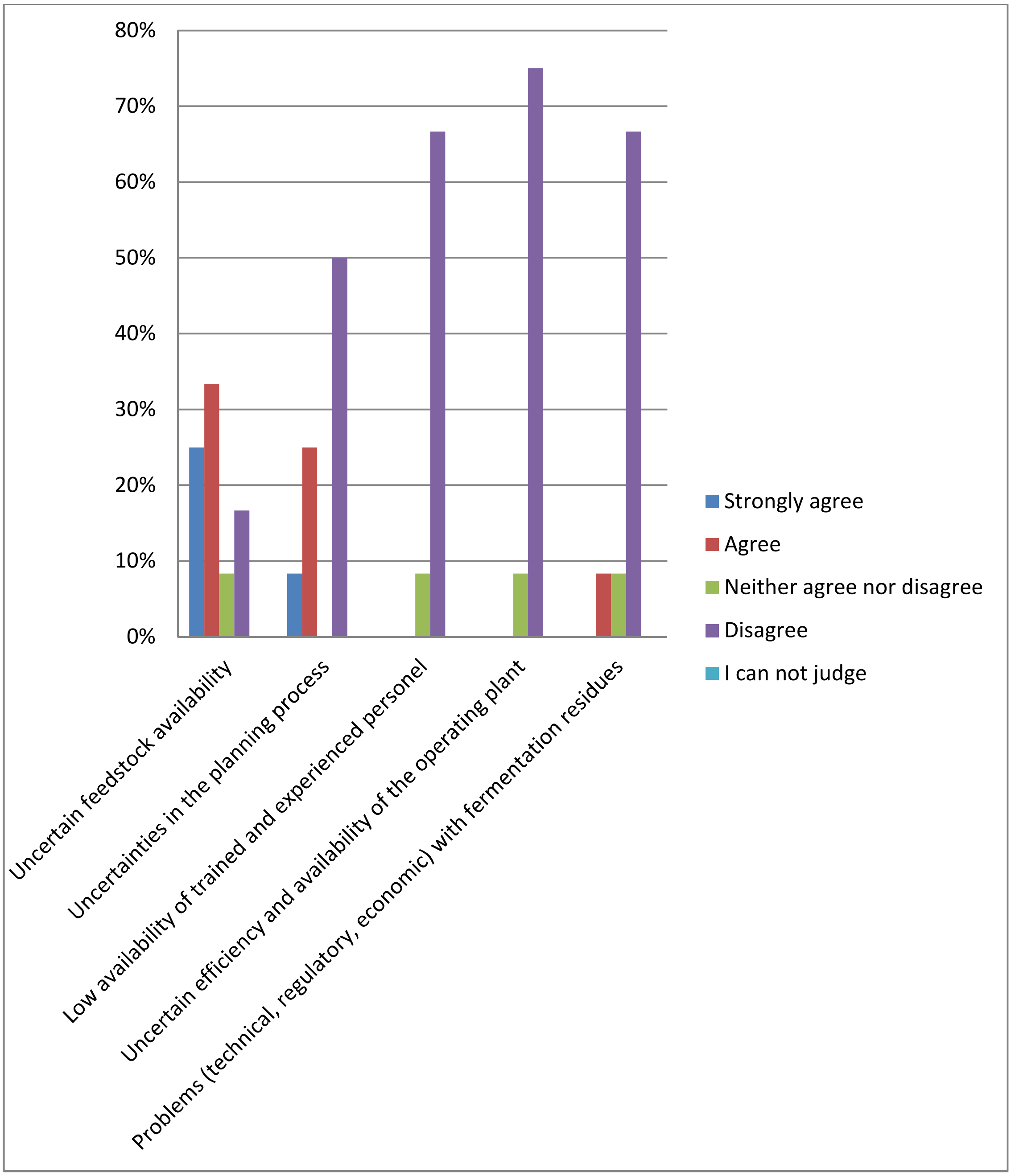


**Figure A-21.** Possible operational barriers following German respondents

Regarding the results of the operational barriers, it is evident that for the German respondents there is no issue concerning trained and experienced personnel, on efficiency and availability of the plants and on possible problems with residues. Uncertainties in the planning process is for some still an issue, but most disagree. As could be expected from the economic barriers, the feedstock availability is a big issue.

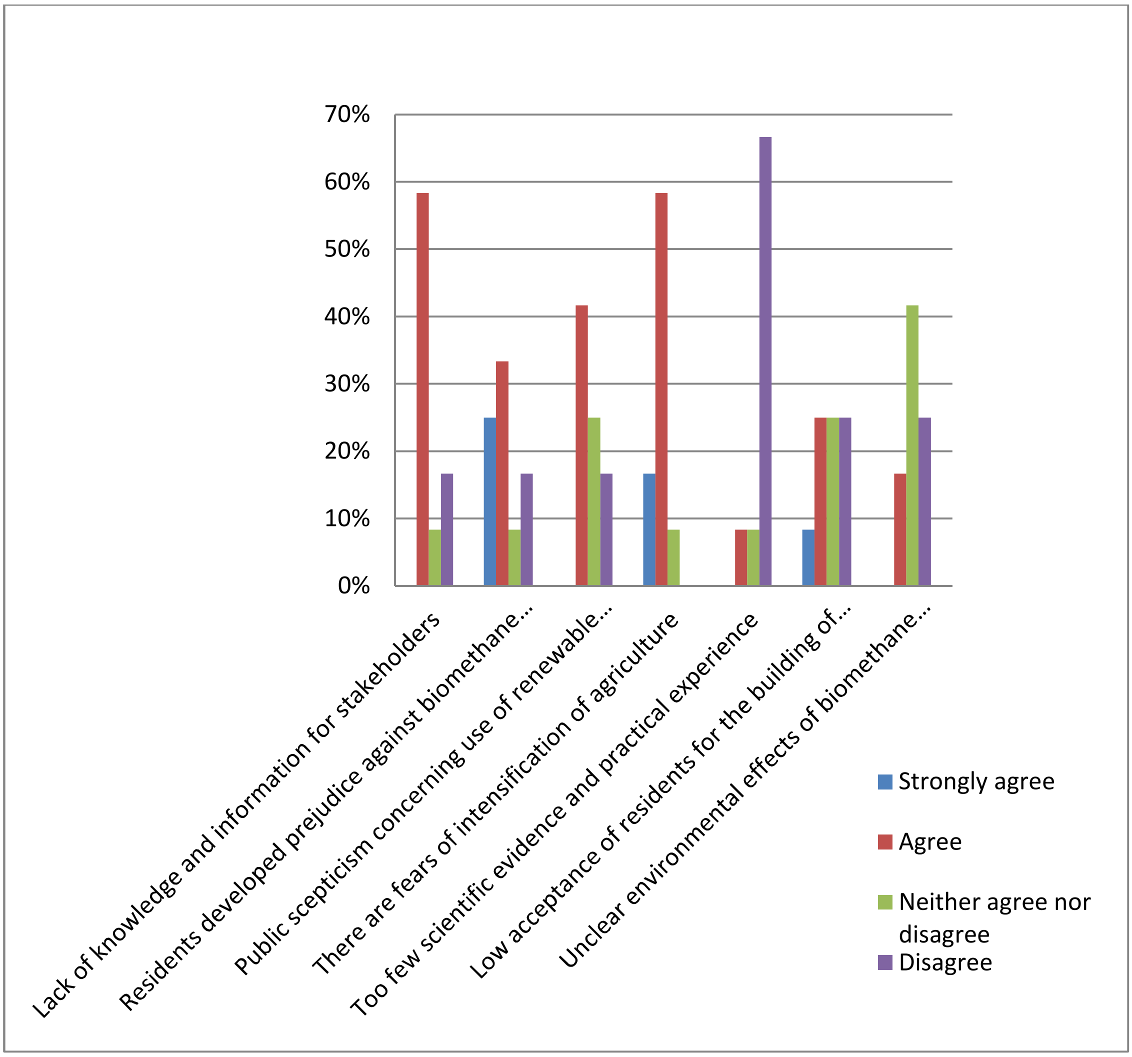


**Figure A-22.** Possible social and environmental barriers following German respondents

Even in a market that is perceived as mature, lack of information is still an important barrier according to the German respondents. Also the public scepticism is perceived as a barrier. As in Austria there is also a significant of the consequences of intensification of agriculture. Practical experience is on the other hand not an issue. No clear opinion is expressed on the unclear environmental effects of biomethane.

## A 2.4 The Netherlands

62% of the Dutch respondents state that there biomethane market is mature, 38% state that it is still premature. 58% of the Dutch respondents expect market growth for biomethane, 42% considers the market is in a stabilising phase. These results are more or less in line with  one from Germany.

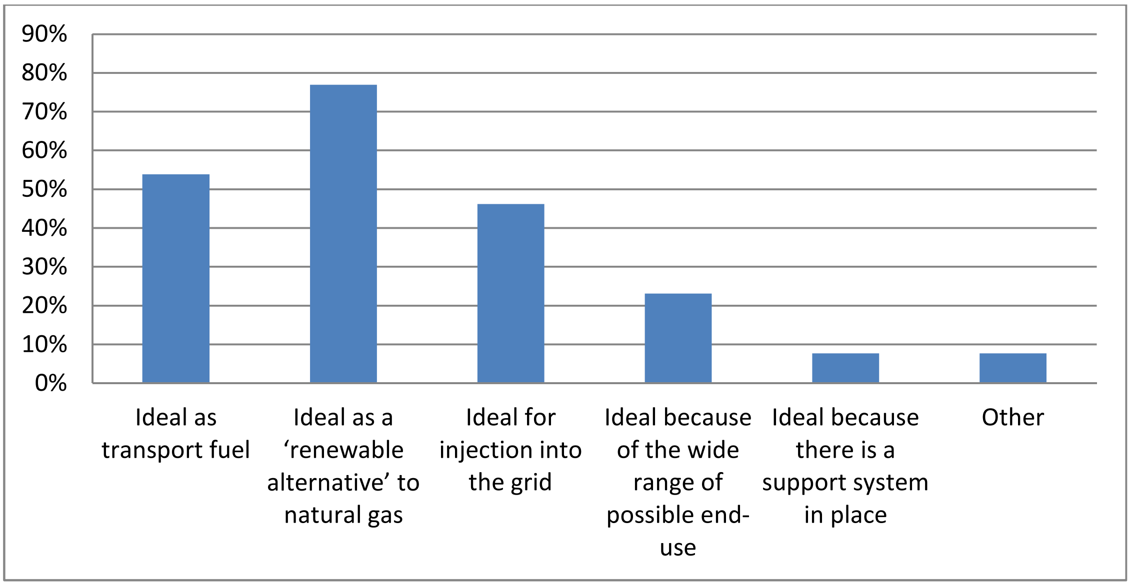


**Figure A-23.** Drivers biomethane following Dutch respondents

The main driver for biomethane in the Netherlands is the fact that it is renewable alternative to natural gas, followed by the driver that it is ideal as transport fuel and ideal for injection into the grid. Compared with Austria, Belgium and Germany, the Netherlands considers transport as a prominent driver for biomethane market growth.

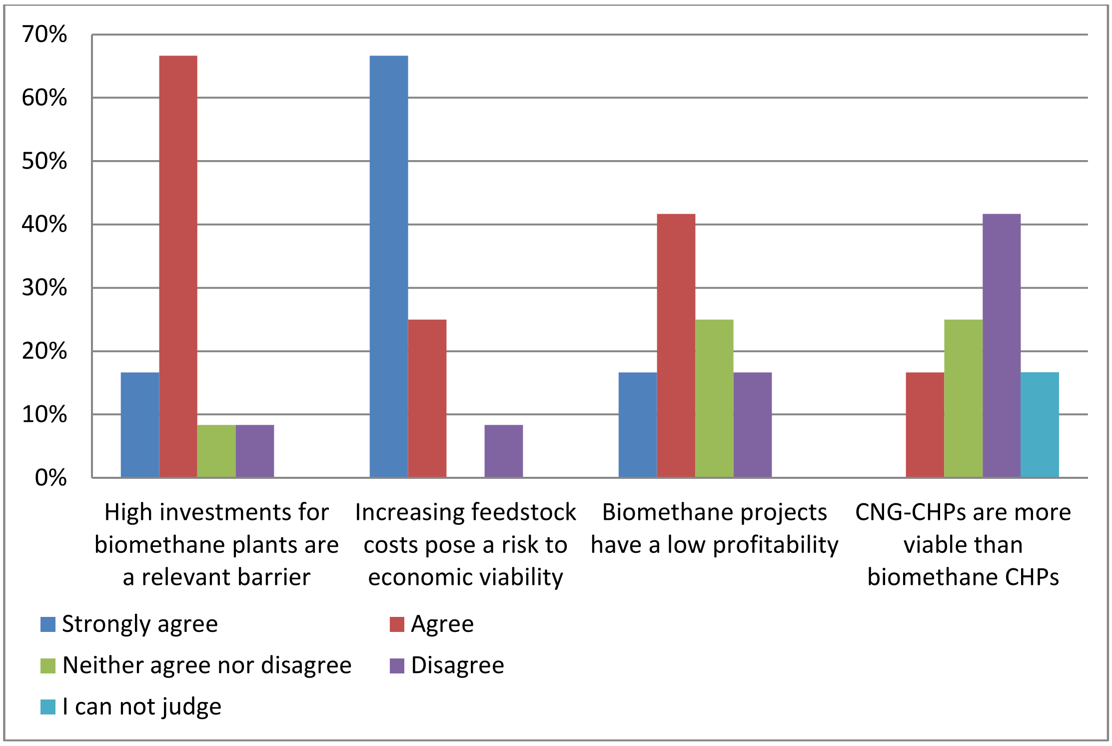


**Figure A-24.** Possible economic barriers following Dutch respondents

In line with the results from Belgium, the high investment costs and the feedstock price are the main economic barriers following the Dutch respondents. The low profitability is not an issue for every respondent. The statement that CNG-CHPs are more viable than biomethane CHPs is not agreed on by the respondents.

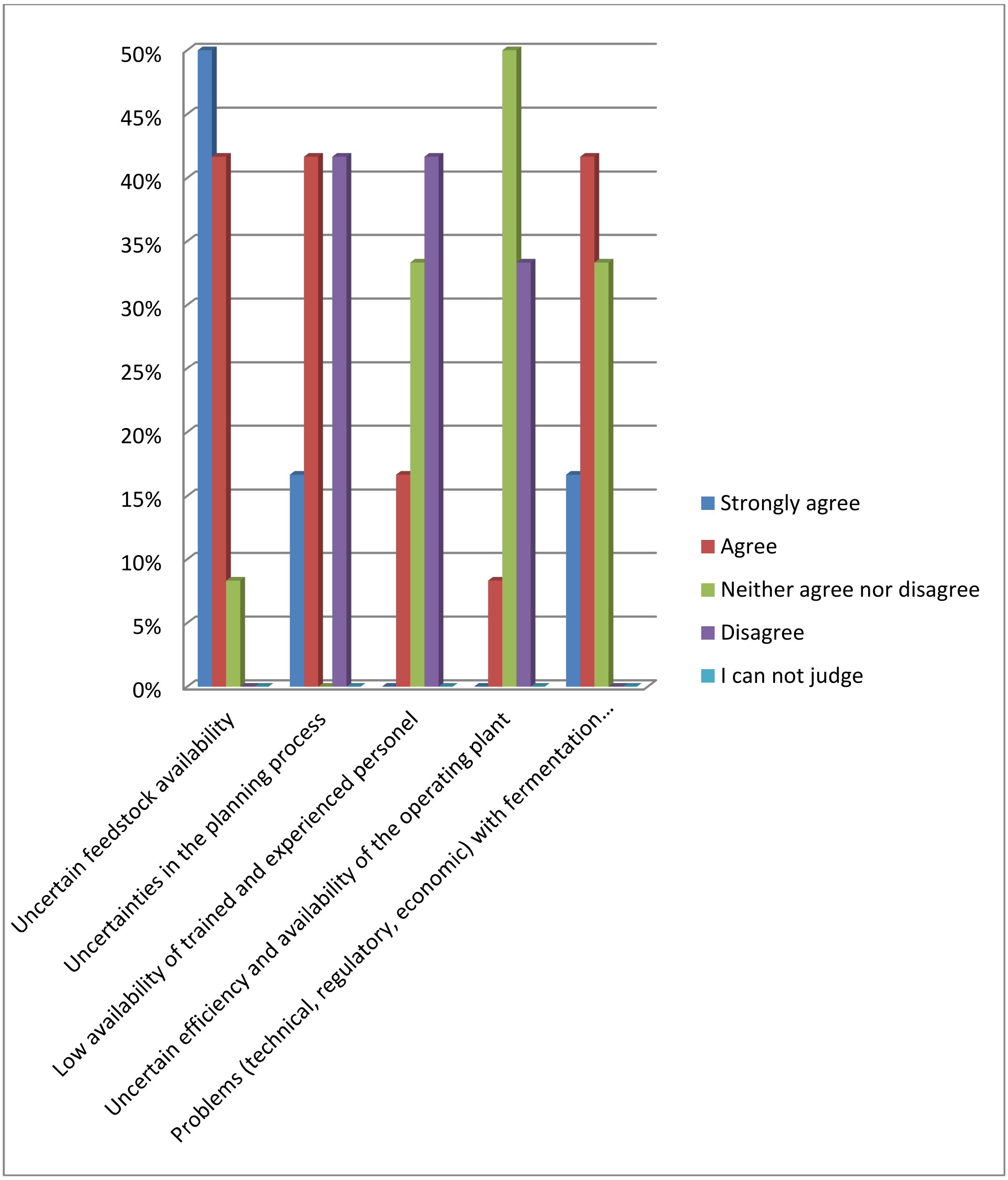


**Figure A-25.** Possible operational barriers following Dutch respondents.

As seen for the other countries, the feedstock availability is an important barrier. Uncertainties in the planning process received a split response from the Dutch respondents. Skilled personnel and availability of the installation are not perceived as important barriers. Problems with fermentation residues on the other hand is a barrier according to the respondents.

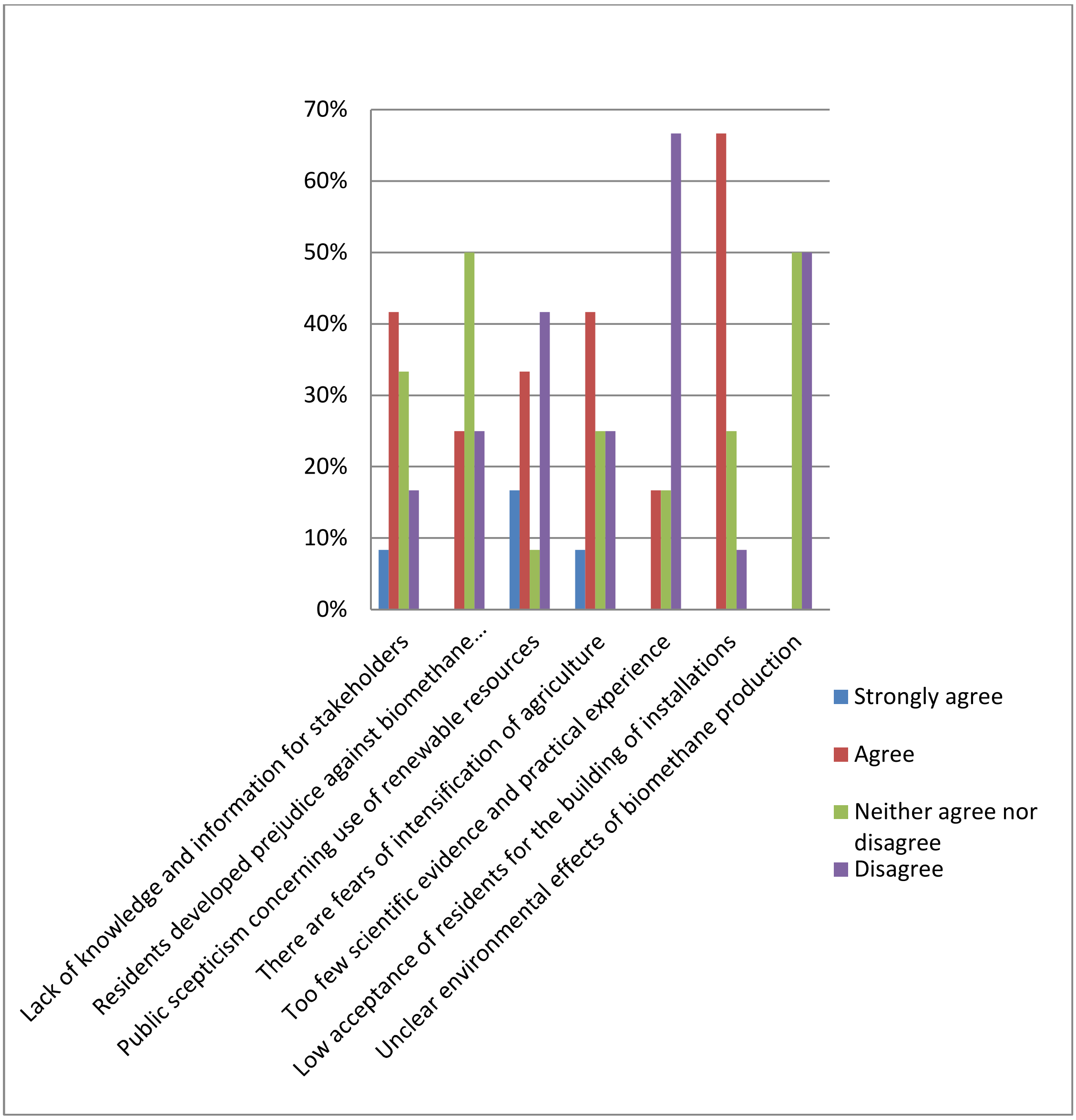


**Figure A-26.** Possible social and environmental barriers following Dutch respondents

Lack of information for the stakeholders and low acceptance of the residents is perceived as a barrier. The fear for intensification of agriculture is present but not so explicitly evident as in Germany and Austria. Scientific evidence and practical experience and unclear effects of biomethane are not perceived as barriers in the Netherlands.

## A 2.5 Sweden

60% of the Swedish respondents state that the market is mature, 40% consider it premature. In relation to the high level of maturity, the respondents have a strong belief that the biomethane market will grow further in the future (83%) and only 13% thinks the market will stabilise.

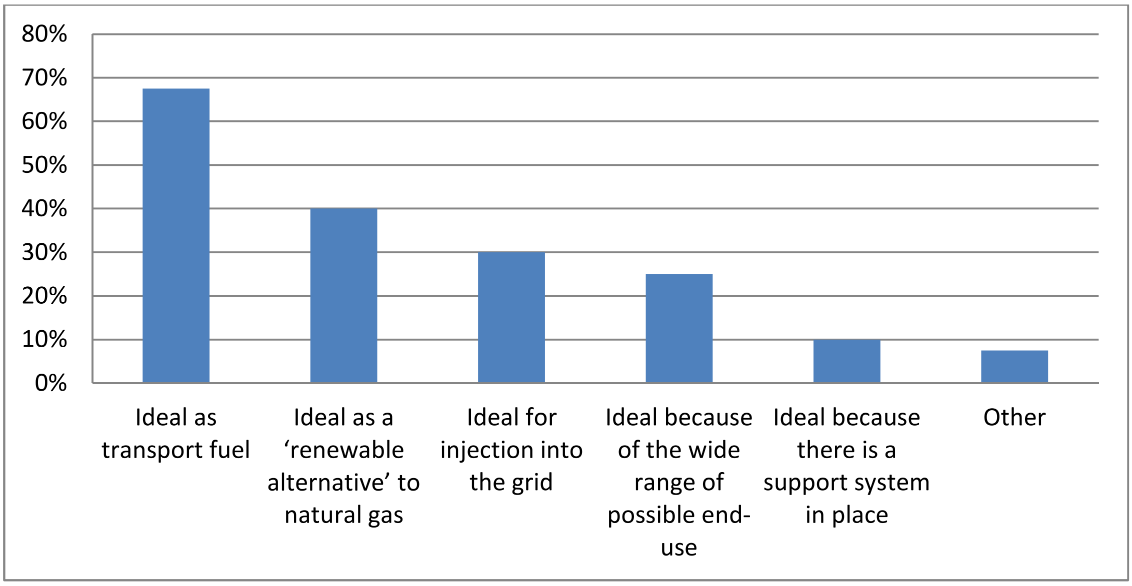


**Figure A-27.** Driver biomethane following Swedish respondents

The main driver in Sweden is that biomethane is ideal as transport fuel (70%), the second driver is that it is an alternative to natural gas. This differs significantly from the drivers perceived in the other countries (Austria, Belgium, Germany, the Netherlands). A possible reason is the more limited use of natural gas and the smaller gas grid present in Sweden.

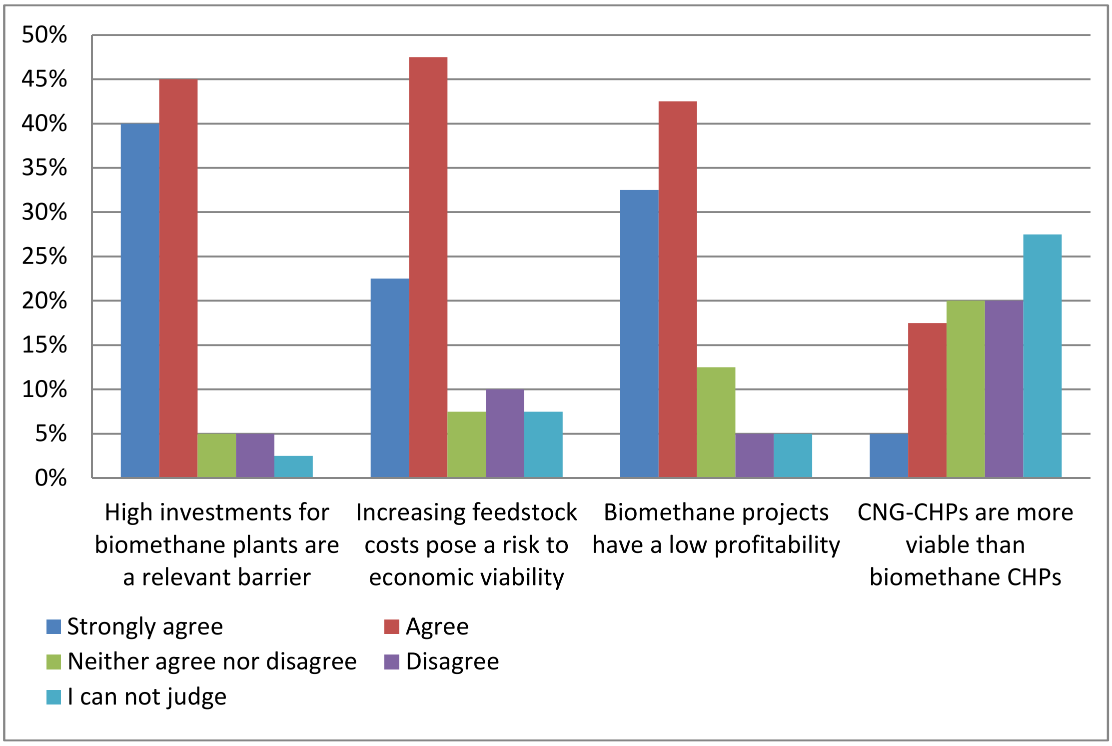


**Figure A-28.** Possible economic barriers following Swedish respondents

High investment cost, increasing feedstock price and low profitability are also economic barriers according to Swedish respondents.

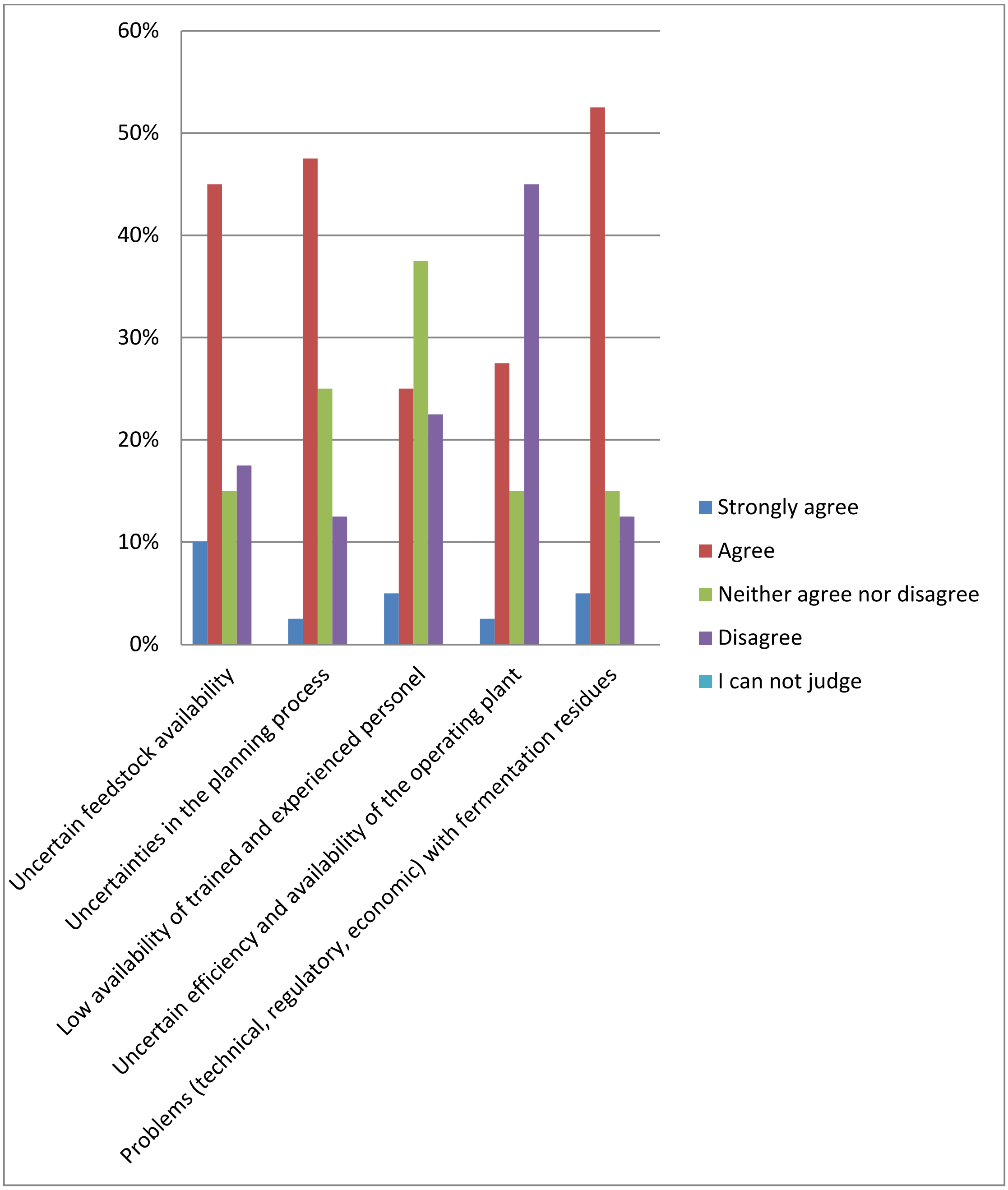


**Figure A-29.** Possible operational barriers following Swedish respondents

The general trend of the other countries can also be found for Sweden. The feedstock availability is a problem. The planning process is perceived as a barrier and problems with fermentation residues. On the availability of experienced personnel and the availability of the plant a mixed response was given.

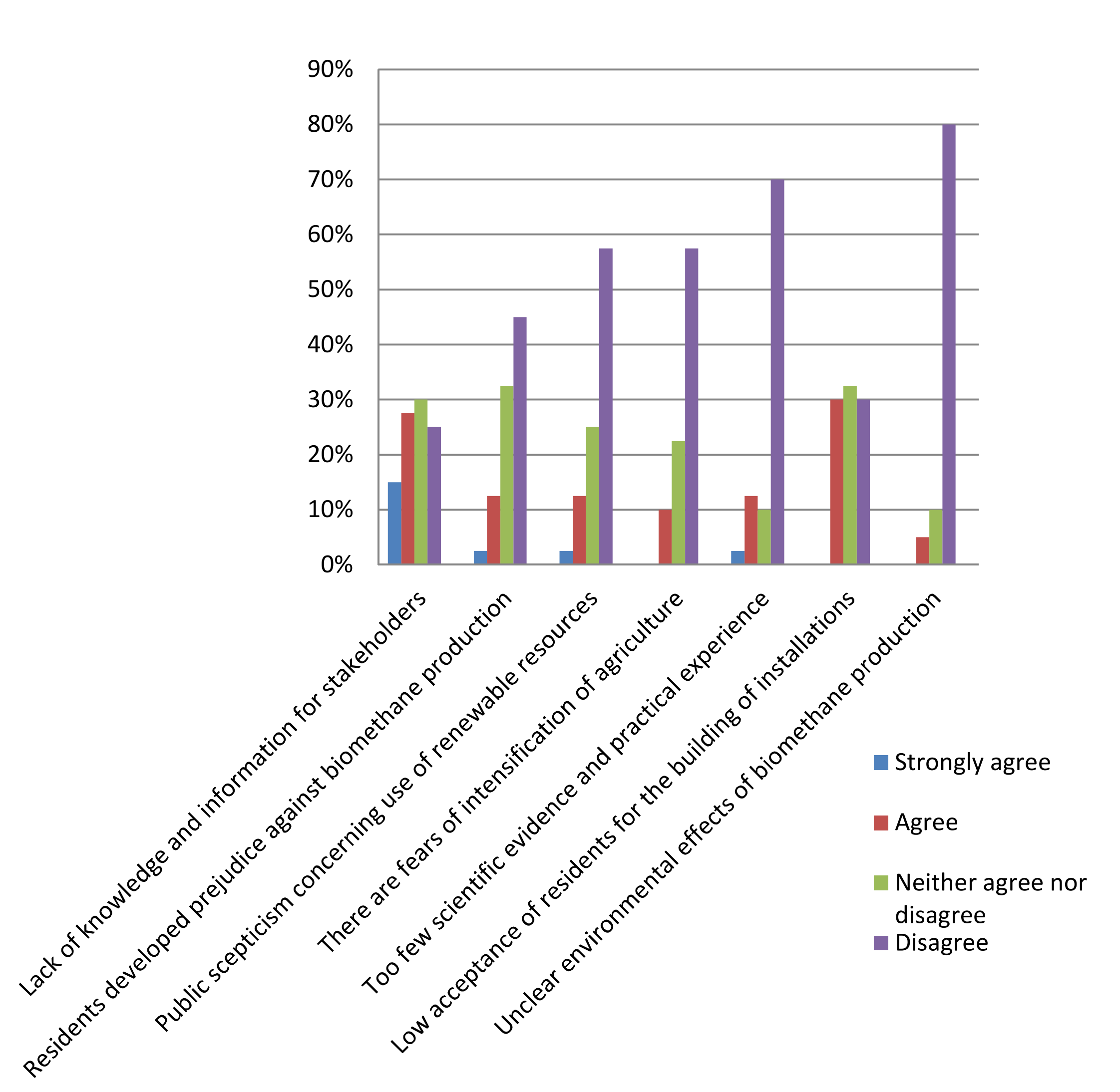


**Figure A-30.** Possible social and environmental barriers following Swedish respondents

For the societal and environmental possible barriers, most respondents disagreed with the statements, so no big barriers are perceived. In line with the results of the other European countries, there is still a need for information and also the acceptance of building installations suffers from the public opinion.

## A 3 Possibilities for transnational bio-methane trade

If an international market will eventually emerge the majority of the respondents see it as an opportunity to create new markets, not as a threat creating additional risks.

### A 3.1 Austria

The Austrian respondents consider it as unlikely (almost 50%) that international trade of biomethane will be achieved. Arguments for agreement and disagreement on this statement are the following:

+ EU harmonisation can enable trade

+ gas grids without renewable biomethane will lose market share for countries striving for 100% renewable energy.
0 biomethane trade will depend on the type and size of players
0 biomethane trade will depend on national legislation
0 biomethane trade will change nothing in the current market
- Biomethane trade will be technically possible, and the amounts of biomethane are not enough for exporting
- Biomethane is too expensive in comparison to the direct use of biogas

In case of international trade it could open new markets is the opinion of 70% of the respondents.

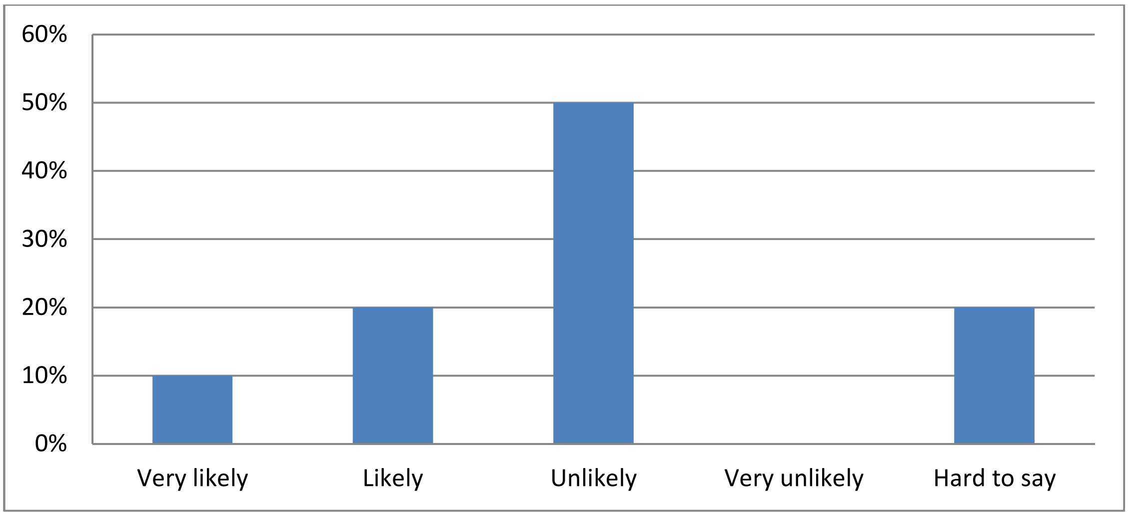


**Figure A-31.** Expectations international trade biomethane following Austrian respondents

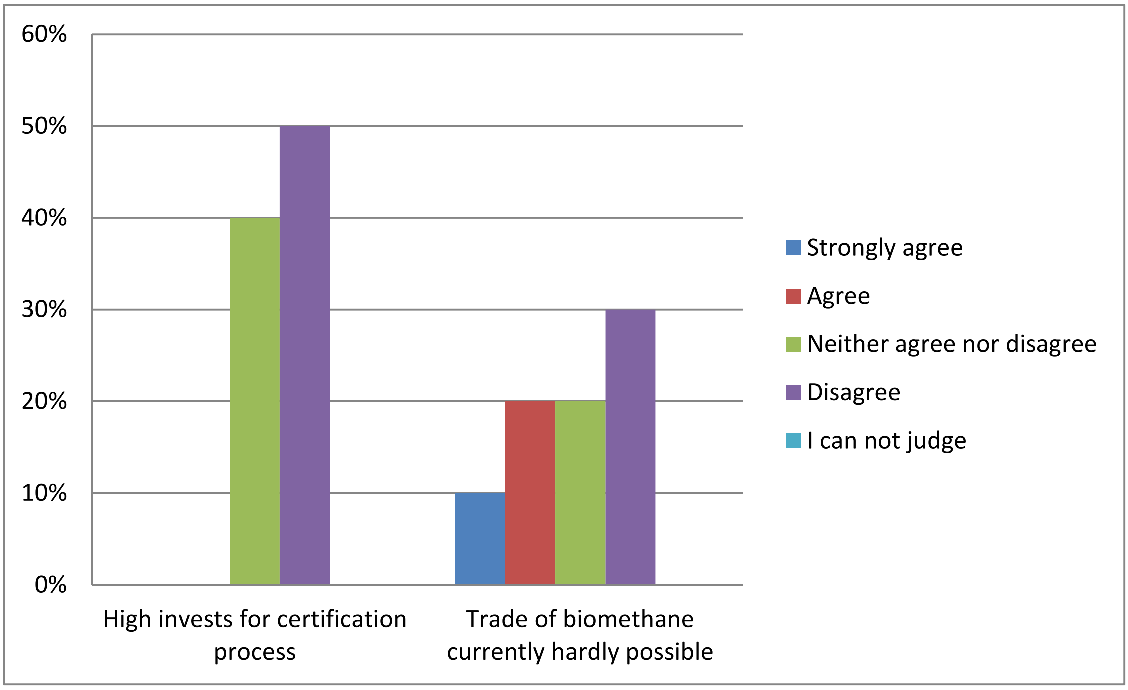


**Figure A-32.** Possible trade barriers following Austrian respondents

The certification process is not perceived as a trade barrier. The fact that trade it not possible at the moment is also not perceived as a barrier for developing a market for biomethane.

## A 3.2 Belgium

Belgian respondents believe more than Austrian respondents in the international trade of biomethane (40%). Belgian respondents believe/hope that it will open new markets. One critical remark of a respondent is that when international trade happens attention should be paid to subsidy migration, in the worst case leading to fraud.

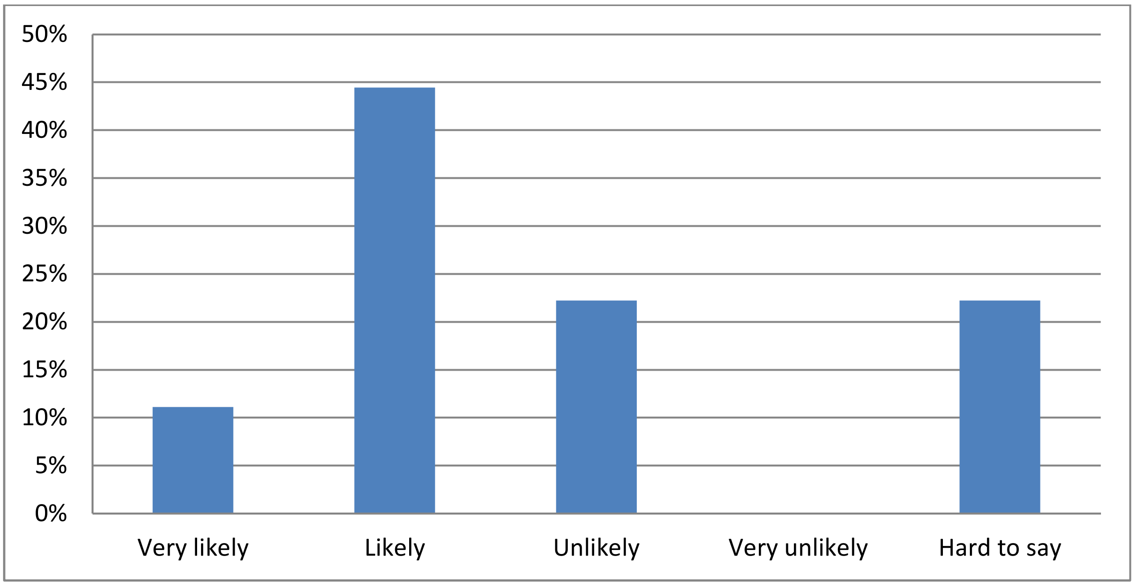


**Figure A-33.** Expectations international trade biomethane following Belgian respondents

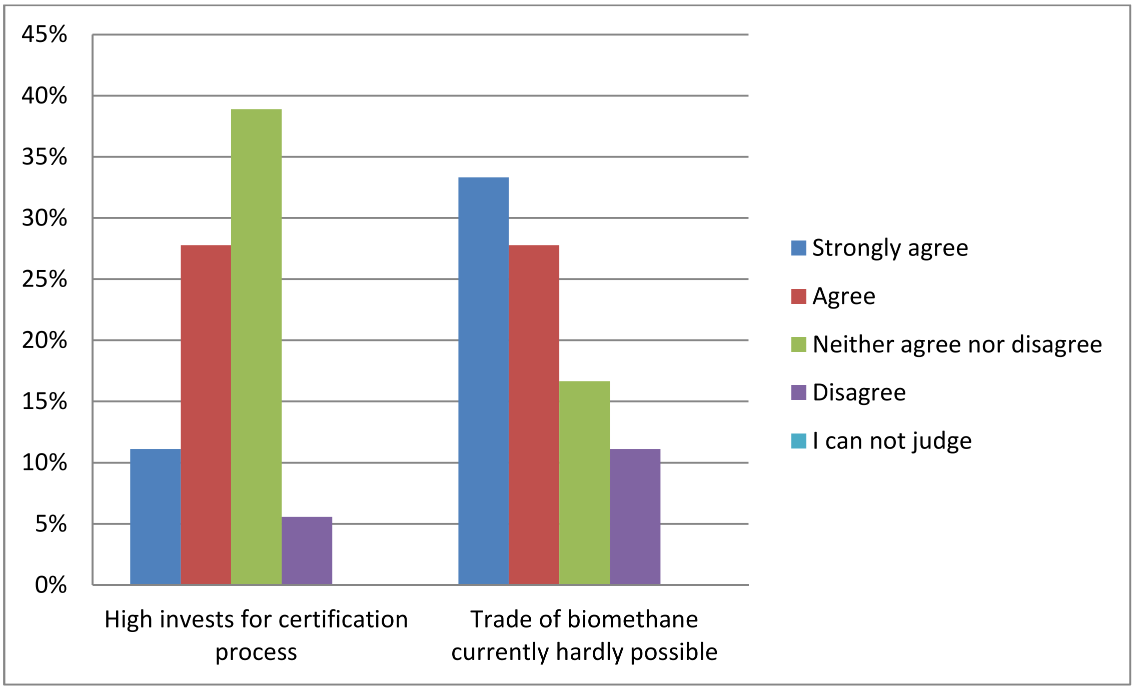


**Figure A-34.** Possible trade barriers following Belgian respondents

Certification cost could be an extra barrier for trade. The fact that trade of biomethane is currently not in place is not helping the internal biomethane market in Belgium move forward. This can be related to the fact that international trade for a country like Belgium without a fully developed policy and market, could look for opportunities (and willingness to pay) in other European countries.

## A 3.3 Germany

40% of the German respondents believe that international trade of biomethane will be possible. The major expectation is that it will open new markets. A critical respondent sees international trade as an additional risk.

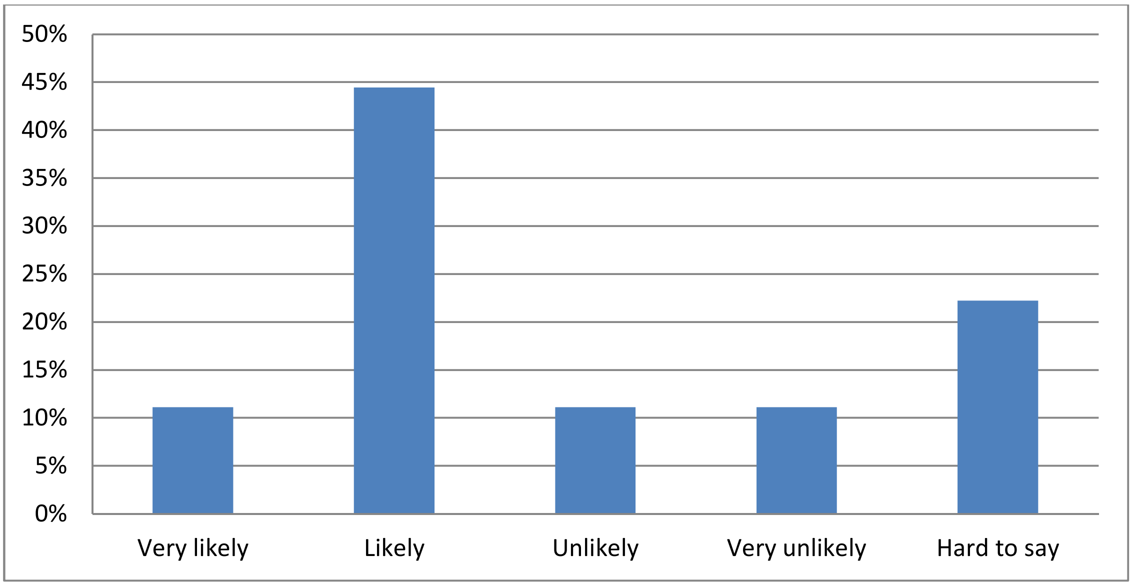


**Figure A-35.** Expectations international trade biomethane following German respondents

The additional cost for a certification process is according to most respondents not perceived as a trade barrier. The fact that currently trade is not possible is for 40% of the respondents a barrier, for almost 25% it is not.

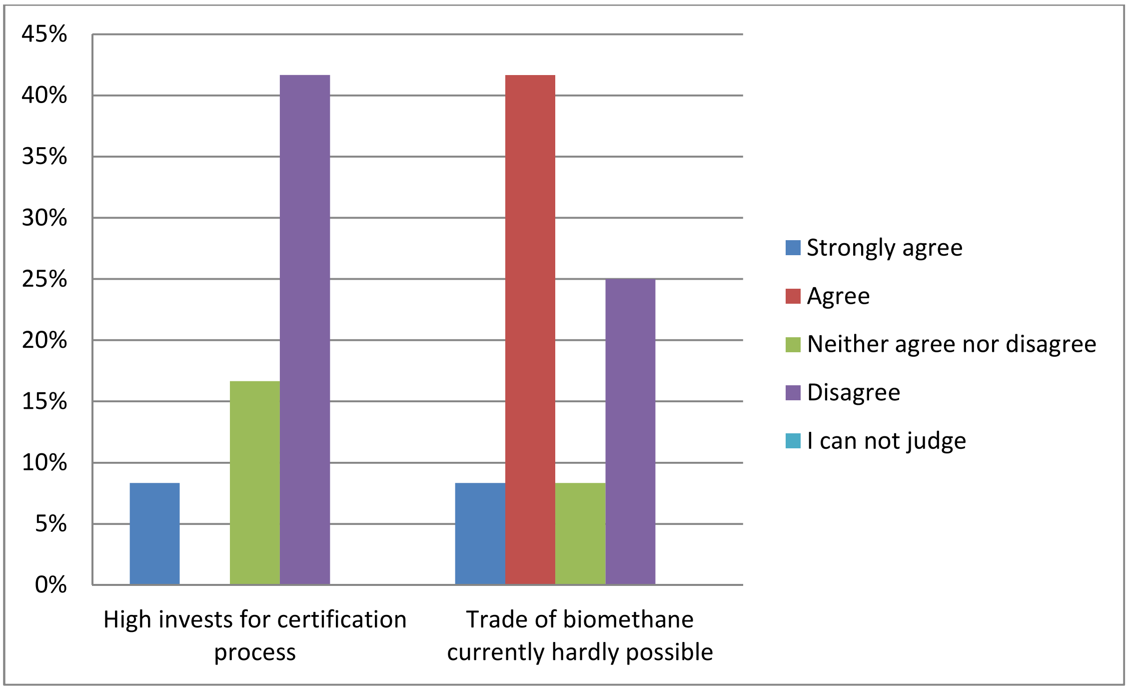


**Figure A-36.** Possible trade barriers following German respondents

## A 3.4 The Netherlands

45% of the Dutch respondents believe in international trade, 30% think it is unlikely that it will break through. Arguments for and against international trade are given below:

+ it will open new markets

+ international trade of natural gas is already happening, the international trade of biomethane would be a logical next step and become a commodity as well.

+ international trade of biomethane could create a level playing field

- When international trade will happen, attention should be paid to subsidy migration. Biomethane trade is attracted by generous subsidy schemes.
- The demand is higher than the production at national level so international trade might not happen.

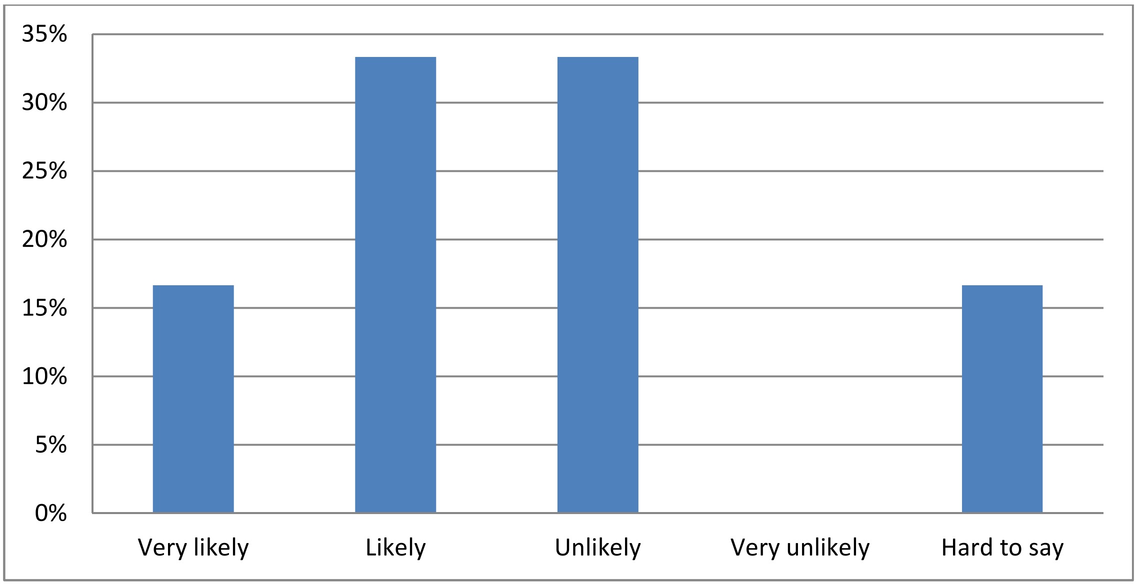


**Figure A-37.** Expectations international trade following Dutch respondents

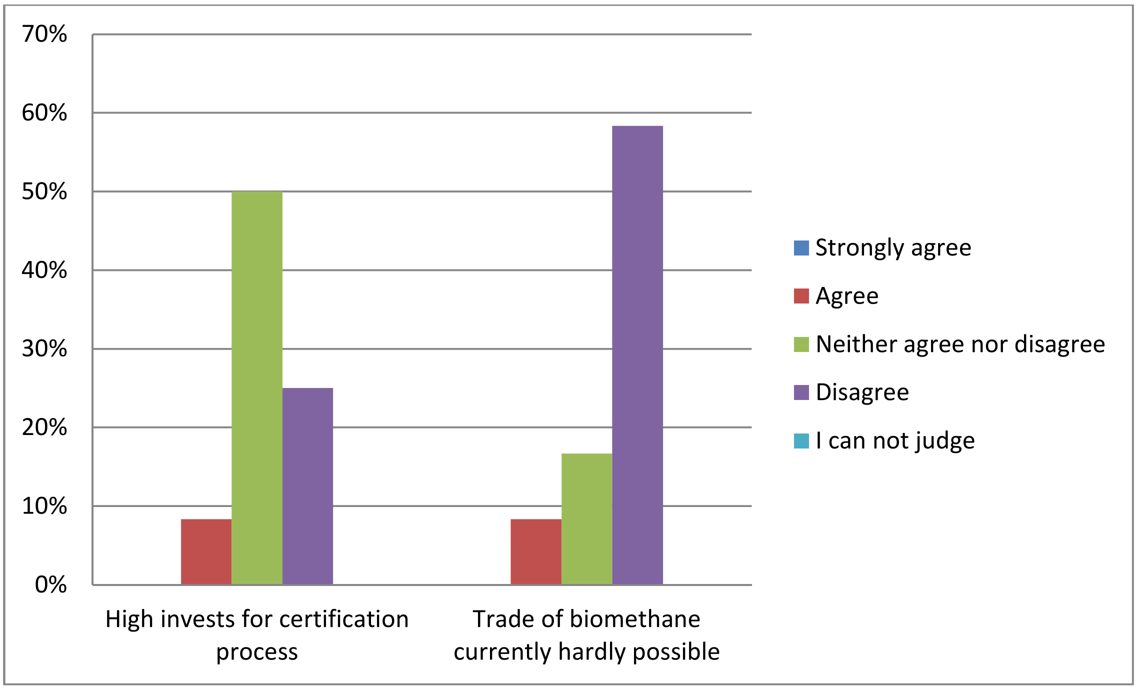


**Figure A-38.** Possible trade barriers following Dutch respondents

The cost of the certification process is not perceived as a possible trade barrier. One comment submitted suggests that the system should be organised in a better way than for green electricity.
The fact that international trade of biomethane is not happening at the moment is not perceived as a barrier for the development of the national biomethane market.

## A 3.5 Sweden

The expectations of the Swedish respondents (60%) is that international trade of biomethane could be possible, some disagree with that statement (12%). Positive and negative arguments for international trade are given here:

+ It will create new markets: especially new suppliers could be attracted. Although a critical remark was made that in the first place it will create new opportunities for existing suppliers and only afterward for new ones. This is related to the fact that according to respondents the demand for biomethane is higher than the production.
+ If the LBG (liquefied biomethane) market would be established in EU than this would enhance the international trade of biomethane.
0 The possibility of international trade will depend on the (inter)national policy instruments.

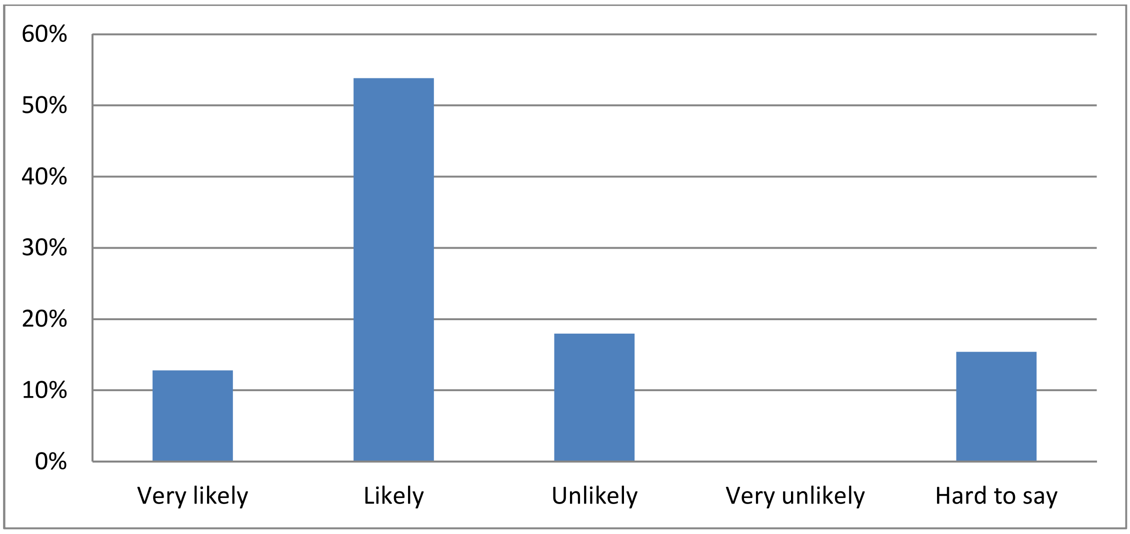


**Figure A-39.** Expectations international trade biomethane following Swedish respondents.

A number of the Swedish respondents (17%) see the certification process as a possible trade barrier, 19% disagree with this and 24% is neutral.

The fact that currently no international biomethane trade possible is not perceived as a barrier for the national biomethane market.

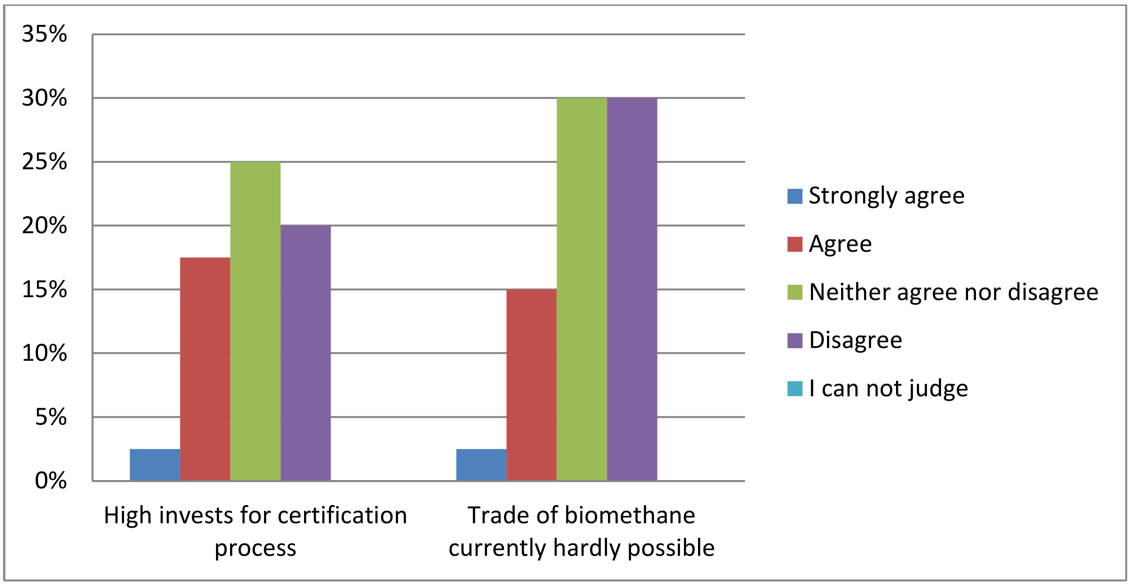


**Figure A-40.** Possible trade barriers following Swedish respondents.

## Authors


Daniela Thrän
*UFZ & DBFZ, Germany*
Eric Billig
Jaqueline Daniel-Gromke
Jens Ponitka
Michael Seiffert
*DBFZ, Germany*
www.dbfz.de

---

Tobias Persson
Mattias Svensson
www.sgc.se

---

John Baldwin
*CNG Services*
www.cngservices.co.uk

---

Lukas Kranzl
Fabian Schipfer
Julian Matzenberger
*TU Wien*
www.tuwien.ac.at

---

Nathalie Devriendt
*VITO*
www.vito.be

---

Mathieu Dumont
*RVO*
www.rvo.nl

---

Jonas Dahl
*DTI*
www.dti.dk

---

Günther Bochmann
*University of Natural Resources and Applied Life Sciences Vienna (BOKU)*
www.boku.ac.at


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