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Comparison of biogas upgrading systems with different biomethane usage paths and decentralized biogas usage in CHP units

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ABSTRACT

Biogas production mostly takes place in rural areas. Whereas this contains great advantages for the input material and digestate logistic there is the disadvantage, that often no sufficient heat sinks are within reach. This leads to inefficiency in energy use. One solution can be the upgrading from biogas to biomethane, which can be fed into the natural gas grid and used where it is needed. This Working paper aims at the ecological comparison between this to pathways.

Biogas upgrading can have advantages from GWP perspective in comparison with decentral biogas usage especially if no heat usage on side of the biogas plant is possible. Whether an advantage exists depends on the effectiveness of the upgrading system (methane leakage, energy demand), the national electricity mix and the chosen reference system. In most cases the biomethane use in new CHP units has to be preferred. The better the national electricity mix is the easier biogas upgrading can generate an advantage in comparison with decentral biogas usage.

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1   Introduction

Biogas production mostly takes place in rural areas. Whereas this has great advantages for the input and digestate logistic often no sufficient heat sinks are available. This leads to inefficiency in energy use.

In Germany according to the DBFZ survey 45 % of the surplus of heat is used for e.g. district heating, heating of buildings, greenhouses or stables and drying. 70 % of the plant operators report, that the heat is used for heating of houses and work buildings, 30 % are using the heat for heating of stables and 27 % report, that the heat is used for drying processes. [DBFZ, 2012]

One solution can be the upgrading from biogas to biomethane, which can be fed into the natural gas grid and used where it is needed.

Table 1 shows the current state of biogas upgrading in selected European countries.

Table 1: Biomethane plants is selected European countries (IEA 2014 / green gas grids)

Country	Biogas Plants	Biogas Upgrading Plants (Feed In)	Upgrading Capacity Nm³/h	Gas filling Stations
Austria	421	10 (7)	2,000	203
Belgium	119	0	0	15
Croatia	12	0		
Denmark	137	1 (1)	180	4
Finnland	34	5 (2)	959	18
France	256	3 (2)	540	149
Germany	9,066	120 (118)	72,000	904
Hungary	58	1 (0)		
Ireland	22	0	0	0
Italy	1,264	1 (0)	540	903
Luxembourg	31	3 (3)	894	7
Sweden	187	53 (11)	16,800	190
The Netherlands	211	16 (16)	6,540	150
U.K.	265	3 (3)	1260	40

Advantages of the biomethane concept are the spatial separation of biogas production and biogas usage. Therefor higher efficiency due to higher heat usage as well as other usage path like fuel are possible. Further on biomethane can reduce the dependency of natural gas imports. Disadvantage of the concept is the additional energy demand for biogas upgrading and transport of biomethane in pipelines. Further on biomethane substitutes natural gas, which is from a climate perspective preferable to other fossil energies.

2 Research Questions

- Ecological advantages or disadvantages of biogas upgrading systems in comparison with decentralised CHP units.

- Cost for upgrading in comparison with additional ecological benefit

3 Methodology

Based on the standardisation for life cycle assessment DIN EN ISO 14040/44 the ecological assessment will be performed. According to this standard the assessment will consist of the following steps:

a) Goal and scope definition phase,

b) the inventory analysis phase,

c) the impact assessment phase, and

d) the interpretation phase.

The process is iterative there is the possibility that, according to the results of the inventory analysis, the impact assessment or the interpretation, goal and scope must be adapted during the process (see Figure 1).
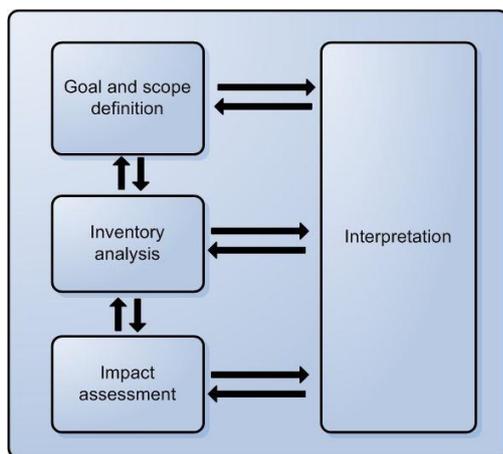
Figure 1:   Stages of LCA [DIN 14040]

System boundaries are going from raw biogas delivered from biogas plant[1] to the utilisation unit e.g. CHP-unit, gas filling station, boiler. Energy and material inputs will be taken into account.

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[1] The biogas plant is not part of the analysed system

Infrastructures will be excluded except for the gasnet as they don't have a significant effect on the results.

As far as possible data from existing biogas upgrading plants will be collected i.e. information about energy demand, material use, etc. Furthermore background data, up- and downstreaming processes data will be taken from Ecoinvent database (v3.1). These data will be completed with literature data.

The focus for the impact assessment will be on the Global warming potential (GWP).

3.1   Goal and scope

Goal

Goal of the evaluation is if and under what conditions biomethane production has ecologic or economic advantages compared with decentralised biogas usage.

Scope

The biogas plant is not integrated. The process chain starts with biogas supply without definition of a biogas plant. To have the same starting product a standard biogas quantity (CH_4: 56%; CO_2 44%) is defined. The influence of different biogas plants and different biogas qualities in the upper stream will be considered in a sensitivity test.

Decentralized biogas usage
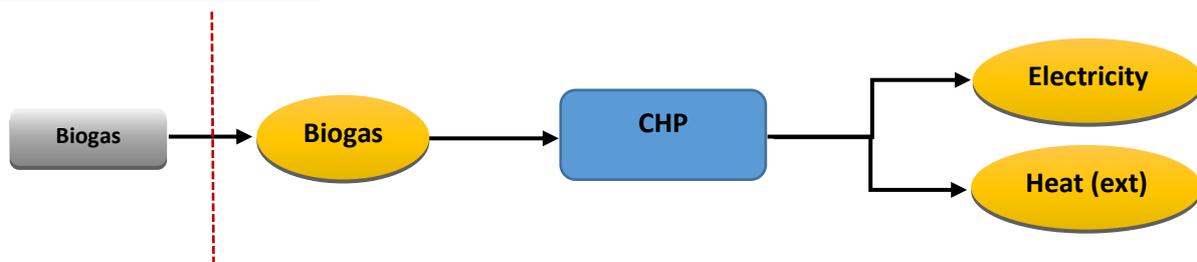
Biogas upgrading and feeding into natural gas grid
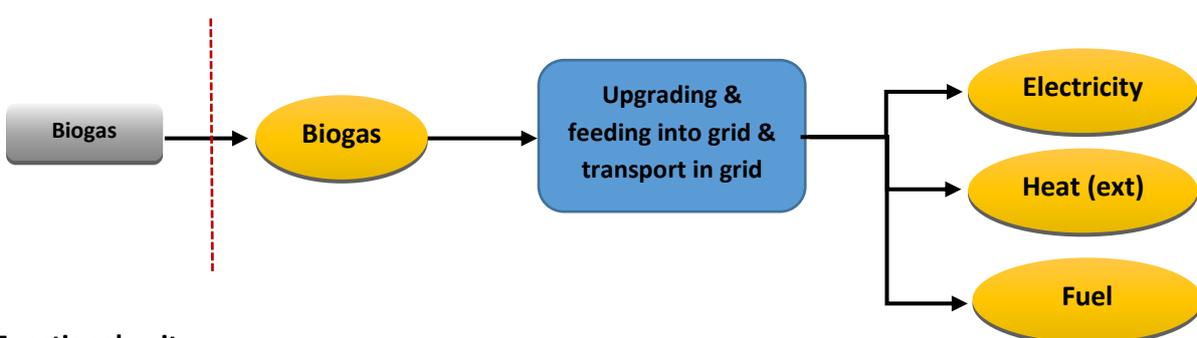
Functional unit

The functional unit is defined as one cubic meter [1 Nm³] of raw biogas.

3.2 inventory analysis

For the biogas upgrading the pressure water scrubbing technology is chosen. This technology is with approx. 50 % market share most common in Europe [FNR 2013].

Data for energy consumption and costs for biogas upgrading have been derived mainly from literature. Data for biogas burner, electricity markets und gas transport are from Ecoinvent database (v3.1). The raw biogas is supposed to have a methane content of 56% the purified gas one of 97 %. Methane leakage is 1 % [Urban 2008]. The leaked methane will be post treated in a biogas burner so that only 0.1 % of the methane emissions will be considered (Dunkelberg et al; 2015). Electricity consumption for the purification is 0.23 kWh/Nm³ raw biogas [FNR 2014]. The assumed net pressure for the injection in the natural gas grid is 7 bar. Here further evaluations on the influence of different pressure levels in the natural gas grid could be interesting.

Figure 2 shows the network model of the pressure water scrubbing technology in umberto®. The raw biogas (P11) is upgraded (T5) the biomethane is fed into the natural gas grid (T9) and transported (T3) through the gas pipeline (T10). The lean gas (P35) is post treated (T14) here emissions occur (P10). The gained energy will be used for the fermenter heating (P25). Energy and water are delivered from T1.
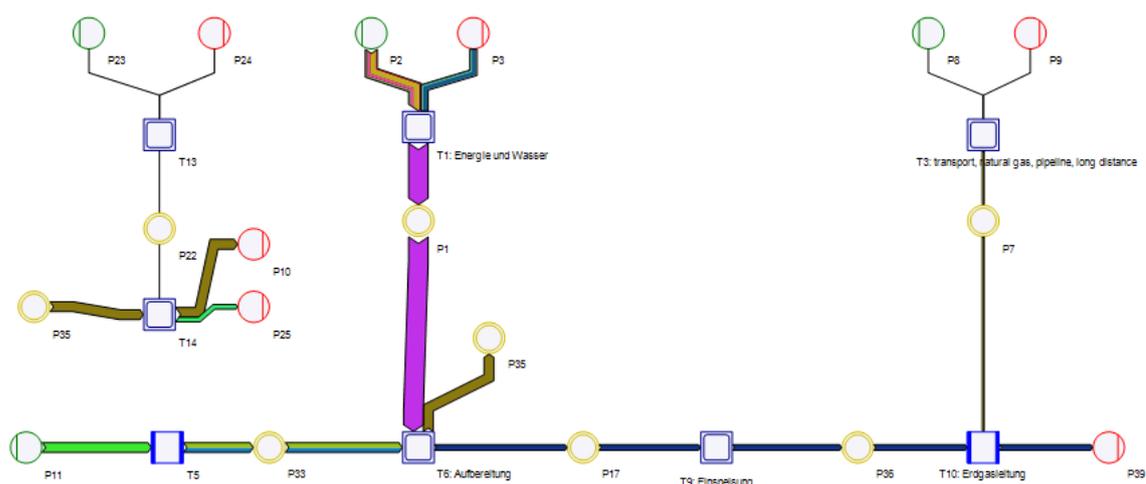

Figure 2: **Network model of the pressure water scrubbing technology in the software umberto®**

The calculation for Germany shows, that most of the CO_2-Equivalents are due to electricity consumption of the purification step. Therefore the upgrading process was calculated for different national electricity mixes. Hereby a variation between 120 g and 730 g CO_2eq/kWh$_{el}$ was chosen. This range correlated with the range in national electricity mix in the project countries.

3.3 Impact assessment

The calculated GWP of biogas upgrading and injection in the natural gas grid reaches from 30 g CO_2eq/Nm raw biogas to 170 g CO_2eq/Nm raw biogas.

To compare the emissions caused by the upgrading of biogas with the decentralised usage of biogas the following cases have been considered.

Case 1 decentralised usage of biogas

The biogas is used in a CHP unit onsite of the biogas plant. 40 % of the produced heat is used as substitute of heat from an oil heating system, the benefit therefore is 321 g CO_2eq /kWh_{th} [Ecoinvent v3.1].

Case 2 biogas upgrading with new CHP unit

The biogas is upgraded to biomethane which is used in a CHP unit offsite. 100 % of the produced heat is used as substitute of heat from a gas heating, the benefit therefore is 202 g CO_2eq /kWh_{th} [Ecoinvent v3.1].

Case 3 biogas upgrading as natural gas substitution

The biogas is upgraded to biomethane which is used as substitute for natural gas. Thus, no difference is made between the utilisation for heat, in a CHP unit or as fuel. The assumption is, that in all this cases natural gas with an emission factor of 202 g CO_2eq./kWh is substituted.

For all cases the following assumptions are made:

For CHP units the electrical efficiency is 38 % and the thermal efficiency 40%. The own power consumption of the biogas plant is 10 %. For the produced electricity minus the own consumption a benefit as substitute of the national electricity mix is given.

Error! Reference source not found. shows the advantages or disadvantages of the biogas upgrading in comparison with the decentralised biogas usage case 1. If the decentral biogas plant can use 40 % of the heat the upgrading with a new CHP unit has slight advantages if the national electricity mix has CO_{2eq} emissions less than 600 g/kWh_{el}. If natural gas is replaced the national electricity mix has to be better than approx. 350 g CO_{2eq}./kWh_{el} to reach advantages for the upgrading case in comparison with the decentral usage of biogas. Here higher advantages can be reached if the national electricity mix has low specific CO_2 emissions.
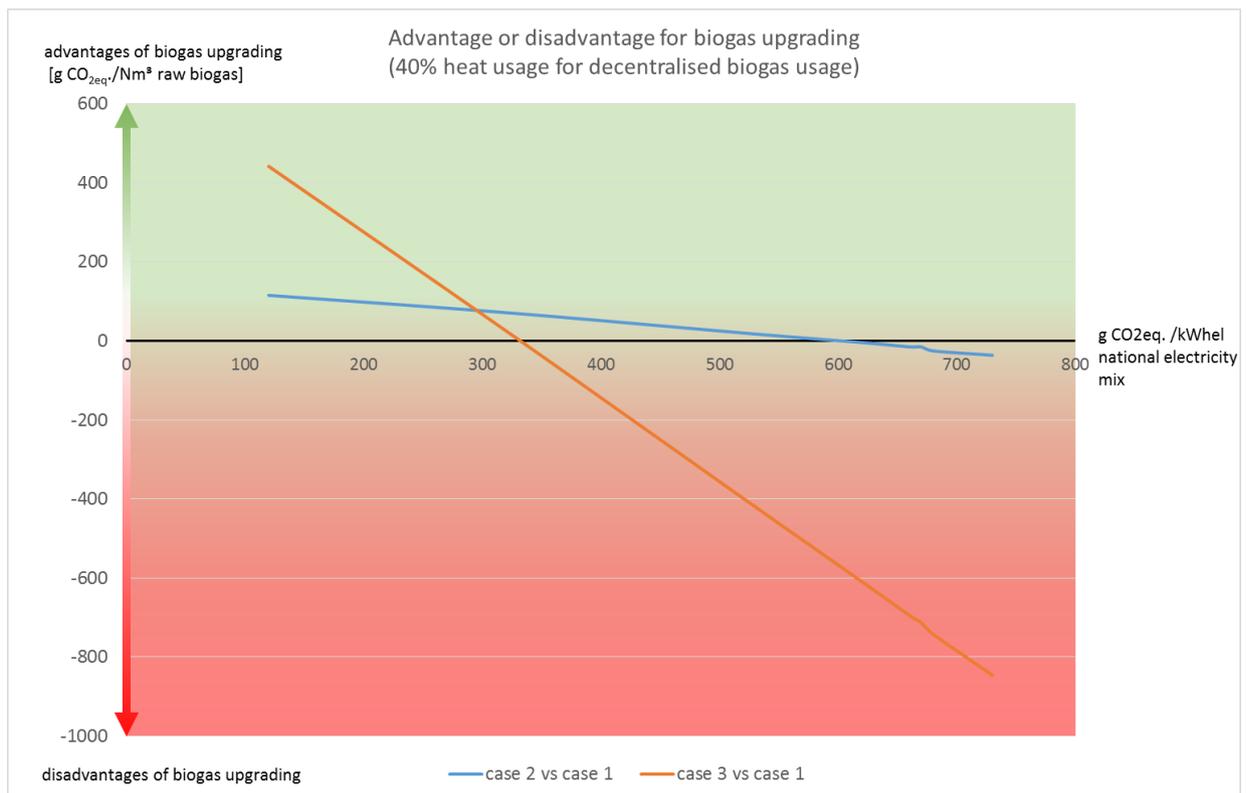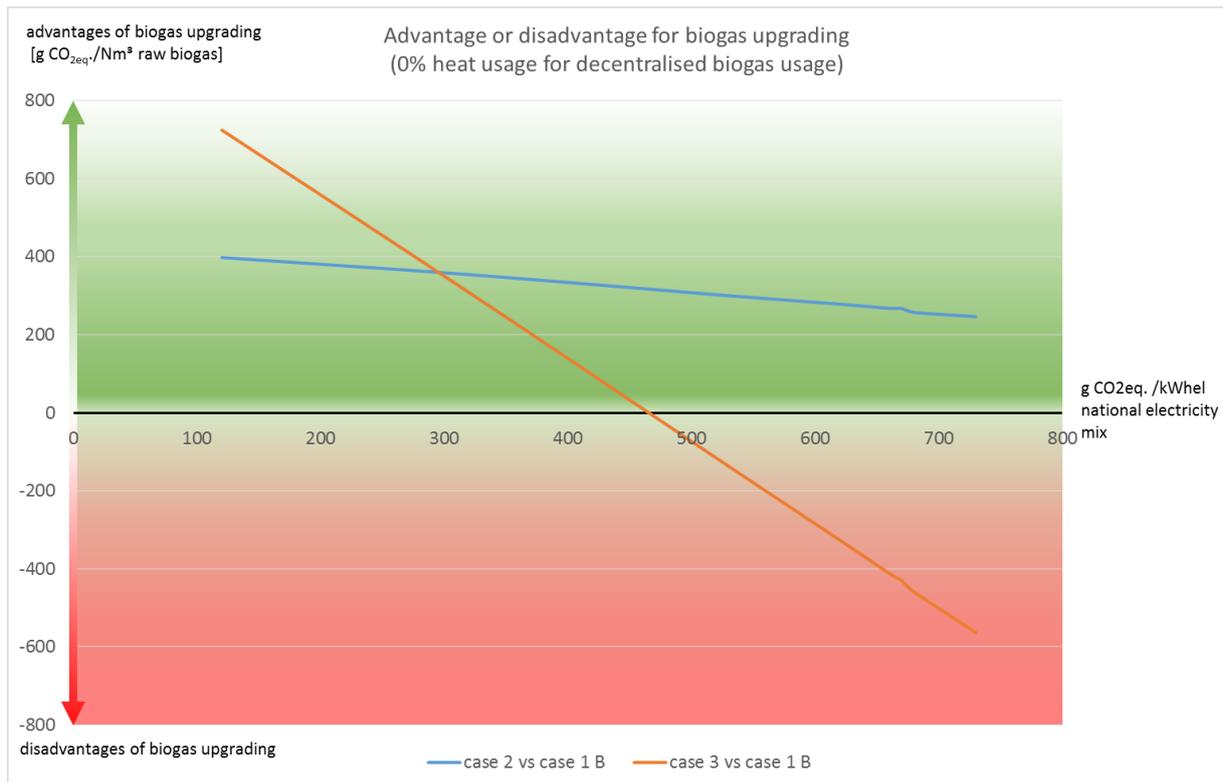
Figure 3: Advantage or disadvantage of biogas upgrading in comparison with decentralised biogas usage with heat external heat usage

As sensitivity analysis the comparison was also made for case 1B with no external heat usage in case of the decentralised biogas usage.

Case 1B decentralised usage of biogas

The biogas is used in a CHP unit onsite of the biogas plant. 0 % of the produced heat is used as substitute of an oil heating system.

Error! Reference source not found. shows the advantages or disadvantages of the biogas upgrading in comparison with the decentralised biogas usage case 1 B. If no heat usage onside of the biogas plant is possible the upgrading of the biogas and subsequent use in a new CHP unit is for all considered cases advantageous. If natural gas is replaced the national electricity mix has to be better than approx. 450 g $CO_{2eq.}$/kWh$_{el}$ to reach advantages for the upgrading case. Here higher advantages can be reached if the national electricity mix has low specific CO_2 emissions.

Figure 4: Advantage or disadvantage of biogas upgrading in comparison with decentralised biogas usage without heat external heat usage

3.4 Interpretation

Error! Reference source not found. shows, that the substitution of natural gas with upgraded biogas doesn't has any advantages in comparison with a decentralised CHP unit with 40 % external heat usage. The only exception are countries with low CO_2eq emissions in their national electricity mix (such as France). Here a slight advantage is possible. This is due to the fact, that the main CO_2eq emissions for the upgrading case are related to the electricity consumption. France has very low GWP per kWh_{el} so here upgrading is in regard of GWP more efficient.

If assumed that new CHP units for the usage of the upgraded biogas are build the comparison shows in nearly all countries slight advantages for the upgrading. Here benefits for substitution of gas heating and for substitution of the national electricity mix have been consider.

Error! Reference source not found. shows the same tendency. Here the advantages for upgrading under estimation of new built CHP units are more significant.

In all cases the advantages of upgraded biogas are higher the lower the emissions for the national electricity market are. So upgrading makes more sense the better the national electricity mix is!

3.5 Cost of GWP advantages

The costs for biogas upgrading strongly depends on the installed upgrading capacities. In Table 2 the upgrading costs, the costs for the connection with the natural gas grid and for transport accounting and storage are listed. Also additional heat revenues are considered.

Table 2: costs biogas upgrading for different upgrading capacities (Scholwin 2015)

	ct/kWh$_{HS}$	ct/kWh$_{el}$
upgrading	1.0 – 1.5 ct/kWh$_{HS}$	2.5 – 3.8 ct/kWh$_{el}$
connection with the grid	1.0 ct/kWh$_{HS}$	2.5 ct/kWh$_{el}$
Transport, accounting, storage	0.6 - 0.8 ct/kWh$_{HS}$	1.5 – 2.0 ct/kWh$_{el}$
Add. Heat revenues	-0.72 ct/kWh$_{HS}$ (case 1) -1.2 ct/kWh$_{HS}$ (case 1B)	-1.8 ct/kWh$_{el}$ (case 1) -3.0 ct/kWh$_{el}$ (case 1B)
Total	1.4 – 2.6 ct/kWh$_{HS}$	3.5 – 6.6 ct/kWh$_{el}$
Total	7.3 – 13.8 ct/Nm³ raw biogas	

For further calculation with average costs of 7.4 ct/kWh$_{el}$ minus the add heat revenues will be used. According to that the following costs will be estimated:

- 9.2 ct/Nm³ raw biogas for the case when the decentral biogas plant hasn't any heat usage and

- 11.7 ct/Nm³ raw biogas for the case when the decentral biogas plant can use 40 % of the heat

In case that the reference biogas plant can use 40 % of the heat up to 440 g CO_2/Nm³ raw biogas - depending on the national electricity mix and if electricity and heat or natural gas are replaced – can be reached as additional CO_2 reduction by the upgrading in comparison with the decentral biogas plant. This means for the best case costs of 0.26 €/kg CO_2 reduction. If there is no heat usage at the reference biogas plant approx. 0.13 €/kg CO_2 reduction can be reached.

3.6   Sensitivity analyses

Methane leakage

Methane leakage in Germany is limited to 0.2 % according to the national legislation. In literature values for the pressure water scrubbing technology of 0.8 % up to 5.5 % are mentioned. So a lean gas treatment is necessary. For the calculations 0.1 % methane leakage have been assumed. In the sensitivity analysis this value increased to 0.5 %. This results in higher CO_2eq emissions of 40 g/Nm³ raw biogas.

Electricity demand

According to Dunkelberg et al the electricity demand is between 0.2 and 0.4 kWh$_{el}$/Nm³ raw biogas. For the calculation 0.23 kWh$_{el}$/Nm³ raw biogas according to URBAN have been assumed. An increase of electricity demand of 50 % (up to 0.345 kWh$_{el}$/Nm³ raw biogas) leads in most countries to an increase of CO_2eq emissions of 50 %. The influence of the electricity demand in countries with low CO_2eq emissions of the national electricity mix (like France) is lower this means that the increase in CO_2eq emissions through the higher energy demand is also lower (e.g. 25 %).

4 Conclusion

The present paper shows, that the CO_2 reduction potential of biogas upgrading systems in comparison to decentral biogas usage are dependent on:

- the <u>national electricity mix</u>: Because of the high influence of the consumed electricity for the upgrading of the biogas the national electricity mix has a high influence on the results. The better the national electricity mix the higher are the positive effects through biogas upgrading. This is because of the lower emissions through the upgrading.

- the <u>electricity demand</u>: The electricity demand of the upgrading system is in most of the countries responsible for the largest part of the CO_2eq emissions. Only in countries with low CO_2eq emissions per kWh_{el} the influence of the electricity demand plays a minor role. Especially in countries with an electricity mix with high specific CO_2eq emissions a higher electricity demand - e.g. because of the need to fed in a high pressure grid – influences strongly the results.

- the <u>methane leakage</u>: Because of the high CO_2eq potential of methane the leakage during the upgrading process has to be low[2]. Here a lean gas treatment like post combustion has to take place.

- the <u>reference system</u>: Here on the one hand the replaced decentral biogas usage has to be considered. As the calculations show the upgrading has especially advantages when the <u>heat usage</u> in the reference biogas plant is in deficit. According to Scholwin 2015 biogas upgrading (under German conditions) is to be preferred if less than 50 % of the free heat can be used on site of the biogas plant. Dunkelberg (Dunkelberg et al, 2015) comes to the result that the heat usage has to be 35 % - 50 % higher to give an advantage for the upgrading system. On the other hand the estimated <u>use of biomethane</u> plays a decisive role. The calculations show that in most of the cases the use in a CHP unit is preferable[3] to the replacement of natural gas. Only in countries with an electricity mix with CO_2eq emissions below the emissions of natural gas the replacement of natural gas is preferable. Also the replaced electricity mix plays a role whether there is an advantage for the biogas upgrading in comparison of a decentral biogas usage. Whereas in this paper the national electricity mix is replaced other studies choose other reference systems e.g. Dunkelberg, 2015 chooses a mix of 50% electricity from coal and 50% from natural gas. This assumptions also have influence on the results.

Biogas upgrading can have advantages from GWP perspective in comparison with decentral biogas usage especially if no heat usage on side of the biogas plant is possible. Whether an advantage exists depends on the effectiveness of the upgrading system (methane leakage, energy demand), the national electricity mix and the chosen reference system. In most cases the biomethane use in new CHP units has to be preferred. The better the national electricity mix is the easier biogas upgrading can generate an advantage in comparison with decentral biogas usage.

Beside the climate benefits biomethane has also the advantages that the natural gas grid can be used as storage and so electricity and heat can be produced on demand this contributes to a flexible energy production. Also the dependence on natural gas imports can be reduced.

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[2] In Germany 0.2 % are allowed

[3] See also Scholwin, 2015

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