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Novel Routes for Biogas Use

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Biofuels

Issues of current biogas fuels CBG and LBG

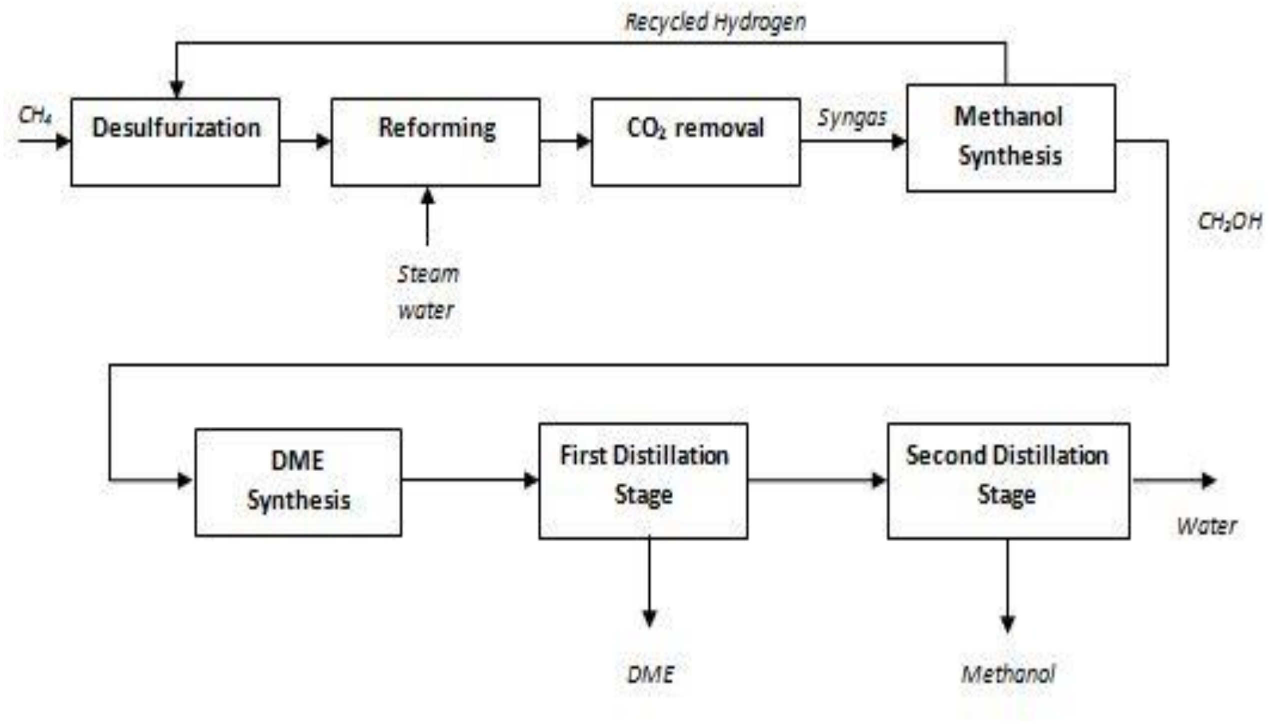
- Limits of grid to certain regions
- Storage and distribution systems (production plant-end users)
- Cost of technology

Prospectives

- Conversion to a higher energy density
- Supply of biofuels to geographically broader and larger market

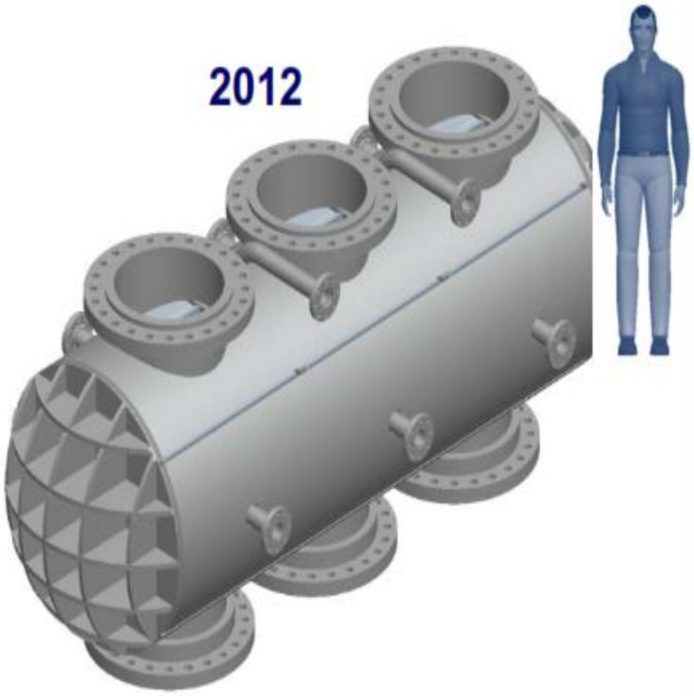
Gas-to-Liquid Technologies (GTL)

- Fischer–Tropsch diesel (FTD)
- Dimethyl ether (DME)
- Methanol



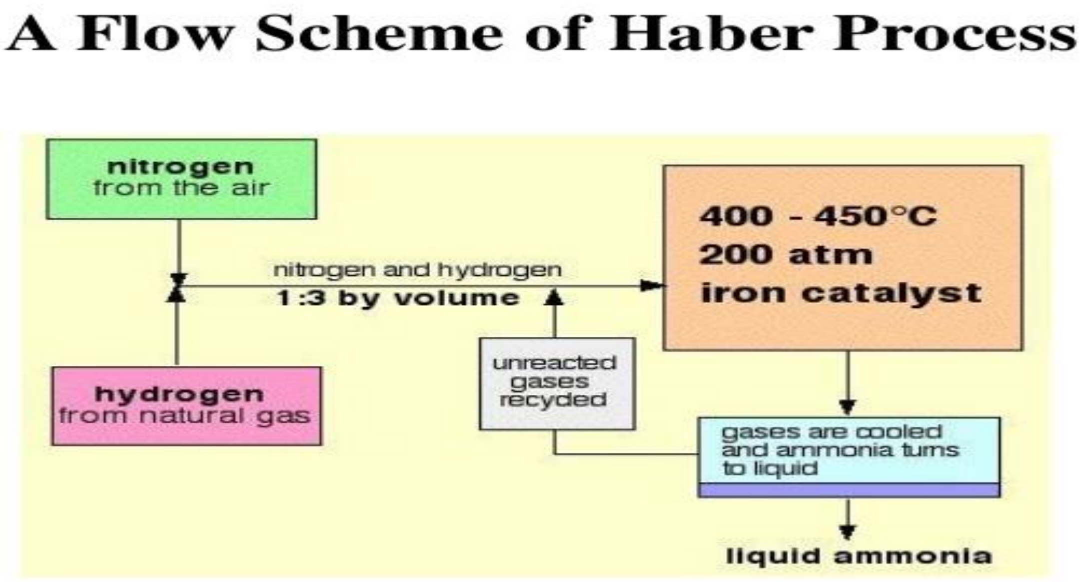
Advantages of GTL Fuel

- ✓ Efficient and powerful engine performance
- ✓ Potential to blend with diesel
- ✓ Reduction in emission (HC, CO, NOx, PM)
- ✓ Short term implememntation
- ✓ Microchannel technologies



Chemicals: Ammonia

- Platform chemical / a precursor to nitrogen fertilizers
- Ammonia is synthesized in the Haber-Bosch process



Biogas novel use

Case study 1: Liquid Fuels

GTL technology (FTD/DME/methanol)

Case study 2: Chemicals

Ammonia

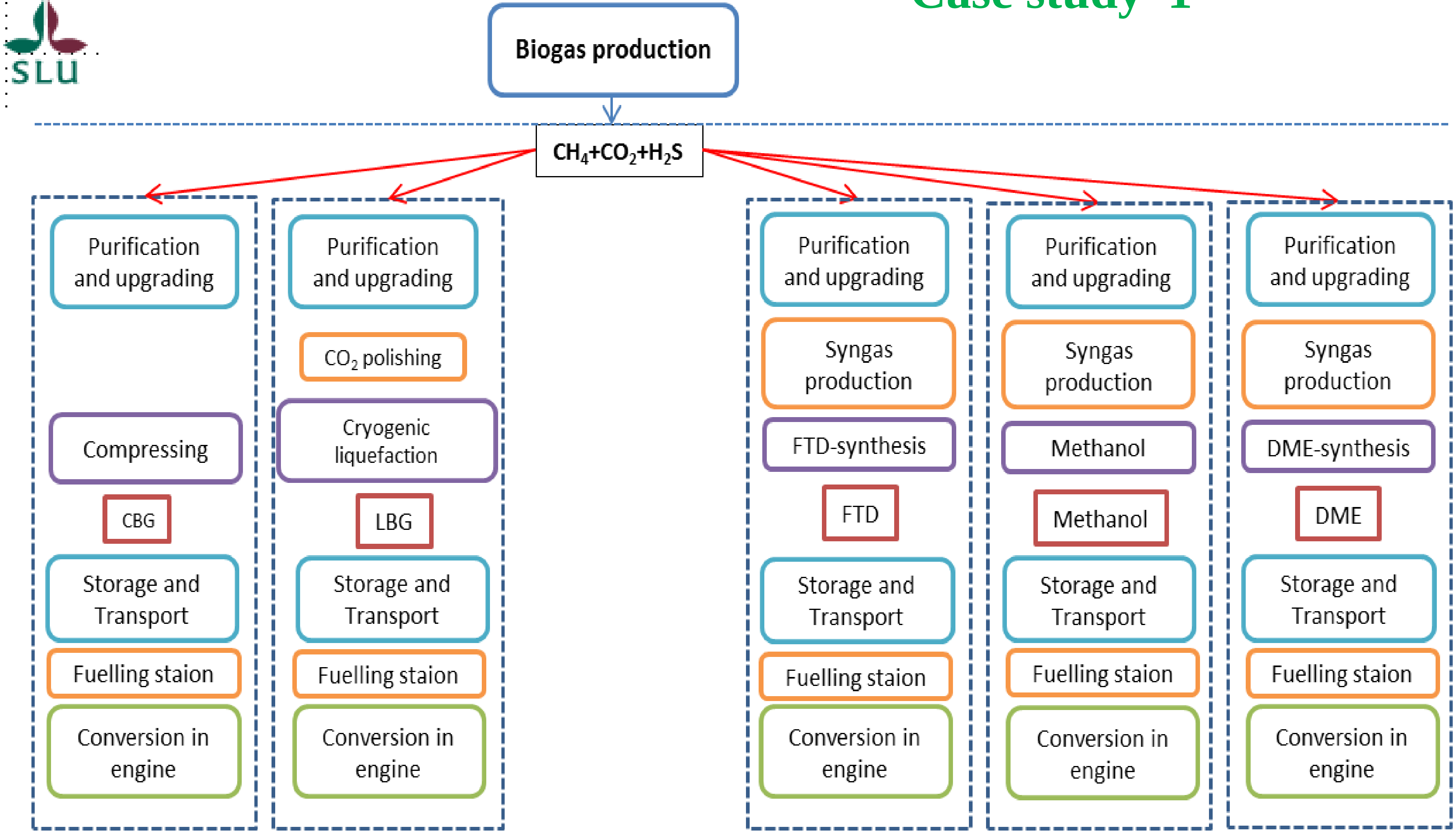
Methodology/Case Selection

- LCA methodology (ISO standards 14040/44) attributional modelling

- Energy and environmental performance

- Inventory data and modelling sheet software (AspenTech's Aspen Plus 7.3.2).

Case study 1



- 1140 Nm^3/h raw biogas (1 atm, 0 C) and annual gross energy production 60 GWh based on 9.97 kWh/Nm^3 CH_4
- Functional unit $1nm^3$ raw biogas

Results-case 1

Table 1. Amount of fuel, heat and steam (LHV) produced (MJ/Nm^3 raw biogas) in the different scenarios and the resulting allocation factors

	Fuel	Heat	Steam	Total energy	Fuel	Heat	Steam
	MJ produced/Nm^3 raw biogas				Allocation factor (%)		
CBG	21.19			21.19	100		
LBG	21.19			21.19	100		
FTD	9.24	2.86	10.29	22.39	41.28	12.77	45.96
Methanol	16.23	1.49	1.78	19.50	83.22	7.65	9.12
DME	19.31	1.65	1.30	22.26	86.73	7.42	5.85

Results-case 1

Table 2. Primary energy input (MJ/Nm^3 raw biogas) for the scenarios studied[a]

	CBG	LBG	FTD	Methanol	DME
	MJ primary energy/Nm^3 raw biogas				
Upgrading	2.14	2.41[b]	0.43 (1.04)	0.86 (1.04)	0.90 (1.04)
Compression	0.86	0	0	0	0
Liquefaction	0	2.99	0	0	0
Syngas/fuel synthesis[c]	0	0	3.42 (8.30)	2.01 (2.42)	2.58 (2.97)
Transport	0.72	0.08	0.05	0.19	0.20
Fuelling station	0.33	0.12	0.09	0.16	0.19
Total PE	4.05	5.59	3.99 (9.47)	3.22 (3.81)	3.87 (4.41)
Specific fuel productivity[d]	5.23	3.79	2.31 (0.98)	5.03 (4.26))	4.99 (4.38)

[a] Values not allocated to fuel for the GTL scenarios are given in brackets

[b] Includes upgrading and a purification step

[c] No external heat was included in the GTL fuel production process

[d] Specific fuel productivity is described as output fuel/total PE in the fuel chain

Results-case 1

Table 3. Global warming potential (g CO_2-eq./Nm^3 raw biogas) for the fuel scenarios studied[a]

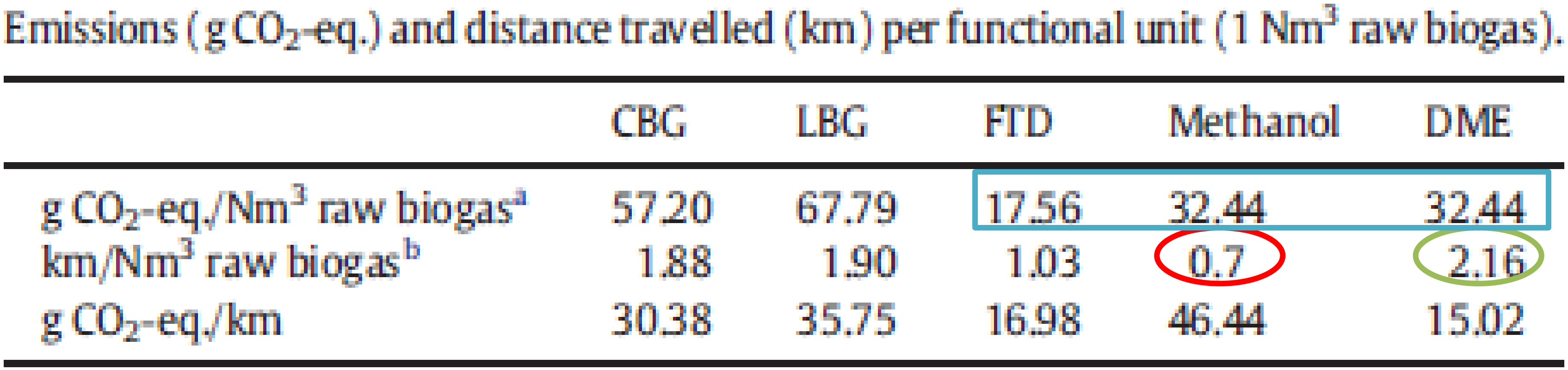
	CBG	LBG	FTD	Methanol	DME
		(g CO_2-eq./Nm^3 raw biogas)			
Upgrading	289	298 [b]	35(84)	70(84)	73(84)
Compression	45	0	0	0	0
Liquefaction	0	157	0	0	0
Syngas/fuel synthesis	0	0	185(449)	106(127)	136(156)
Transport	8	1	1	2	2
Fuelling station	18	6	5	8	10
Total GWP	360	462	226(540)	187(222)	221(253)

[a] Values not allocated to fuel for the GTL scenarios are given in brackets

[b] Includes upgrading and a purification step

Results-case 1

Table 4.



Emissions (g CO_2-eq.) and distance travelled (km) per functional unit (1 Nm^3 raw biogas).

	CBG	LBG	FTD	Methanol	DME
g CO_2-eq./Nm^3 raw biogas[a]	57.20	67.79	17.56	32.44	32.44
km/Nm^3 raw biogas[b]	1.88	1.90	1.03	0.7	2.16
g CO_2-eq./km	30.38	35.75	16.98	46.44	15.02

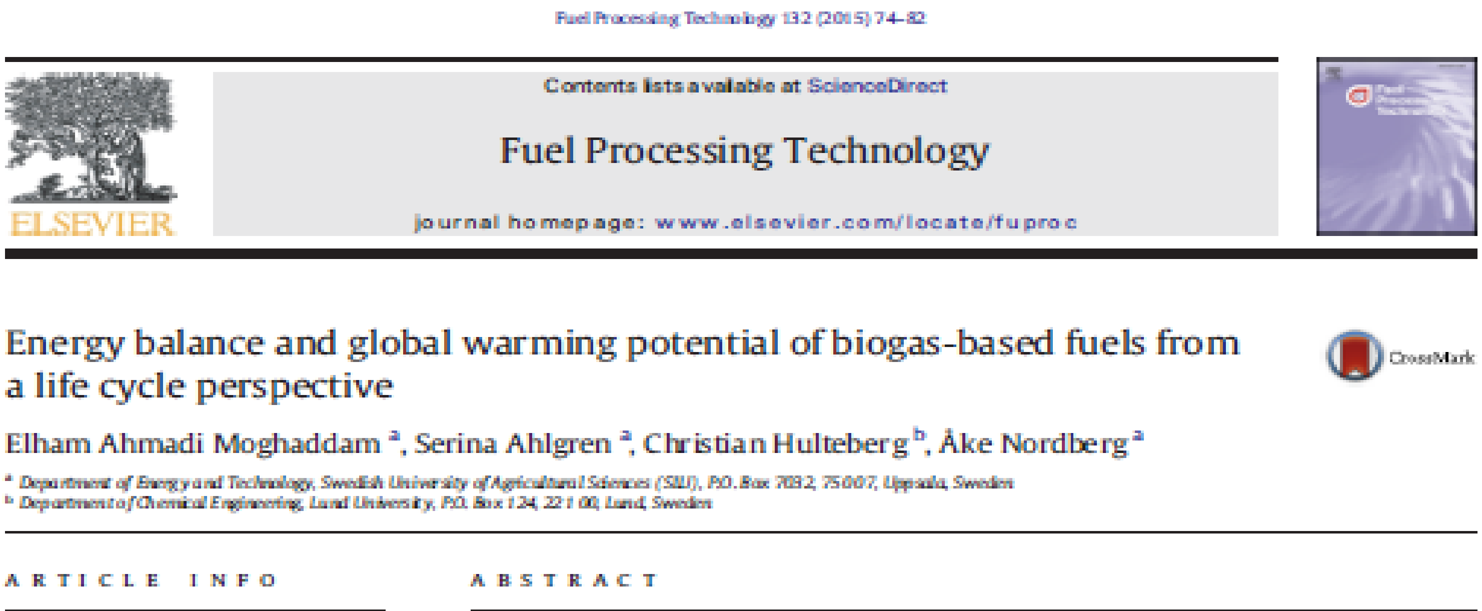
Moghaddam et al., 20154.

Results-case 1

- The CBG, methanol and DME-scenarios resulted in the highest specific fuel yields (5.2, 5.0 and 5.0 MJ primary energy/Nm3 biogas, respectively

- The methanol, FTD and DME-scenarios resulted in approximately half of the GWP from the LBG and CBG-scenarios

- Taking the energy efficiency and GWP into account, DME showed the best performance of the fuel conversion scenarios studied.



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Energy balance and global warming potential of biogas-based fuels from a life cycle perspective

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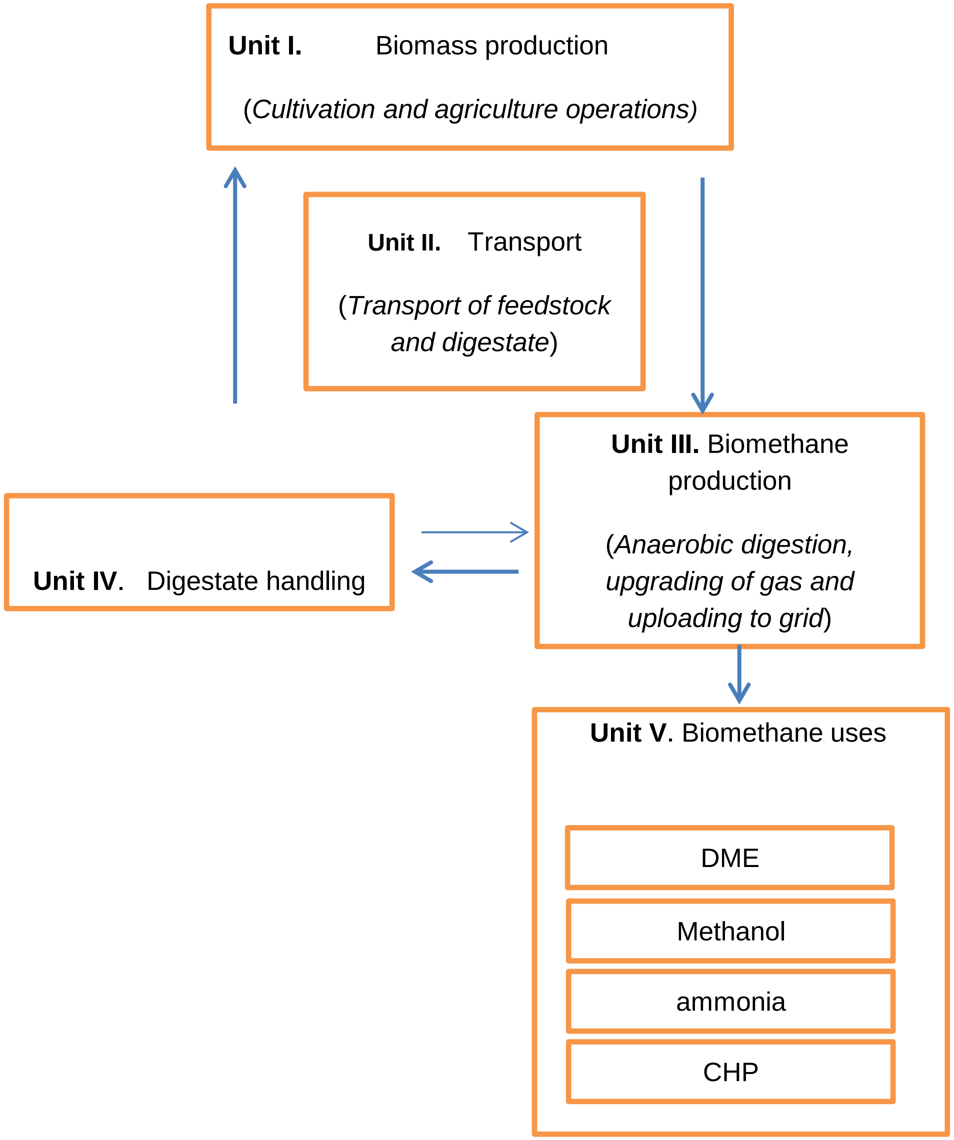
ARTICLE INFO

ABSTRACT

Case study 2



Unit I. Biomass production

(*Cultivation and agriculture operations)*

Unit II. Transport

(*Transport of feedstock and digestate*)

Unit III. Biomethane production

(*Anaerobic digestion, upgrading of gas and uploading to grid*)

Unit IV. Digestate handling

Unit V. Biomethane uses

DME

Methanol

ammonia

CHP

Figure 2. System borders of the study

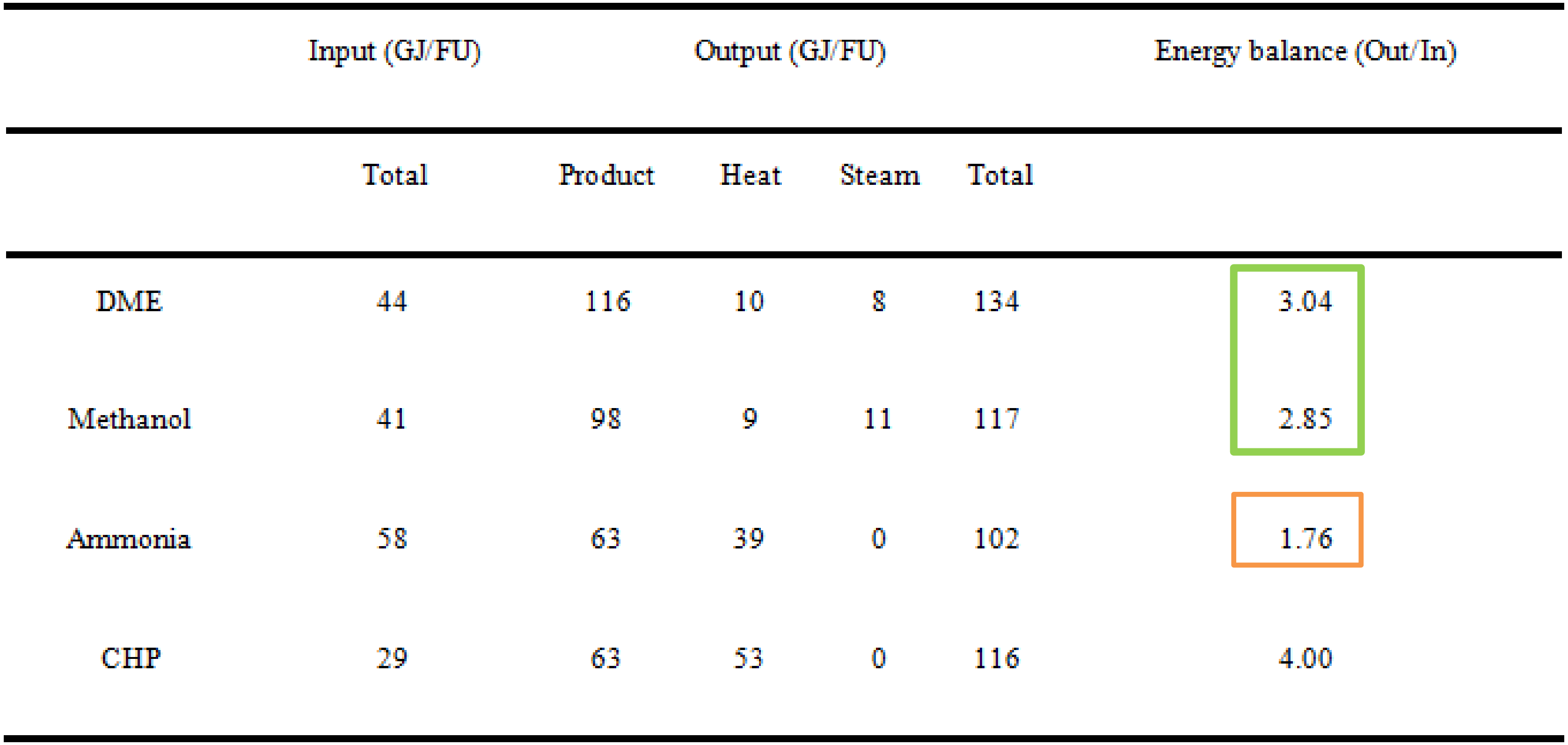
- Assessment of impacts associated with production of methanol, DME, and ammonia as platform chemicals generated from biogas using maize crops, in comparison to utilizing the biogas in a CHP

- Comparison of the environmental impacts of the bio-based products (methanol, DME, ammonia, and CHP) with those of their fossil-based alternatives

- Functional unit I hectare land cultivated with maize during one year

Results-case 2

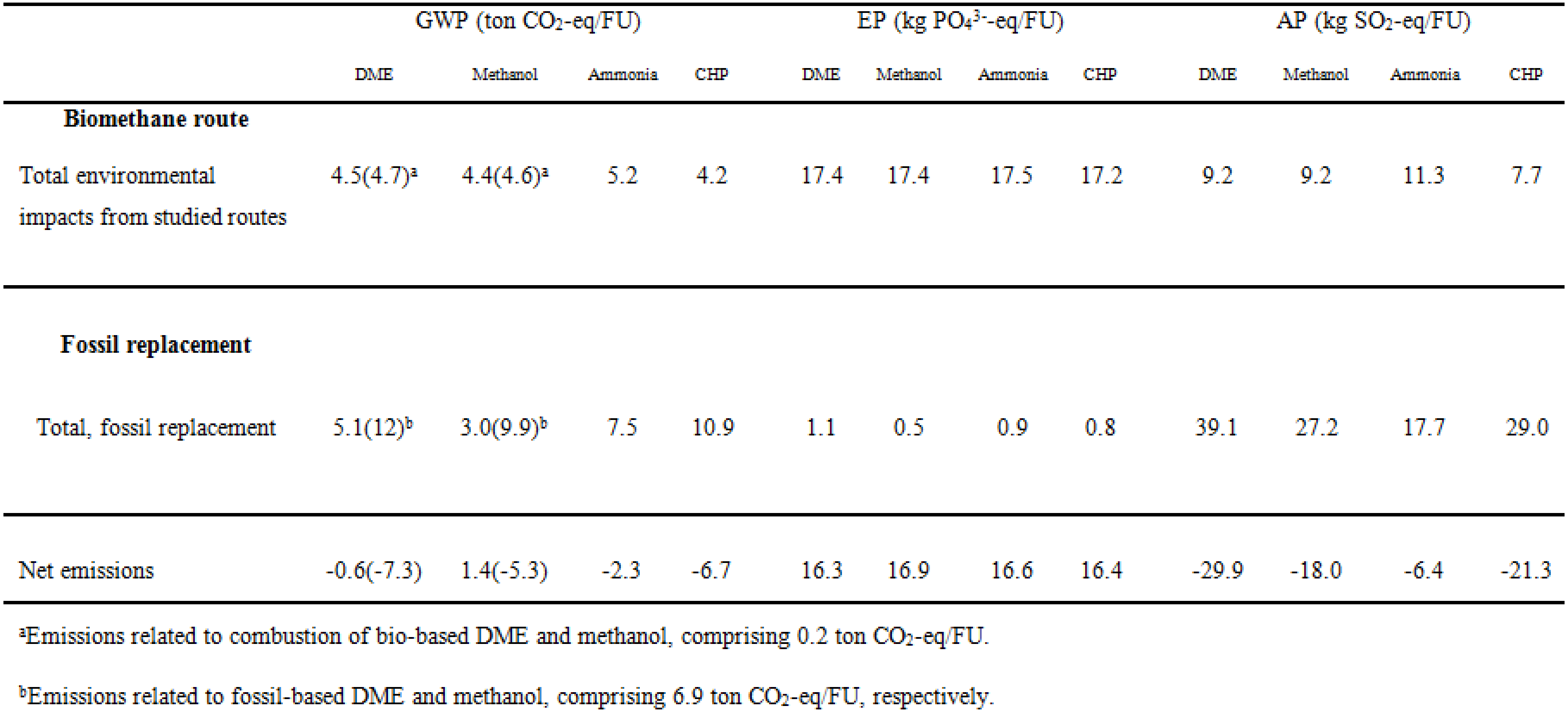
Table 5. Amount of product, heat and steam (GJ /FU) produced in the different scenarios



	Input (GJ/FU)	Output (GJ/FU)				Energy balance (Out/In)
	Total	Product	Heat	Steam	Total	
DME	44	116	10	8	134	3.04
Methanol	41	98	9	11	117	2.85
Ammonia	58	63	39	0	102	1.76
CHP	29	63	53	0	116	4.00

Results-case 2

Table 6. Total environmental impacts from the different routes studied and from the fossil substitute, and net emissions for the routes



	GWP (ton CO_2-eq/FU)				EP (kg PO_4^{3-}-eq/FU)				AP (kg SO_2-eq/FU)			
	DME	Methanol	Ammonia	CHP	DME	Methanol	Ammonia	CHP	DME	Methanol	Ammonia	CHP
Biomethane route												
Total environmental impacts from studied routes	4.5(4.7)[a]	4.4(4.6)[a]	5.2	4.2	17.4	17.4	17.5	17.2	9.2	9.2	11.3	7.7
Fossil replacement												
Total, fossil replacement	5.1(12)[b]	3.0(9.9)[b]	7.5	10.9	1.1	0.5	0.9	0.8	39.1	27.2	17.7	29.0
Net emissions	-0.6(-7.3)	1.4(-5.3)	-2.3	-6.7	16.3	16.9	16.6	16.4	-29.9	-18.0	-6.4	-21.3

[a] Emissions related to combustion of bio-based DME and methanol, comprising 0.2 ton CO_2-eq/FU.

[b] Emissions related to fossil-based DME and methanol, comprising 6.9 ton CO_2-eq/FU, respectively.

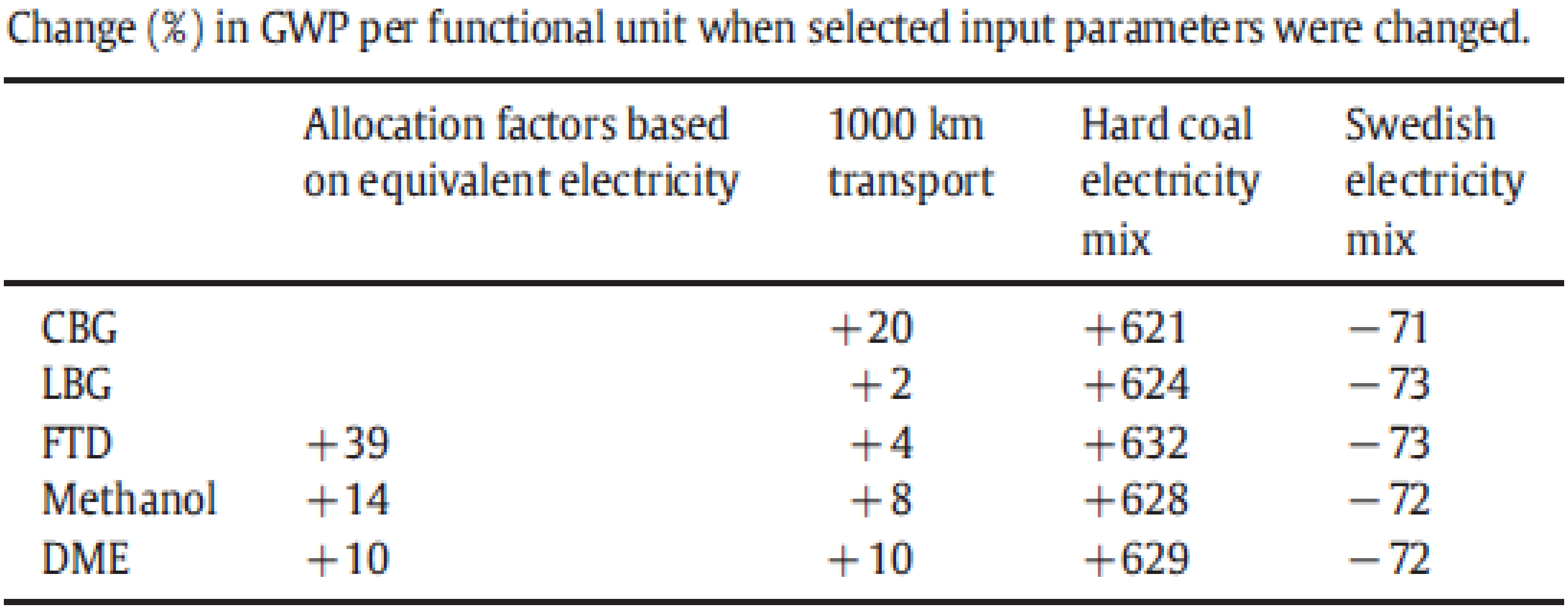
Results-case 2

- Among the different routes ammonia had the highest energy Input (lowest energy balance) and highest environmental impacts

- DME had the best performance in comparison to bio-based and fossil-based routes.

Thank you
for your attention

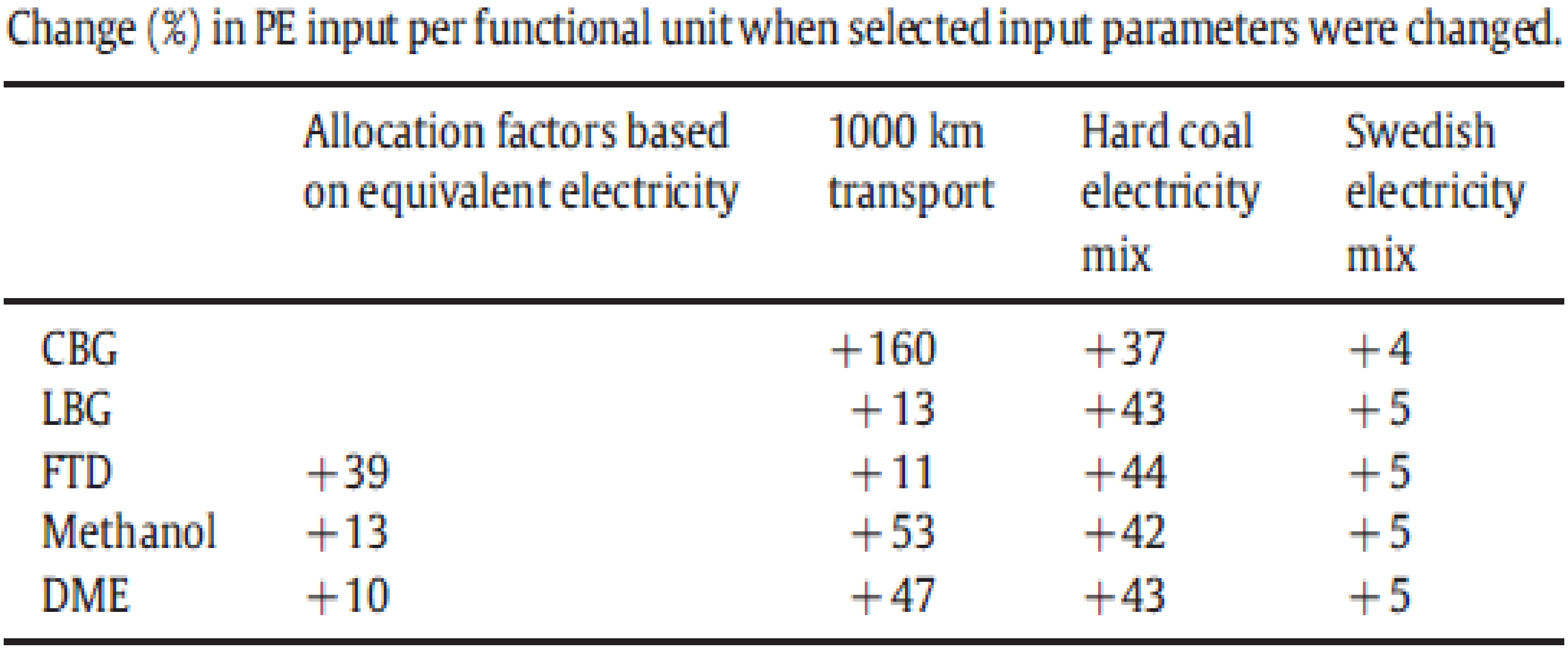
Sensitivity Analysis-Case study 1



Change (%) in GWP per functional unit when selected input parameters were changed.

	Allocation factors based on equivalent electricity	1000 km transport	Hard coal electricity mix	Swedish electricity mix
CBG		+20	+621	−71
LBG		+2	+624	−73
FTD	+39	+4	+632	−73
Methanol	+14	+8	+628	−72
DME	+10	+10	+629	−72

Sensitivity Analysis-Case study 1



Change (%) in PE input per functional unit when selected input parameters were changed.

	Allocation factors based on equivalent electricity	1000 km transport	Hard coal electricity mix	Swedish electricity mix
CBG		+160	+37	+4
LBG		+13	+43	+5
FTD	+39	+11	+44	+5
Methanol	+13	+53	+42	+5
DME	+10	+47	+43	+5

Results-case study 2:
energy inputs and environmental impacts

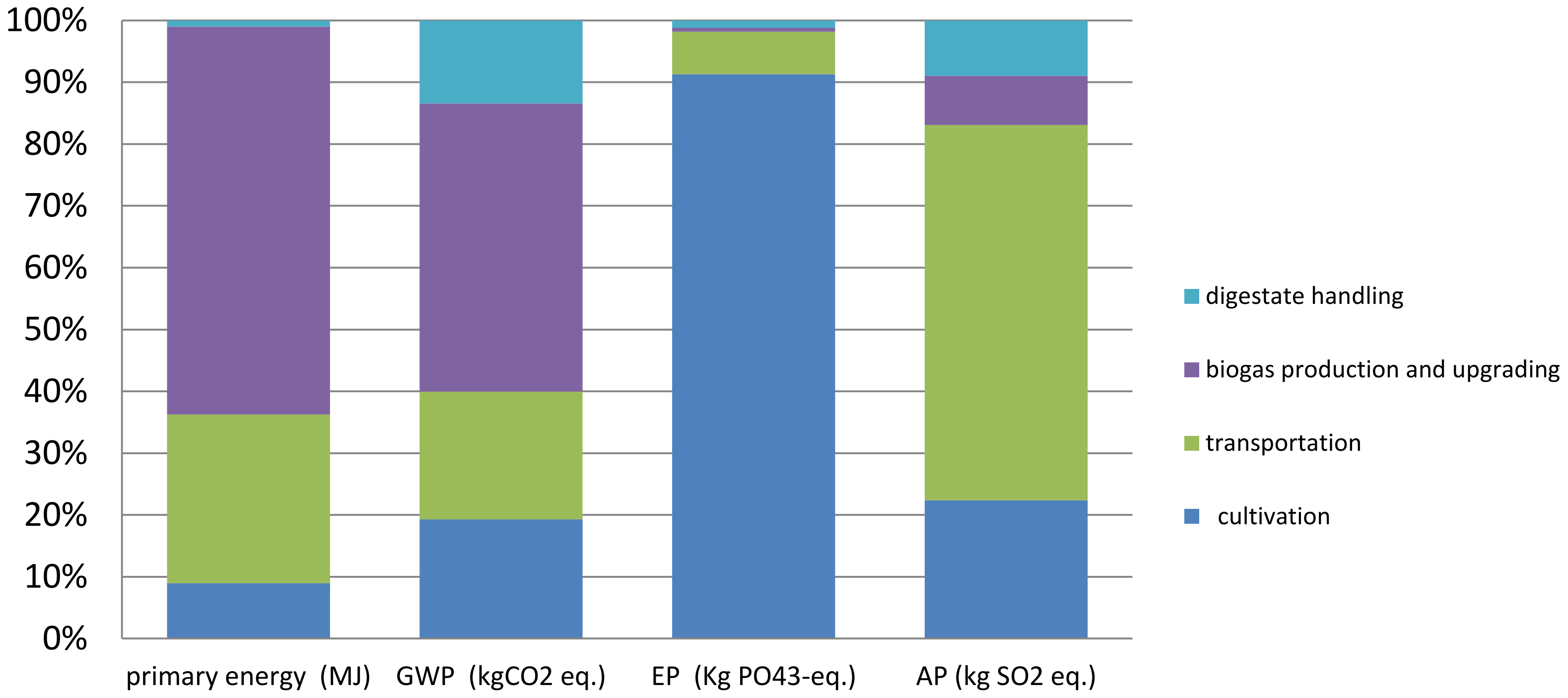


Fig 3. energy inputs and environmental impacts-biomass-to-biomethane production units

Results-Case study 2: Energy Inputs

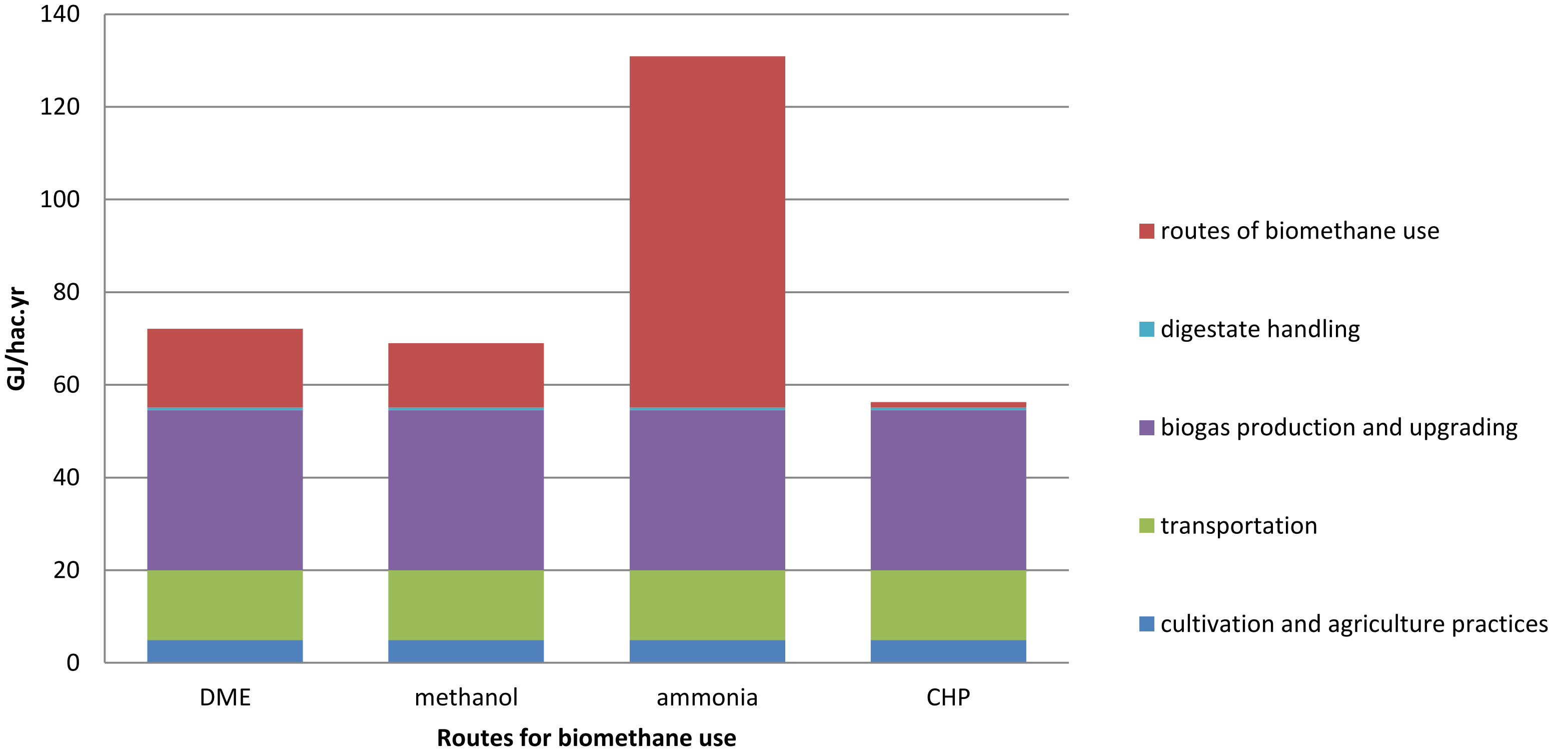


Fig 4. primary energy input to different routes of biomethane use

Results-Case study 2: Energy Inputs

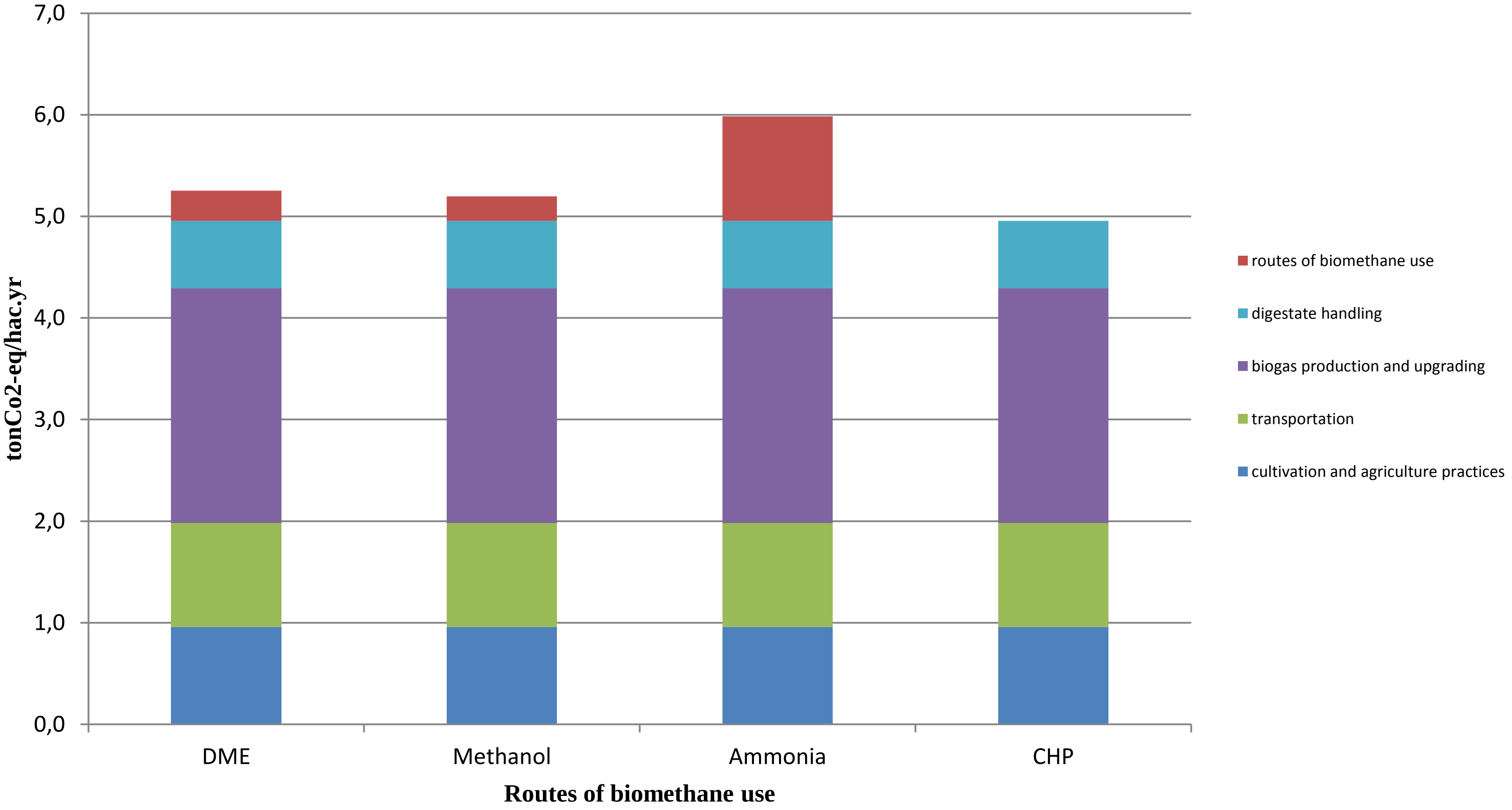


Fig 5. GWP of different routes of biomethane use

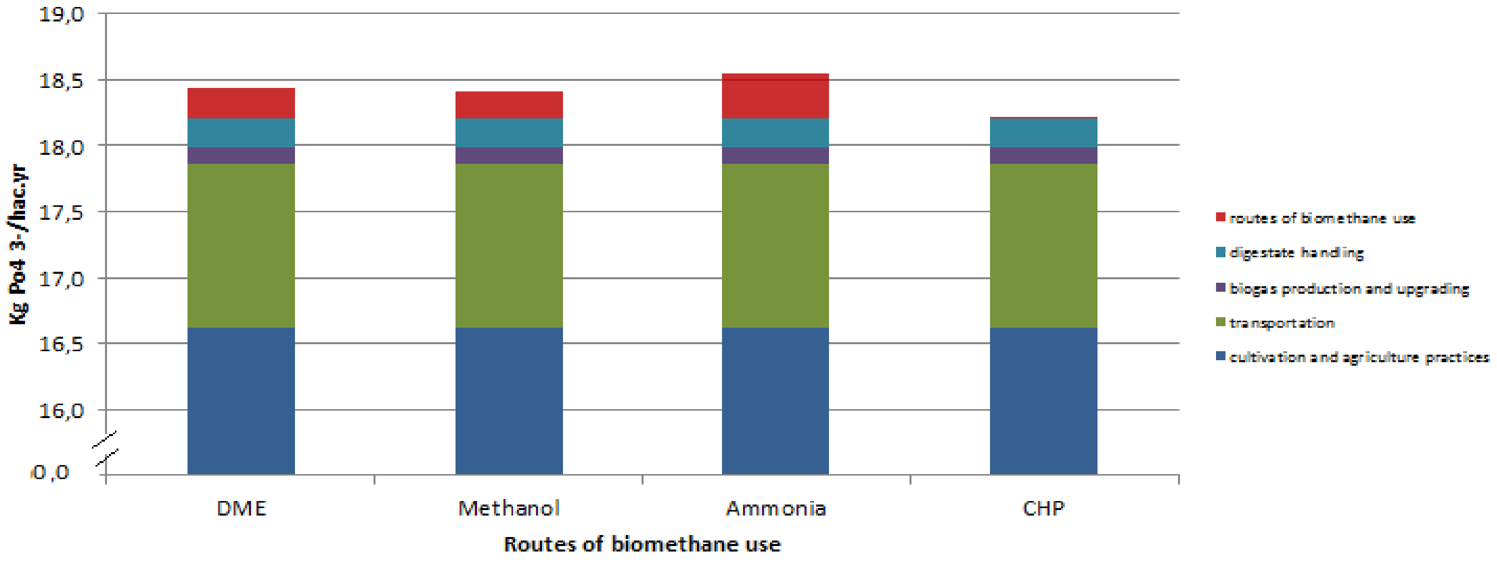


Fig 6. EP of different routes of biomethane use

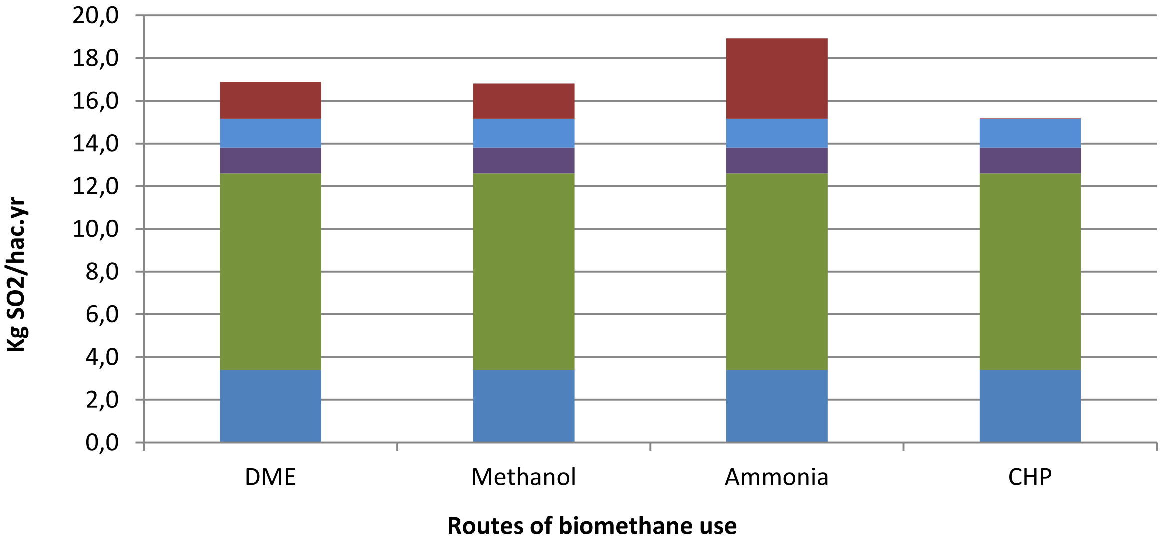


Fig 7. AP of different routes of biomethane use

- Overview and Research Question
- Methodology/Case Selection
- Discussion of Data/Results
- Analysis
- Conclusion

	GWP (ton CO_2-eq/FU)				EP (kg PO_4^{3-}-eq/FU)				AP (kg SO_2-eq/FU)			
	DME	Methanol	Ammonia	CHP	DME	Methanol	Ammonia	CHP	DME	Methanol	Ammonia	CHP
Biomethane route												
Total environmental impacts from studied routes	4.5(4.7)[a]	4.4(4.6)[a]	5.2	4.2	17.4	17.4	17.5	17.2	9.2	9.2	11.3	7.7
Fossil replacement												
Fuel/Chemical/Electricity	4.7	2.6	6.7	9.4	1.1	0.5	0.8	0.7	37.0	24.7	14.7	24.9
Heat	0.3	0.2	0.8	1.5	n	n	0.1	0.1	0.8	0.7	3.0	4.1
Steam	0.1	0.2	n	n	n	n	n	n	1.3	1.8	n	n
Total, fossil replacement	5.1(12)[b]	3.0(9.9)[b]	7.5	10.9	1.1	0.5	0.9	0.8	39.1	27.2	17.7	29.0
Net emissions	-0.6(-7.3)	1.4(-5.3)	-2.3	-6.7	16.3	16.9	16.6	16.4	-29.9	-18.0	-6.4	-21.3

Characteristics of maize as an energy crop and digestate assumed in the study

Maize yield	t WW/ha/yr	43
Dry matter (DM) concentration	%	30
Methane yield	Nm^3/t DM	316
Biomethane yield	GJ/ha/yr	143[a]
Digestate yield	ton/ha/yr	34.4

[a] Gross production of biogas including internal use; net biogas production is 130 GJ/ha.yr.

Change (%) in primary energy input and environmental impacts (GWP, EP, and AP) per functional unit when selected input parameters were changed

Sensitivity analysis	**DME**	**Methanol**	**Ammonia**	**CHP**
Hard coal electricity mix				
Primary energy	50	50	53	43
GWP	362	337	433	219
EP	40	36	55	23
AP	1433	1328	1624	979
Swedish electricity mix				
Primary energy	17	16	18	14
GWP	-6	-5	-7	-3
AP	-4	-4	-4	-3
Higher range N_2O emissions factor				
GWP	112	114	97	119
Lower range N_2O emissions factor				
GWP	-17	-17	-14	-18
Improved upgrading technology				
GWP	-17	-17	-14	-18

Effects of different changes made in the sensitivity analysis on the emissions reduction potential of the different biobased routes studied

	GWP (ton CO_2-eq/FU)				EP (kg PO_4^{3-}-eq/FU)				AP (kg SO_2-eq/FU)			
	DME	Methanol	Ammonia	CHP	DME	Methanol	Ammonia	CHP	DME	Methanol	Ammonia	CHP
Default	-0.6 (-7.3)	1.4 (-5.3)	-2.3	-6.7	16.2	16.9	16.6	16.4	-29.9	-18.0	-6.4	-21.3
Hard coal electricity mix	15.6 (8.9)	16.3 (9.6)	20.3	2.5	23.1	23.1	26.2	20.3	102.5	103.7	177.7	53.8
Swedish electricity mix	-0.9 (-7.6)	1.1 (-5.5)	-2.6	-6.8	16.2	16.8	16.6	16.4	-30.2	-18.4	-6.8	-21.5
Higher range-N_2O emissions factor	4.4 (-2.3)	6.4 (-0.3)	2.8	-1.6	16.2	16.8	16.6	16.4	-29.8	-18.0	-6.35	-21.3
Lower range N_2O emissions factor	-1.4 (-8.1)	0.6 (-6.1)	-3.0	-7.4	16.2	16.8	16.6	16.4	-29.8	-18.0	-6.3	-21.3
Improved upgrading technology	-1.4 (-8.1)	0.6 (-6.1)	-3.0	-7.4	16.2	16.8	16.6	16.4	-29.8	-18.0	-6.3	-21.3

*The CHP system studied comprised a combustion (gas) turbine with an installed electricity capacity of 9500 kW and heat generation of 8100 kW_{th} with a total efficiency of 90%. This capacity is over-dimensioned in relation to the amount of biomethane produced

*The AD plant assumed in this case has an annual digestate output of 86 000 ton.