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Report SUSTAINABLE INNOVATION

Author(s):	Silje Arnøy, Kari-Anne Lyng, Ingunn Saur Modahl and John Baxter (Østfoldforskning) Rune Bakke (Telemark University College) Jon Hovland (Tel-Tek)

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Environmental and economic analysis of local and central biogas plants, including pipeline transport of biogas

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Project Manager (Østfoldforskning)
Ingunn Saur Modahl

Research Manager
Hanne Lerche Raadahl

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Summary

DisBiogass is a collaborative project between Telemark University College (HiT), Tel-Tek and Ostfold Research focusing on climatic and economic impacts through the value chain of biogas production from manure. The project was funded by the Norwegian Research Council through Oslofjordfondet and was carried out from 2011 to 2013.

The analysis comprises five scenarios modelled to explore the importance of localisation and size of biogas plants, and transportation modes used to transport manure, digestate and biogas when utilising manure from farms for biogas.

- Scenario 0: Direct use of manure (replaces mineral fertilizers).
- Scenario 1: Central biogas plant with central upgrading of the biogas to fuel quality (the farmers deliver manure and get back digestate).
- Scenario 2: Local biogas plant, local utilization of biogas (replaces heat).
- Scenario 3: Local biogas plant, central upgrade plant. Compression and transportation of biogas to upgrading plant.
- Scenario 4: Local biogas plant, central upgrade plant. Transportation of produced biogas through pipeline network to upgrading plant.

The Ostfold Research Biogas Model (Møller et al. 2013), developed in 2011 (with further development in 2012) is used as basis for the analysis. The model is based on LCA methodology (ISO 14040-44), and is developed as a net emissions model. The model includes ten phases of which eight contribute to emissions and two contribute to avoided emissions. Avoided emissions arise because produced biogas replaces products and energy that does not have to be produced when the biogas and digestate are produced. The Biogas Model also includes an economic value chain model which was developed to enable comprehensive decision making processes including both environmental and economic factors, and to easily facilitate the decision processes of investors, governments and farmers when considering establishment of central and local (farm) biogas plants. The economic model is developed as a tool in Microsoft Excel.

Both the climatic and economic results from the scenario analysis show that all scenarios where manure is utilised for biogas production (Scenarios 1-4) represent a considerable advantage compared to the scenario where manure is used directly by the farm as fertiliser (Scenario 0). Scenario 4, which is the scenario where raw biogas is transported in a pipe line from the farm to the centralised upgrading plant, comes out as the best scenario. However, the difference between transporting compressed biogas to a centralised upgrading plant and transporting raw biogas through a pipe line (scenario 4 and 3), is almost negligible.

1 Introduction

DisBiogass is a collaborative project between Ostfold Research, Telemark University College (HiT) and Tel-Tek focusing on climatic and economic impacts through the value chain of biogas production. The project was funded by the Norwegian Research Council through Oslofjordfondet and was carried out from 2011 to 2013.

The aim of the project was to contribute to development of more cost effective and sustainable biogas production and distribution technologies from small and distributed farms in Norway, for utilization of biogas as a vehicle fuel in areas that can utilize the energy most effectively.

The first round of analyses for climate and economic impacts, which focused on utilising manure from pigs and cattle for biogas production, were conducted in April-June 2012, based on four scenarios outlined by Tel-Tek (Scenarios 0-3, see below). These analyses, including assumptions and results, are described in two work reports with internal distribution in the project group. In 2013, as the project proceeded, it was decided to add a scenario to the analysis; scenario 4.

In late 2012 and early 2013, The Ostfold Research Biogas Model, used as basis for the analyses, was updated in respect to new and enhanced data material. The Biogas Model as per January 2013 is documented in Møller et al. (2012). The model was also updated in October 2013, which will be documented in the next version of The Biogas Model documentation report. In reference to the updated model it was considered interesting to update the analyses from 2012 to reveal the effects of updates. It was additionally considered important to gather all assumptions and results regarding the analyses in *one* official report instead of the two project internal work reports. This report therefore comprises assumptions and results of the analysis – both for the four 2012 scenarios and the added 2013 scenario.

For scenario 0-3 the analyses are based on the same input data as in the first run of the analyses. A new data collection was carried out for scenario 4. All data were obtained by Jon Hovland and Rune Bakke at Tel-Tek.

- Scenario 0: Direct use of manure (replaces mineral fertilizers).
- Scenario 1: Central biogas plant with central upgrading of the biogas to fuel quality (the farmers deliver manure and get back digestate).
- Scenario 2: Local biogas plant, local utilization of biogas (replaces heat).
- Scenario 3: Local biogas plant, central upgrade plant. Compression and transportation of biogas to upgrading plant.
- Scenario 4: Local biogas plant, central upgrade plant. Transportation of produced biogas through pipeline net work to upgrading plant.

2 Description of Scenarios

The first four scenarios are the same as for the first round of analyses in 2012. The scenarios and data material are based on a pilot biogas plant in Telemark used as a study case for Tel-Tek. To explore the impacts of transporting raw biogas via a pipeline to a central upgrading facility, a fifth scenario is added. The background for this scenario is an existing pipeline from a landfill located in Klepp in Rogaland. By constructing a 13 km extension to the already existing pipeline, farms with local biogas plants can send raw biogas through the pipeline to a central upgrading plant. A schematic diagram of the scenario basis is given in Figure 1.

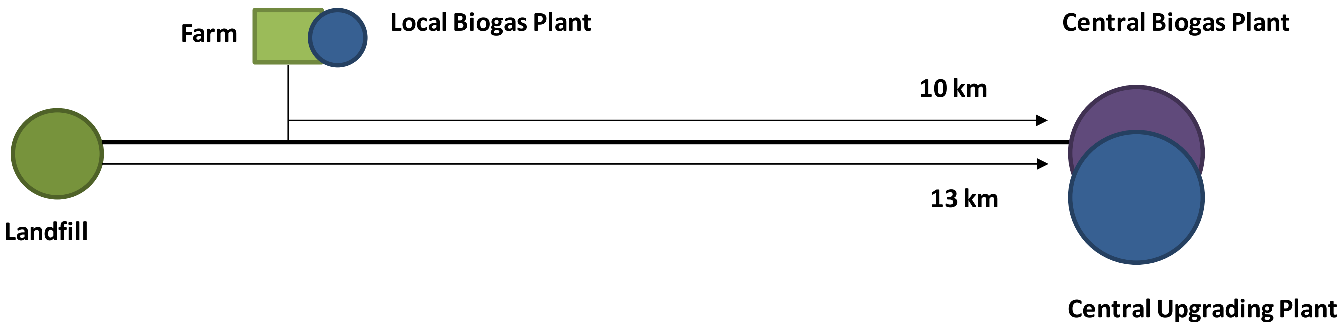


Figure 1: Schematic diagram of the scenarios.

Results from a study (Ernst Axelsen, Hå biopark) performed to assess the biogas potential in the Rogaland region in Norway show that within a 10 km radius of where the future centralised biogas plant could be placed, there is 211 000 tons of cattle manure distributed over 70 farms, and 288 000 tons of pig manure distributed over 96 farms. Based on these results each farm produces 3 000 tons of wet manure. Hence, a farm located 10 km (conservative estimate) from the central biogas/upgrading plant, producing 3 000 tons of wet pig/cattle manure (average), is assumed for use in the calculations. This farm is placed in close proximity to the forthcoming extension of the raw gas pipeline.

2.1 Scenario 0

Scenario 0 is the reference scenario and reflects what is assumed to be today's use of manure from farms. One farm is included in the scenario, and it is assumed that the manure is used directly by the farm, as fertiliser, and replaces use of mineral fertiliser. No transport is included in this scenario.

2.2 Scenario 1

Scenario 1 explores the impacts of utilising manure from the farm (3 000 tons) at a central biogas plant located at the end of the extension of the pipeline from the landfill. The produced biogas is upgraded to fuel quality at an upgrading plant placed adjacent to the biogas plant. It is assumed that the fuel quality biogas replaces diesel used for transport. The digestate from the biogas production is returned to the farmer and used as fertiliser, and is assumed to replace mineral fertiliser. The manure from the farm is transported 10 km by truck, and the digestate is transported the same 10 km back to the farm by truck.

2.3 Scenario 2

Scenario 2 explores the impacts of utilising manure from the farm (3 000 tons) at a local biogas plant (located adjacent to the farm). The biogas is utilised locally at the farm and is assumed to replace heat produced by oil. It is assumed that 100% of the heat produced by the biogas is utilised at the farm. The digestate from the biogas production is used by the farmer as fertiliser, and is assumed to replace mineral fertiliser. No transport is included in this scenario.

2.4 Scenario 3

Scenario 3 explores the impacts of utilising manure from the farm (3 000 tons) at a local biogas plant (located adjacent to the farm). The biogas is compressed and transported 10 km by truck to the upgrading plant located adjacent to the central biogas plant. The produced biogas is upgraded to fuel quality and is assumed to replace diesel used for transport. The digestate from the biogas production is used by the farmer as fertiliser, and is assumed to replace mineral fertiliser.

Transport of raw compressed biogas has to our knowledge not been tested. It seems to be technically feasible (Hovland 2013). The cost of producing and delivering compressed raw biogas to a central upgrading plant has therefore a much higher uncertainty than Scenario 4.

2.5 Scenario 4

Scenario 4 explores the impacts of using manure from the farm (3 000 tons) at a local biogas plant (located adjacent to the farm). The biogas is transported via the extension of the raw gas pipeline 10 km to the upgrading plant located adjacent to the central biogas plant. The produced biogas is upgraded to fuel quality and is assumed to replace diesel used for transportation. The digestate from the biogas production is used by the farmer as fertiliser, and is assumed to replace mineral fertiliser.

Transport of raw biogas in pipeline is a technology in use in Sweden and other countries. The data used is based on reports from Svenskt Gasteknisk Center (Berglund et al. 2012; van Eekelen et al. 2012).

3 Use of the Biogas Model

The Biogas Model was developed in 2011 with main support by SLF (the Norwegian Agricultural Authority). The model was further developed in 2012, and is now in its third development phase in the project named “Bio Value Chains”, financed by SLF and EnergiX (The Research Council of Norway). The model is based on LCA methodology (ISO 14040-44), is created in the software SimaPro, and is developed as a net emissions model. This implies that all phases of the biogas production value chain are included, from manure and/or household waste generation, through storage, transportation, production, use and waste management. The model includes ten phases of which eight contribute to emissions and two contribute to avoided emissions. Avoided emissions arise because produced biogas replaces products and energy that does not have to be produced when the biogas and digestate are produced. A detailed description of the model is given in the report: “Miljønytte og verdikjedeøkonomi ved biogassproduksjon, fase II - Matavfall og husdyrgjødsel” (Environmental effects and life cycle costs of producing biogas from food waste and manure, phase II) (Møller et al. 2013).

3.1 Adaptation of The Biogas Model to use in the DisBiogas project

Extra parameters were created in the first round of the analyses to enable the use of The Biogas Model for the specific scenarios that were to be analysed in the DisBiogas project. These parameters are shown in table 1.

Table 1: Parameters created to adapt The Biogas Model to the scenarios in the DisBiogas project

Parameter	**Base value**	**Comment**
Oppgradering_komprimering (Upgrading_compression)	0	On/off-parameter. Is put equal to 1 if upgraded biogas is compressed and transported. Base value: 0.
Komprimering_elbruk (Compression_eluse)	0.17	[kWh/Nm3] Source: PSA-technology from IEA-table in memo regarding upgrading from Tel Telk. Base value: 0.17. Assumed that this is valid for Nm3 biogas input to upgrading process.
Komprimering_trp (Compression_trp)	10	[km] Transport distance from biogas plant to central upgtrading plant.
Calculated parameters		
Komprimert_gass (Compressed_gas)	(1-0.001)*0.005	Amount of compressed biogas per m3 raw biogas. Assumed loss at compression is 0.1% of the amount non-compressed gas. 0.005 m3 compressed gas/Nm3 produced biogas. Source: HiT/Tel Tek in DisBiogass project.

In addition to the added parameters shown in table 1, project specific processes and product stages (SimaPro features) were added to The Biogas Model to enable analysis of the scenario including transportation of raw biogas via pipeline. These additions compromise processes for pipeline transport including infrastructure and upgrading of biogas including construction and energy necessary to pump the biogas through the pipeline. The extension of the pipeline was assumed to require 1.5 tons of polyethylene (PE) plastic per farm that is assumed to use the pipe line. This amount also includes the smaller pipes connecting the local biogas plant at the farm to the central pipeline. The pipeline has an expected life time of 40 years; hence the yearly impact from the construction of the pipeline which is allocated to the farm is 1 500 kg/40 years = 8.36 kg/year. It is assumed that the energy demand to pump the biogas through the pipeline is 0.05 kWh / Nm3.

3.2 Assumptions

Table 2 shows the parameter values that were changed in order to analyse pig and cattle manure in the DisBiogass project. A sensitivity analysis of pig manure, according to the conditions given in the scenarios, was also made. For all the other parameters base values from Møller et. al., (2013) are used.

Table 2: Parameter values for the analysis

Parameter	Scenario 0	Scenario 1	Scneario 2	Scenario 3	Scneario 4	Comment
Pig dependent parameters (main values)						
Sv_trp_behandling (Pig_trp_treatment)	-	10	-	-	-	[km] Transport of pig manure from storage at farm to biogas plant. Base value: 50 km.
Sv_metaninnh_biogass (Pig_methanecont_biogas)	0,65	0,65	0,65	0,65	0,65	Portion methane in produced biogas in the plant from pig manure. Base value 0.65. Source: Calsson and Uldal, 2009.
Sv_Nm3_per_tonn_TS (Pig_Nm3_per_ton_DM)	330	330	330	330	330	[Nm3/ton DM] Produced amound biogas (65% methane) per ton DM pig manure. Base value: 330 Nm3/ton DM. Source: Calsson and Uldal, 2009.
Sv_substrat_TS (Pig_substrate_DM)	0,06	0,06	0,06	0,06	0,06	DM-content in pig manure as substrate. Base value: 0.08. Source: Daugstad, 2011.
Pig dependent parameters (sensivity analysis)						
Sv_trp_behandling (Pig_trp_treatment)	-	10	-	-	-	[km] Transport of pig manure from storage at farm to biogas plant. Base value: 50 km.
Sv_metaninnh_biogass (Pig_methanecont_biogas)	0,65	0,65	0,65	0,65	0,65	Portion methane in produced biogas in the plant from pig manure. Base value 0.65. Source: Calsson and Uldal, 2009.
Sv_Nm3_per_tonn_TS (Pig_Nm3_per_ton_DM)	330	330	330	330	330	[Nm3/ton DM] Produced amound biogas (65% methane) per ton DM pig manure. Base value: 330 Nm3/ton DM. Source: Calsson and Uldal, 2009.
Sv_substrat_TS (Pig_substrate_DM)	0,08	0,08	0,08	0,08	0,08	DM-content in pig manure as substrate. Base value: 0.08. Source: Daugstad, 2011.
Cattle dependent parameters						
Sf_trp_behandling (Cattle_trp_treatment)	-	10	-	-	-	[km] Transport of cattle manure from storage at farm to biogas plant. Base value: 50 km.
Sf_metaninnh_biogass (Cattle_methanecont_biogas)	0,65	0,65	0,65	0,65	0,65	Portion methane in produced biogas in the plant from cattle manure. Base value 0.65. Source: Calsson and Uldal, 2009.
Sf_Nm3_per_tonn_TS (Cattle_Nm3_per_ton_DM)	260	260	260	260	260	[Nm3/ton DM] Produced amound biogas (65% methane) per ton DM cattle manure. Base value: 260 Nm3/ton DM. Source: Assessment performed by Tormod Briseid, Bioforsk, assessing different sources.
Sf_substrat_TS (Cattle_substrate_DM)	0,08	0,08	0,08	0,08	0,08	DM-content in cattle manure as substrate. Base value: 0.08. Source: Daugstad, 2011.
Substrate independent parameters						
Biogassanlegg_elforbruk (Biogasplant_eluse)	-	38	43	43	43	[kWh/ton DM] Electricity use in the biogas plant per ton DM input to the plant. Based on assessment of literature values. Source: Bernstad et. al., 2011. Base value: 75 kWh/ton DM.
Biogassanlegg_varmeforbruk (Biogasplant_heatuse)	-	280	333	333	333	[kWh/ton DM] Heat use in the biogas plant per ton DM input to the plant. Based on assessment of literature values. Source: Bernstad et. al., 2011. Base value: 250 kWh/ton DM.
Oppgradering_elforbruk (Upgrading_eluse)	-	0,26	-	0,26	0,26	[kWh/Nm3] Source: PSA-technology from IEA-table in memo regarding upgrading from TelTek. Base value 0.25. Assumed that this is valid for Nm3 biogas input to upgrading process.
Oppgradering_metantap (Upgrading_methaneloss)	-	0,001	-	0,001	0,001	Portion methane lost in the upgrading process. Normal values between 1 and 2, base value: 0,015 (1,5%, PSA-technology)
Trp_biogassanl_lager (Trp_biogasplant_storage)	-	10	-	-	-	[km] Transport distance from biogas plant to central upgrading plant.
Andel_v_erst_elektrisitet (Part_h_replace_el)	-	-	1	-	-	Part of the produced heat replacing electricity. Value between 0 and 1. Base value: 0. OBS! All "Part_h_replace"-parameteres have to add up to 1!
Andel_v_erst_fjernvarmemiks (Part_h_replace_dh)	-	-	-	-	-	Part of the produced heat replacing district heating. Value between 0 and 1. Base value: 0. OBS! All "Part_h_replace"-parameteres have to add up to 1!
Andel_v_erst_olje (Part_h_replace_fueloil)	-	-				Part of the produced heat replacing light fuel oil. Value between 0 and 1. Base value: 1. OBS! All "Part_h_replace"-parameteres have to add up to 1!
Oppgradering_komprimering (Upgrading_compression)	0	0	0	1	0	On/off-parameter. Is put equal to 1 if upgraded biogas is compressed and transported. Base value: 0.

4 Global Warming Potential results

All results are given for one farm with an assumed tonnage of 3 000 tons wet manure/year. Parameter values impacting the analysis are given in table 2.

4.1 Results for pig manure scenarios

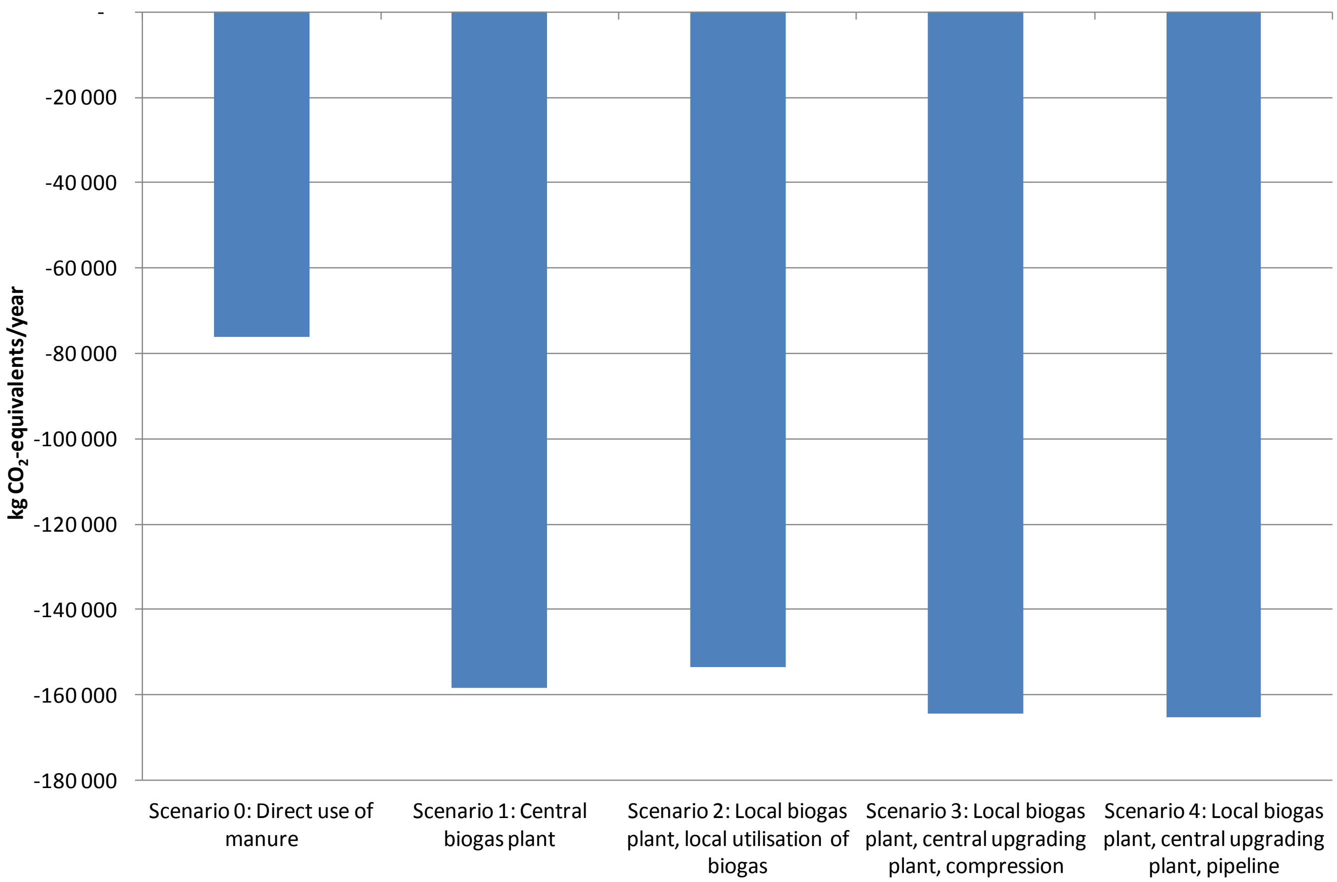


Figure 2: Net climate gas emissions for the pig manure scenarios

The results for pig manure are shown in Figure 2. The results show the net global warming potential for each of the five scenarios. The key findings are as follows:

- All scenarios where manure is utilised for biogas production (Scenarios 1-4) represent a considerable environmental advantage, and are considerably more advantageous compared to the scenario where manure is used directly by the farm as fertiliser (Scenario 0). Hence, the net environmental benefit (i.e. negative environmental load) is greater for Scenarios 1-4 than it is for Scenario 0.
- The four scenarios which include biogas production are not very different from each other in terms of overall environmental advantage; scenarios 1, 2, 3 and 4 give almost equal results.

- Use of biogas as a transport fuel seems to be better than using biogas for heating, and a local biogas plant combined with transporting biogas to a centralised upgrading plant is better than transporting manure to a centralised biogas/upgrading plant.
- Scenario 4, which is the scenario where raw biogas is transported in a pipe line from the farm to the centralised upgrading plant, comes out as the best scenario. However, the difference between transporting compressed biogas to a centralised upgrading plant and transporting raw biogas through a pipe line (scenario 4 and 3), is almost negligible.

Key points regarding the results in Figure 2:

- The figures are presented “per year” but this depends on an assumed level of production (tonnage of manure, ultimately the number of animals). As such, only the trends / differences between the results, rather than the absolute numbers, should be considered significant.
- Scenario 2, based on the local use of biogas, assumes that 100% of the heat is used. After an internal discussion, it was suggested that 70% may be a more realistic figure, and that a better like-for-like comparison might be achieved by also assuming a 70% “efficiency” for Scenario 2. This is depicted in figure 8.

Figure 3 shows how the environmental loads and advantages are distributed across the different life cycle phases for the five scenarios shown in Figure 2.

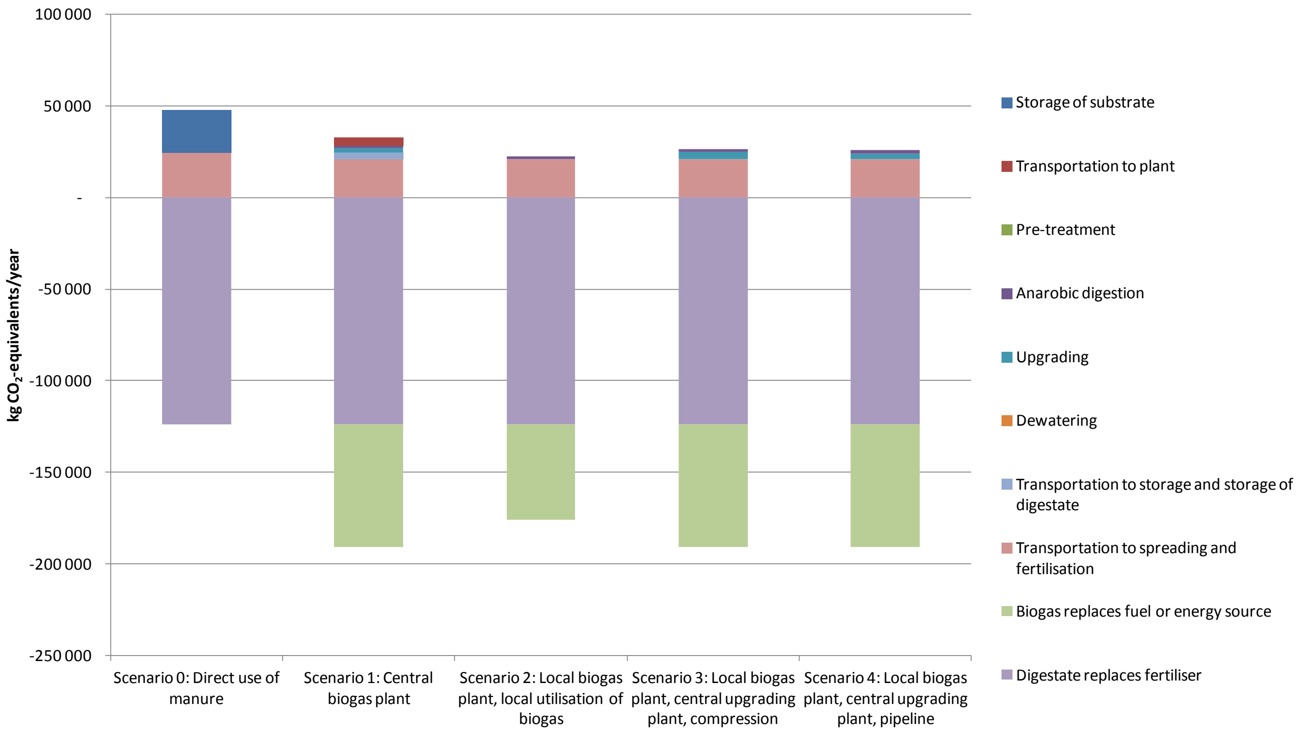


Figure 3: Climate gas emissions, shown for each life cycle stage, for the pig manure scenarios.

Key points from figure 3 are as follows:

- The additional environmental advantage of the scenarios which include biogas production, compared to the reference scenario, results from the replacement of a fuel / energy carrier.
- Emissions from digestate after spreading (N_2O-emissions) are the single most important environmental burden for all scenarios.
- The amount of replaced mineral fertiliser and storage of C in the soil for fertiliser and digestate result in high gain for all scenarios.
- Transportation of raw biogas in pipe line (Scenario 4) is the “best” scenario, but the difference compared to transportation of compressed gas by truck (Scenario 3) is almost negligible. This is because transport of biogas is a small part of the total environmental loads.

An examination of the sensitivity of the pig results to the key parameter DM content was carried out. Figure 4 shows the overall environmental impact of each scenario in the same format as before. The parameters changed related to the dry matter content of the manure itself, as follows (table 3):

Table 3: Changed parameters for sensitivity analysis of pig manure

	Base scenarios	**Sensitivity scenarios**
Amount of biogas produced per ton (dry matter) of manure	330 Nm3 / ton DM	330 Nm3 / ton DM
Dry matter content of manure	0.06	0.08

The base and sensitivity scenarios have the same “efficiency” of biogas production (amount of biogas produced per ton dry matter manure), but the base scenario has a lower dry matter content in the manure. This difference in dry matter content results in biogas production per mass of actual (wet-weight) manure produced that is marginally higher for the sensitivity scenarios than for the base scenarios.

The sensitivity results show that all five scenarios are considerably more advantageous, from the environmental standpoint, than the base scenarios. The overall trends do not change (scenarios 1, 2, 3 and 4 are approximately equivalent to each other). The marked increase in environmental advantage, however, suggests that the overall results are quite sensitive to the dry matter content in the manure.

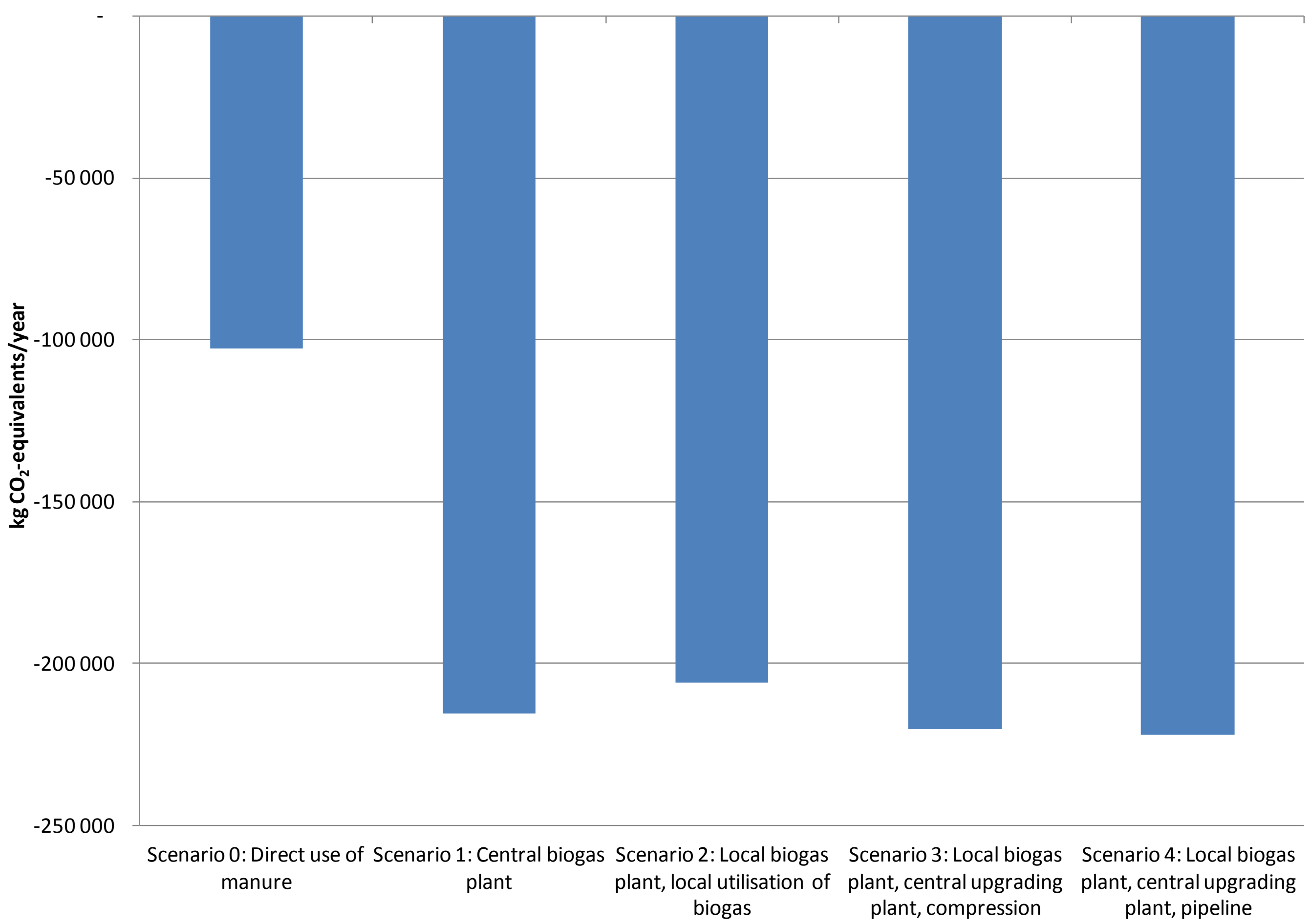


Figure 4: Net climate gas emissions for the pig manure scenarios, sensitivity analysis (increased DM content of manure)

The breakdown of environmental loads and advantages for the sensitivity cases is shown in Figure 5. Comparing this with Figure 3 for the base cases shows that the elements of environmental burden (transport to spreading and fertilisation, and storage) increase a little for the sensitivity case, but that this is more than compensated for by the increases in advantage, arising from the replacement of energy carriers and (in particular) fertiliser.

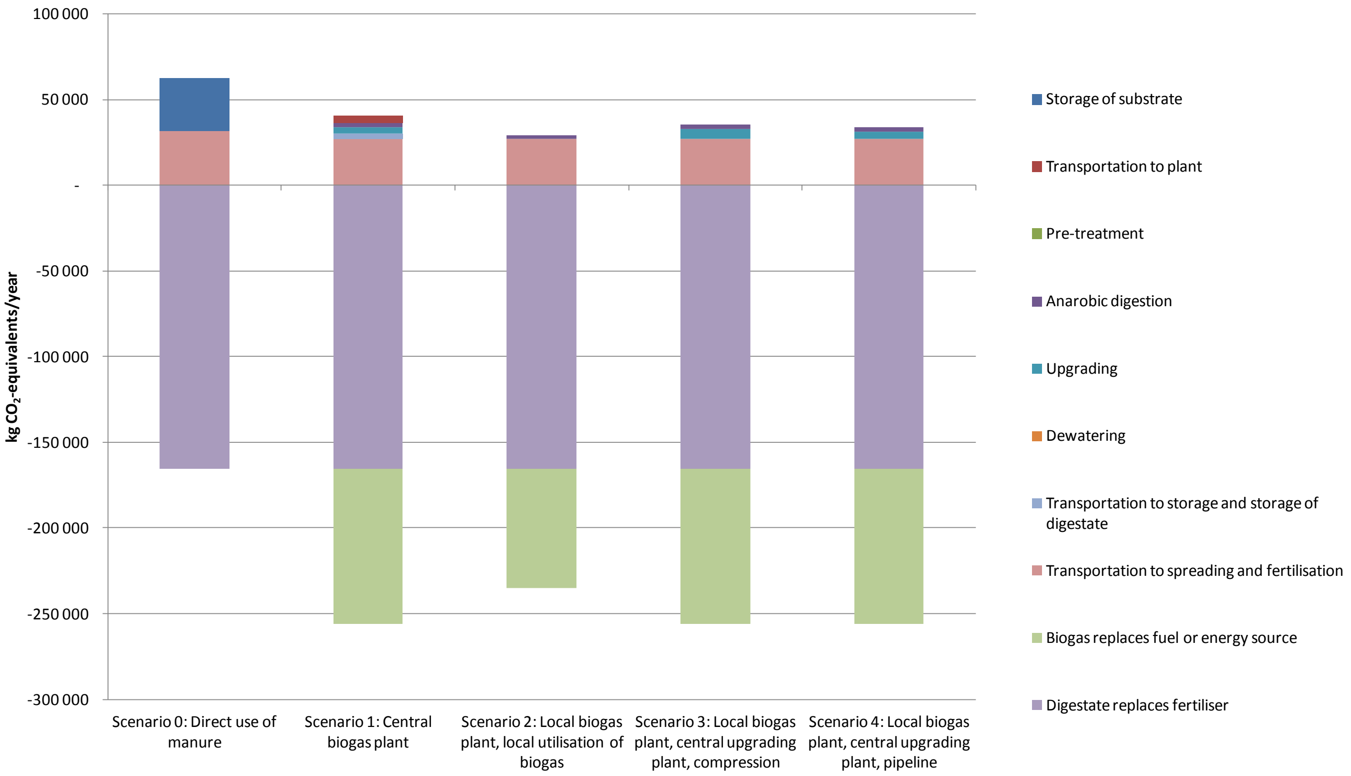


Figure 5: Climate gas emissions shown for each life cycle stage, for the pig manure scenarios, sensitivity analysis (increased DM content of manure).

4.2 Results for cattle manure scenarios

As for the pig results, the overall “per year” figures for treatment of cattle manure are based on an assumed manure tonnage, hence only the trends between the results (rather than the absolute numbers) should be considered particularly meaningful. The parameters for the cattle analyses were as in the previous Ostfold Research documentation report (OR 34.12, Møller et al., 2012). Parameters that were changed are shown in Table 2.

The overall environmental results for treatment of cattle manure are shown in Figure 6. These results show that, for all scenarios, the environmental advantage appears to be reduced compared to the pig scenarios. As for the pig results, the results for Scenario 2 assume 100% “efficiency” in the use of produced biogas.

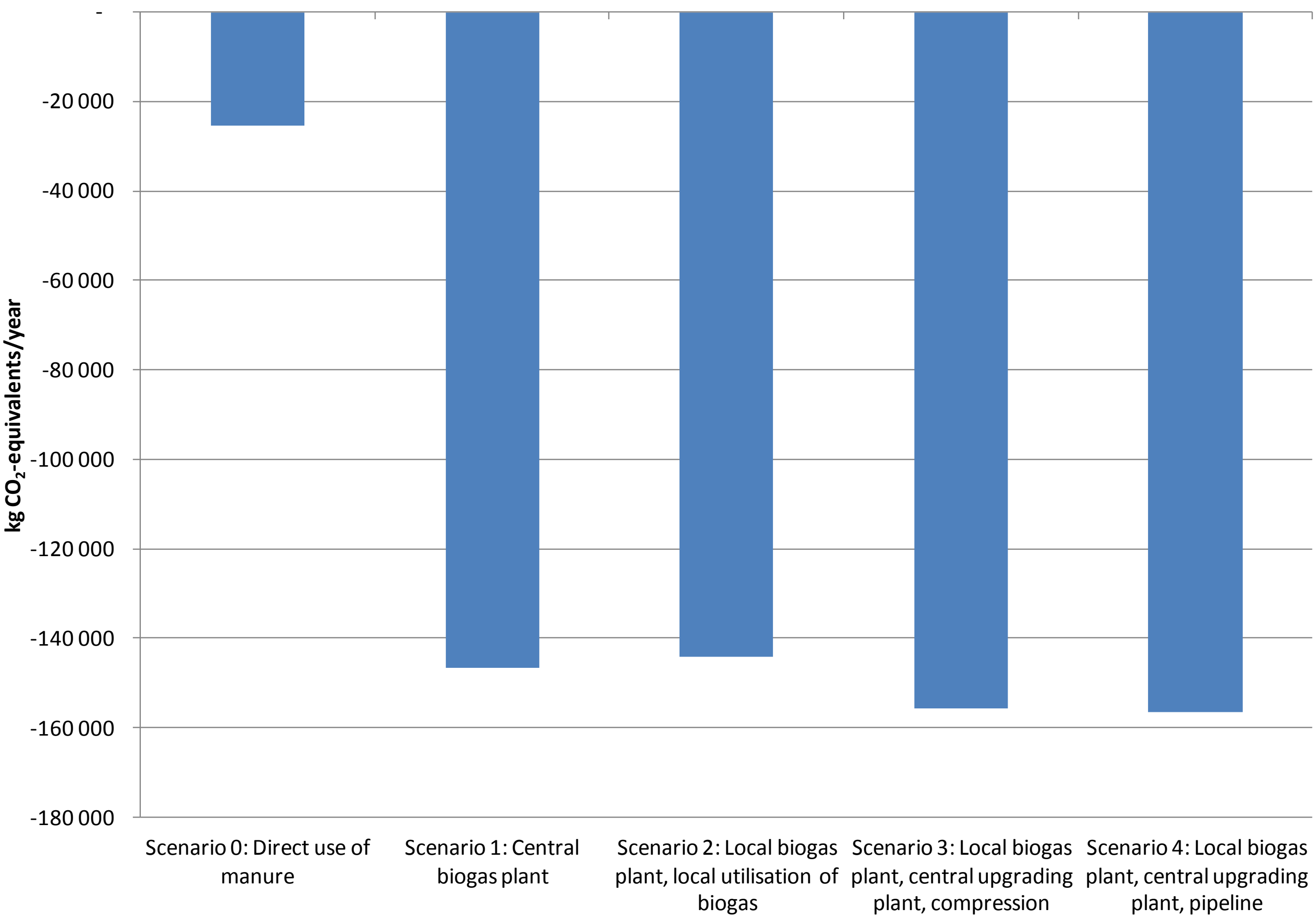


Figure 6: Net climate gas emissions for the cattle manure scenarios

Figure 7 shows the environmental burdens and benefits associated with the different process steps as shown previously for pig manure. This would appear to indicate that the small reduction in overall environmental advantage for cattle can be attributed to an increase in burdens (from the various transport and storage steps) that exceed an increment in the environmental benefits from replacement of fuel and fertiliser increase in the cattle scenarios.

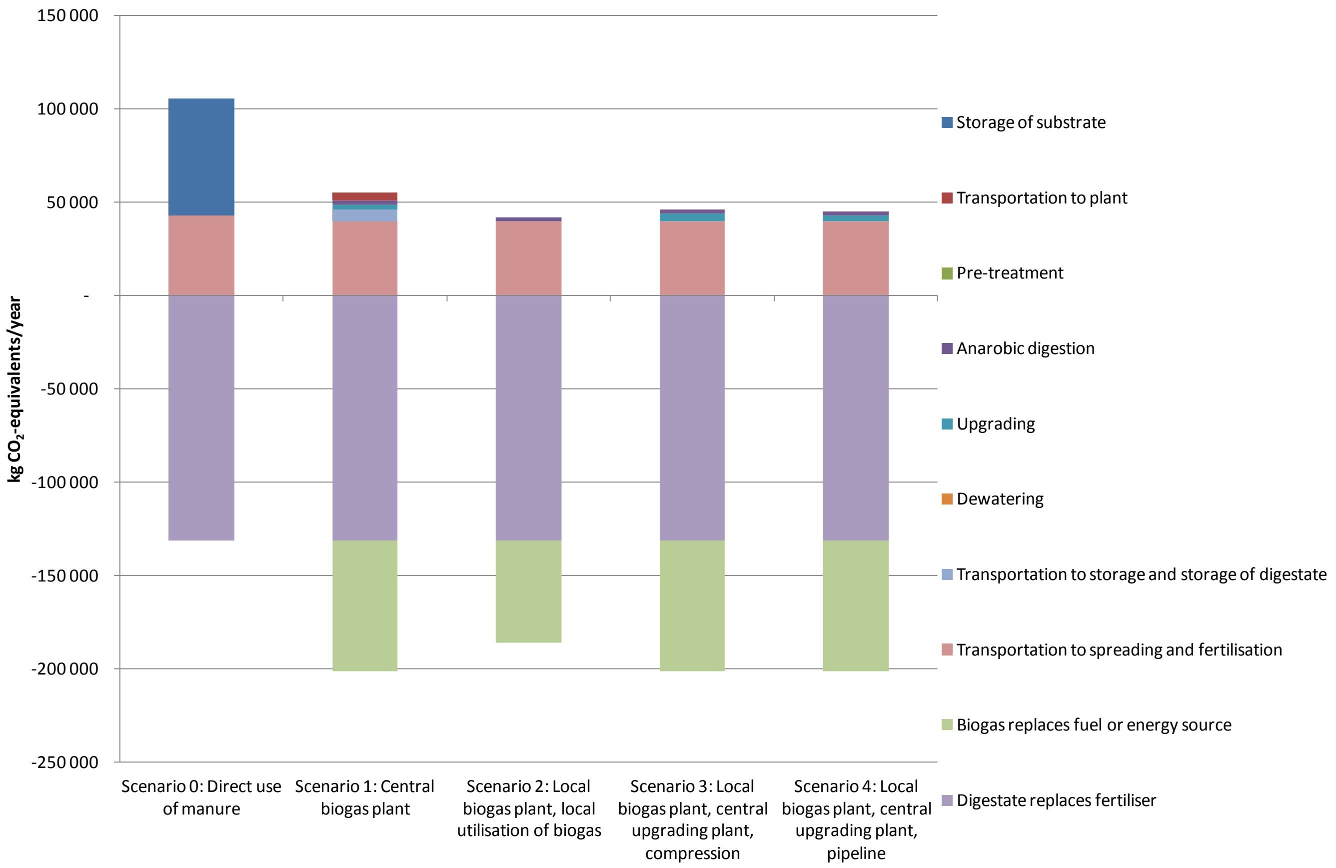


Figure 7: Climate gas emissions, shown for each life cycle stage, for cattle manure

In summary the trends for the cattle scenarios are quite similar as for the pig scenarios. Also the cattle scenarios show that:

- All four scenarios which include a biogas plant result in higher net benefits than the reference scenario.
- It is environmentally better to use the biogas as fuel for transport than to use it for heating.
- Central and local localisation of a biogas plant with a centrally placed upgrading plant has approximately the same net environmental benefit.
- Environmentally there is only a marginal difference between compression and transportation of biogas by truck versus transportation of raw biogas through a pipeline.

4.3 Sensitivity analysis

Figure 8 shows that the assumed percentage of heat utilisation is important. With an assumed 100% utilisation scenario 2 obtains almost equal net emissions as the other scenarios which upgrade the biogas at a central upgrading plant. By assuming that only 70% can be utilised for heating the net gains decreases in scenario 2. Hence, the result largely depends on how much of the produced heath can replace other fuels.

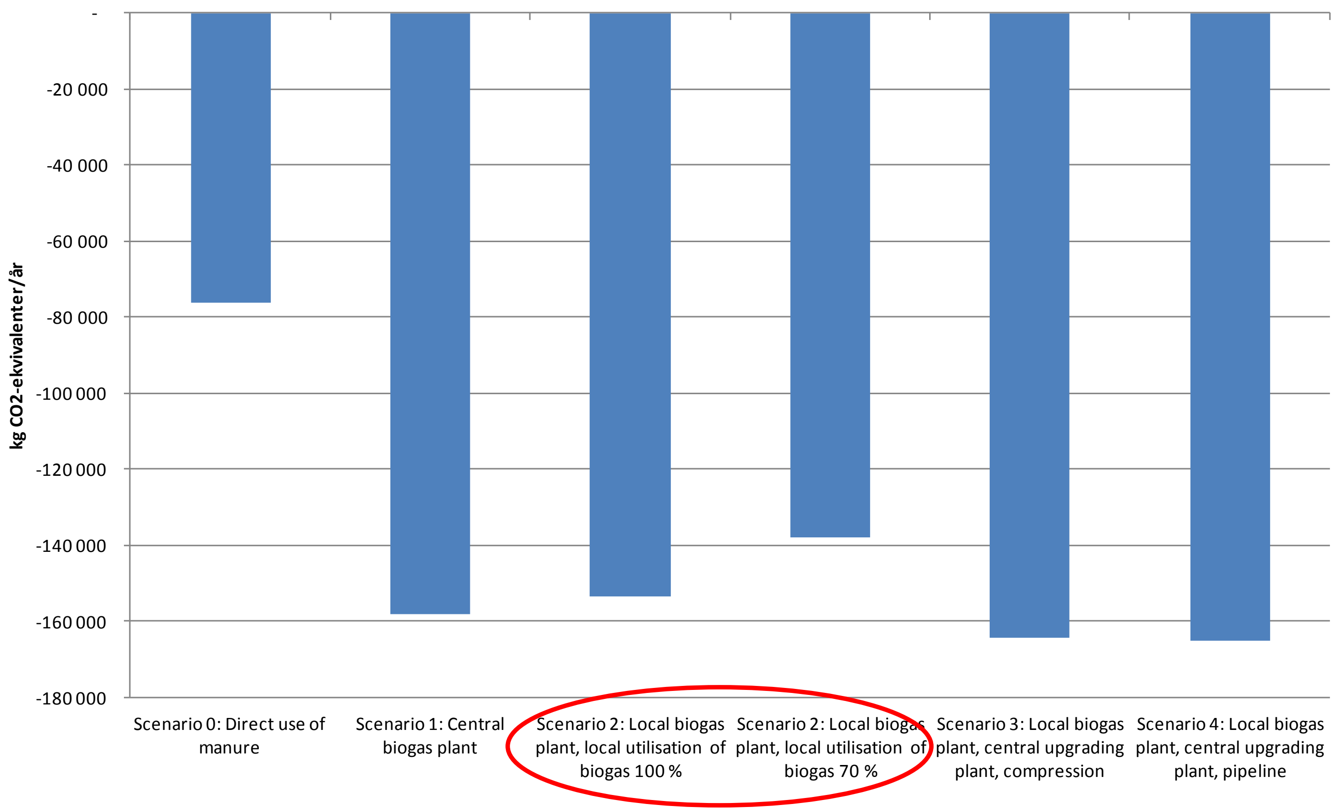


Figure 8: Net climate gas emissions for the pig manure scenarios, heat scenario

In addition to the sensitivity analysis of the pig manure regarding the heat utilisation, analyses where the various transport distances and energy use for compression of biogas were done for scenario 1 and 3. The results are shown in Figure 9.

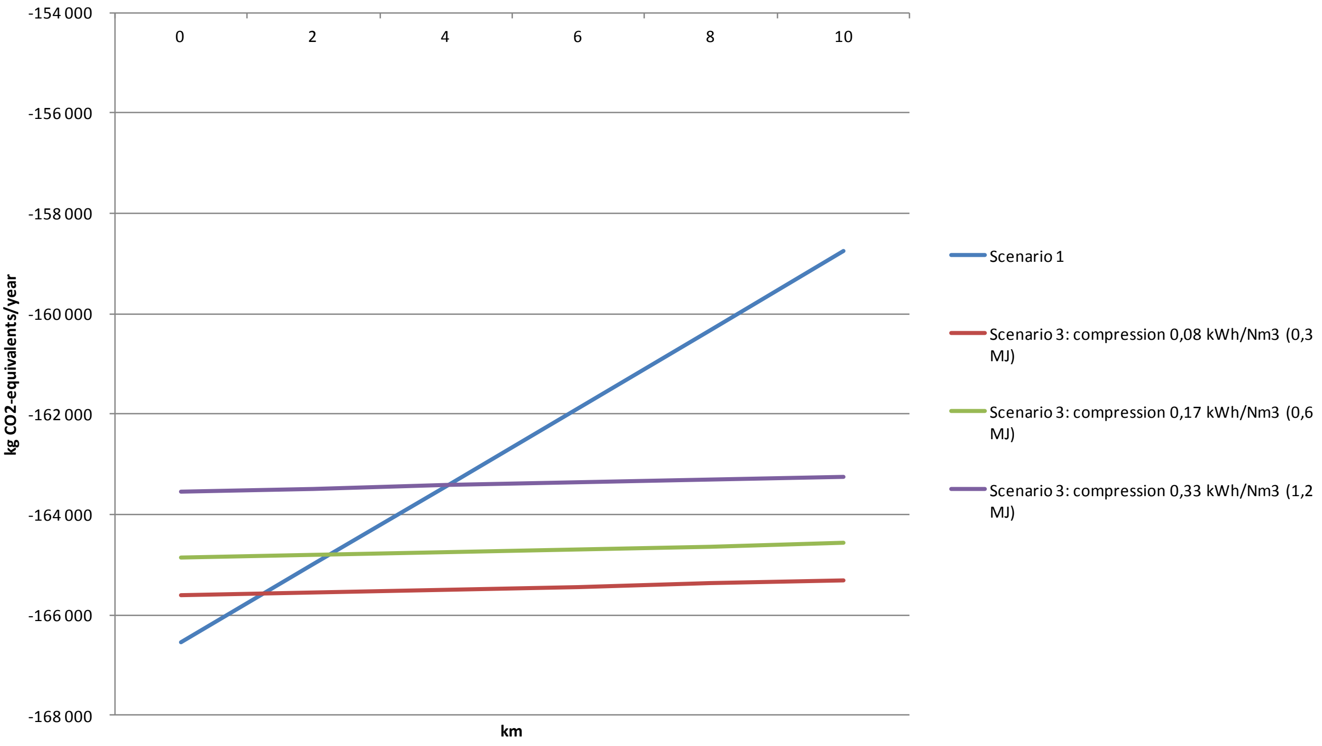


Figure 9: Relationship between transportation distances and energy use for compression of biogas

The transport distance for compressed gas has little significance. The transport distance for untreated manure between the farm and the centrally placed biogas plant has larger significance as the amount of manure has to be transported to the plant, and back to the farm again. Given the assumptions of the analysis and the assumed level of compression energy of 0.17 kWh / Nm^3, Scenario 3 will be better than Scenario 1, as long as the transport distance for compressed gas and untreated manure is larger than 3 km.

5 Economics

As a complement to the model focusing on environmental impacts of biogas production through the value chain, an economic value chain model was developed. The economic model was developed to easily facilitate the decision processes of investors, governments and farmers when considering establishment of central and local (farm) biogas plants. The economic model aims to facilitate these kinds of decision making processes, in addition to highlighting important economic/financial aspects for all included actors. The economic model was developed to enable comprehensive decision making processes including both environmental and economic factors. Many aspects of such a decision process can be challenging. A primary goal of the economic model is therefore to illustrate that despite high input costs when establishing biogas plants, the value chain of biogas production might often be profitable. The economic model is developed as a tool in Microsoft Excel. The tool allows user calculations of various operational and sales aspects.

5.1 Assumptions

Utilising The Biogas Model for the economic analysis of the four scenarios described previously required some adapting of the original model. The economic analysis of the scenarios only considers the cost structure of the farm when utilising manure from the farm as an input to biogas production. The other actors in the value chain are not considered here (central biogas plant, upgrading plant). Economic assumptions are outlined in the following. Scenario 0, the reference scenario, is not analysed and is assumed to have a value of zero. Only pig manure is considered in the economic analysis.

According to the scenario descriptions given in chapter 2 the following investments in infrastructure are required for each scenario. The costs are given in terms of costs for the farmer.

Table 4: Infrastructure costs

Investment object	NOK	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Manure/digestate storage	500 000	x	x		
Gas boiler	150 000		x		
Compression equipment	50 000			x	
Anaerboic digester	600 000		x	x	x
Pipe line connection	50 000				x

Investment support given by Enova is 40% of total investment cost reducing total investment costs per scenario. The required rate of return is 7%, and the repayment period is 15 years.

Table 5: Infrastructure investment costs per scenario

	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Manure/digestate storage	500 000	500 000	-	-
Gas boiler	-	150 000	-	-
Compression equipment	-	-	50 000	-
Anaerboic digester	-	600 000	600 000	600 000
Pipe line connection	-	-	-	50 000
Total	500 000	1 250 000	650 000	650 000
Investment subsidy	40 %	40 %	40 %	40 %
Total including subsidy	300 000	750 000	390 000	390 000

The above given costs regards investments required for the infrastructure at the farms. Additionally, there will be operational costs. Assumptions regarding these are summed here:

- Transportation costs are allocated to the central biogas plant or central upgrading plant. Hence it is assumed that the transportation cost of manure and digestate, and transportation cost for compressed gas either by truck or pipe line, is not a cost that the farmer has to bear.
- In scenario 1, where the farmer sends manure to a central biogas plant and gets digestate returned, it is assumed that the farmer is given compensation for storing the manure at the farm (35 NOK/m^3), and that the farmer pays for the digestate he gets returned (10 NOK/ m^3).
- Using digestate instead of buying mineral fertilizer gives avoided costs of 43 NOK/m^3 for all scenarios.
- Energy use is based on the values given in table 2. For the economic analysis (per wet weight manure) this results in electricity use of 2.58 kWh/m^3 and heat use of 19.98 kWh/m^3. Cost of electricity is 0.7 NOK/kWh and cost of process heath 0.4 NOK/kWh.
- Yearly maintenance costs are assumed to be 2% of total investment cost.
- It is assumed that the sales price for compressed gas is 582 NOK/m^3 and for raw gas at atmospheric pressure is 3 NOK/m^3.
- Additionally it is assumed that 100% of the heat produced in scenario 2, which is not used internally at the farm, is sold. It is assumed that the sales price for this heat is the same as the cost of heat, 0.4 NOK/kWh.

Based on values given in table 2 and the above assumptions annual values for input and output energy are given in table 6.

Table 6: Annual energy input and output for the economic analysis of the pig scenarios

	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Manure				
Tons/year	3000	3000	3000	3000
Digestate				
Received (tons/year)	3000	3000	3000	3000
Biogas				
kWh/year		268 725	268 725	268 725
- produced heat	-	228 416	-	-
- sold heat (kWh/year)	-	168 476	-	-
- compressed biogas (m3/year)	-	-	208	-
- raw biogas (m3/year)	-	-	-	41 550
Purchased process energy				
- electricity (kWh/year)	-	7 740	7 740	7 740
- heat (kWh/year)	-	-	59 940	59 940

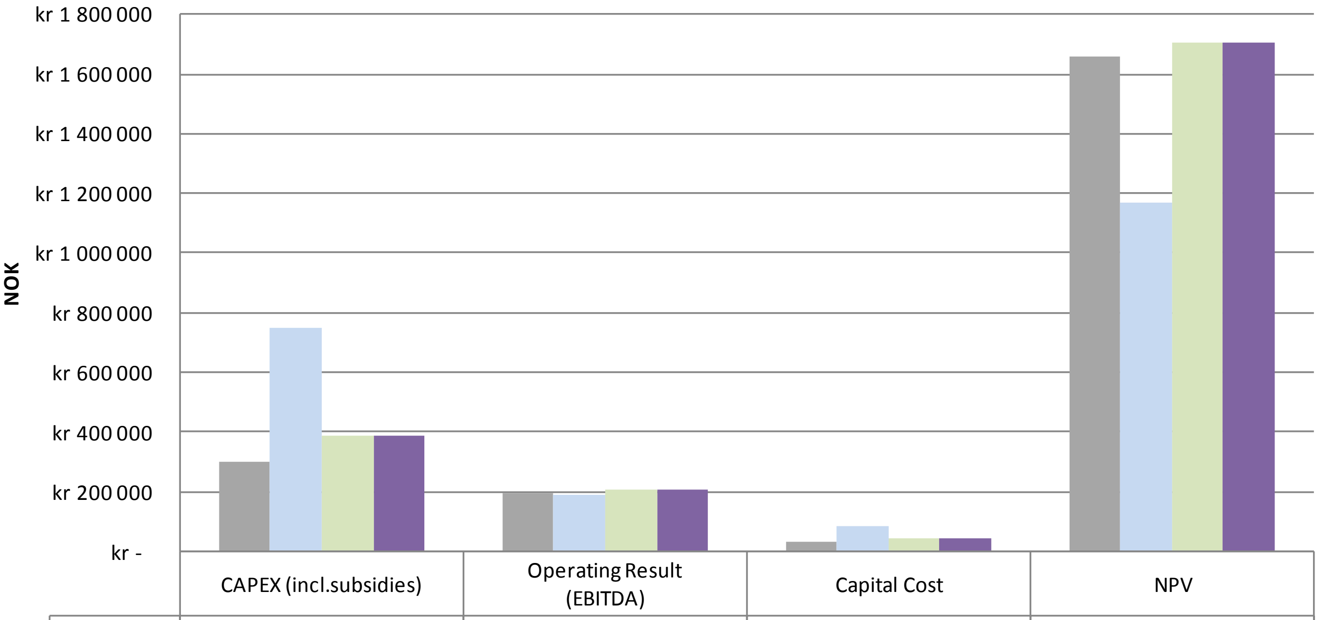
5.2 Economic results for pig manure

The description of costs and revenue gives the following annual cash flow for treatment of pig manure:

Table 7: Yearly cash flow

Revenues	Sceanario 1	Sceanario 2	Sceanario 3	Sceanario 4
Storage compensation from biogas plant	105 000	-	-	-
Avoided expences by using digestate	129 000	129 000	129 000	129 000
Sales revenues	-	67 390	120 805	120 926
Avoided expences local heating	-	23 976	-	-
Total revenues	234 000	220 366	249 805	249 926
Costs				
Purchase of digestate	30 000	-	-	-
Maintenance	10 000	25 000	13 000	13 000
Electricity	-	5 418	5 418	5 418
Process heat	-	-	23 976	23 976
Total costs	40 000	30 418	42 394	42 394
Operating result (EBITDA)	194 000	189 948	207 411	207 532
Capital cost	33 333	83 333	43 333	43 333
Operation result (EBIT)	160 667	106 615	164 078	164 199

Operating result (EBITDA) refers to earnings before interest, taxes, depreciation and amortization; hence the EBITDA result shows the earnings for each scenario before interest, taxes, depreciation and amortization. This value gives an indication of the current operational profitability for each scenario. The operating result (EBIT) refers to earnings before interest and taxes, i.e. it is the operational result after deducting capital cost. Table 7 does not include investment costs (CAPEX). This is included in figure 10.



	CAPEX (incl.subsidies)	Operating Result (EBITDA)	Capital Cost	NPV
Scenario 1	kr 300 000	kr 194 000	kr 33 333	kr 1 660 935
Scenario 2	kr 750 000	kr 189 948	kr 83 333	kr 1 169 982
Scenario 3	kr 390 000	kr 207 411	kr 43 333	kr 1 706 494
Scenario 4	kr 390 000	kr 207 532	kr 43 333	kr 1 707 716

Figure 10: Economic results for the pig manure scenarios

Figure 10 shows the economic analysis for pig manure. In all of the economic results presented here, the reference scenario (0) has Net Present Value of zero. Figure 10 shows the investment cost (CAPEX), the annual net operating return (operating result EBITDA), the annual cost of capital and the net present value (NPV) for the four non-base scenarios.

Key points regarding figure 10:

- Scenario 1 has the lowest investment cost. This is because the farm delivers manure to a central biogas plant. The total cost for scenario 1 is therefore higher than what is presented here, but the scope of the analysis is limited to the farm's finances. The net present value is correspondently also high. This indicates that for the farm it is profitable to deliver manure and pay to get digestate delivered back given that the farm is compensated for storing manure at the farm.
- Scenario 2 involves a substantial capital outlay and consequent capital cost. The net present value is the lowest considering all the scenarios indicating that even though the farm can sell excess heat, scenario 2 gives the lowest profitability. The farm in scenario 2 would therefore benefit from selling the produced biogas to a central upgrading plant, instead of utilising it locally for heat.
- Scenarios 3 and 4 have nearly identical costs and revenues, and generate the highest net present values.

Figure 11 breaks the results from figure 10 into the various cost and revenue elements.

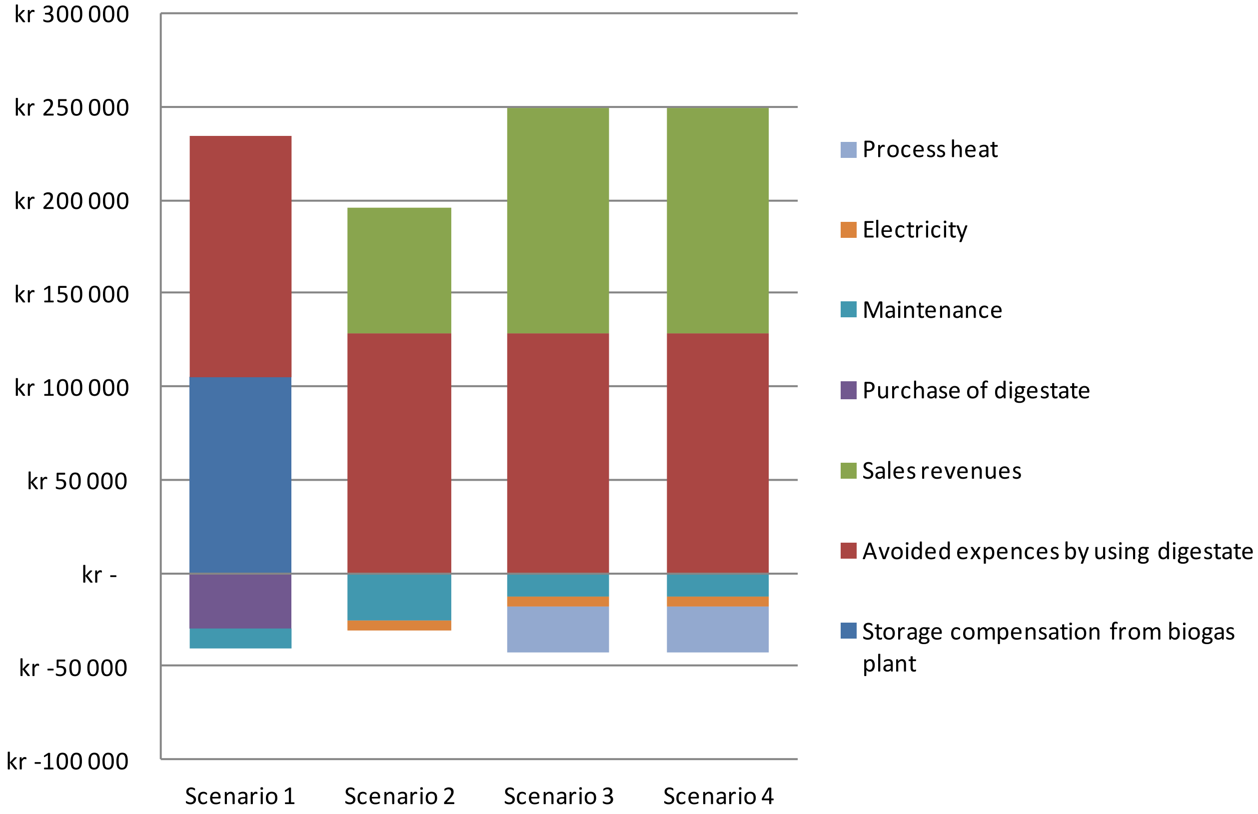


Figure 11: Annual cash flow distributed by cost/revenue element for the pig manure scenarios.

Figure 11 shows that what differentiates the scenarios most is the price of what the biogas is assumed to replace. For scenarios 3 and 4, in which the biogas is sold to a central upgrading plant, the sales revenues are considerably higher than the sales revenues for scenario 2 where excess heat is sold. Scenario 1 does not gain sales revenues directly, but are compensated by the biogas plant for storing manure. The compensation is lower than the sales revenues in scenarios 3 and 4, and higher than sales revenues in scenario 2. Scenario 2 has the lowest operational costs, largely due to not having to buy process heat. Operational costs in scenarios 1, 3 and 4 have little difference, but are made up of different elements. The highest contributor to operational costs in scenario 1 is purchase of digestate, whereas in scenarios 3 and 4 it is process heat that is the largest contributor to costs.

Life cycle cost (LCC) is a measure for total costs accumulated during the life time of an investment. LCC includes investment costs and operational costs in the investment year, in addition to interest-adjusted operational costs for the life time of the investment (15 years). It is a measure commonly used to reveal that operational costs impact the total costs of an investment; an investment with low investment cost and higher operational costs compared to an investment with high investment cost and lower operational costs is not necessarily more advantageous when considering the life time of the investment. The LCC analysis performed in this analysis shows that scenario 1 has the lowest life cycle costs closely followed by Scenarios 3 and 4. Scenario 2 generates the highest life cycle costs. Figure 12 shows LCC and NPV-results for each scenario.

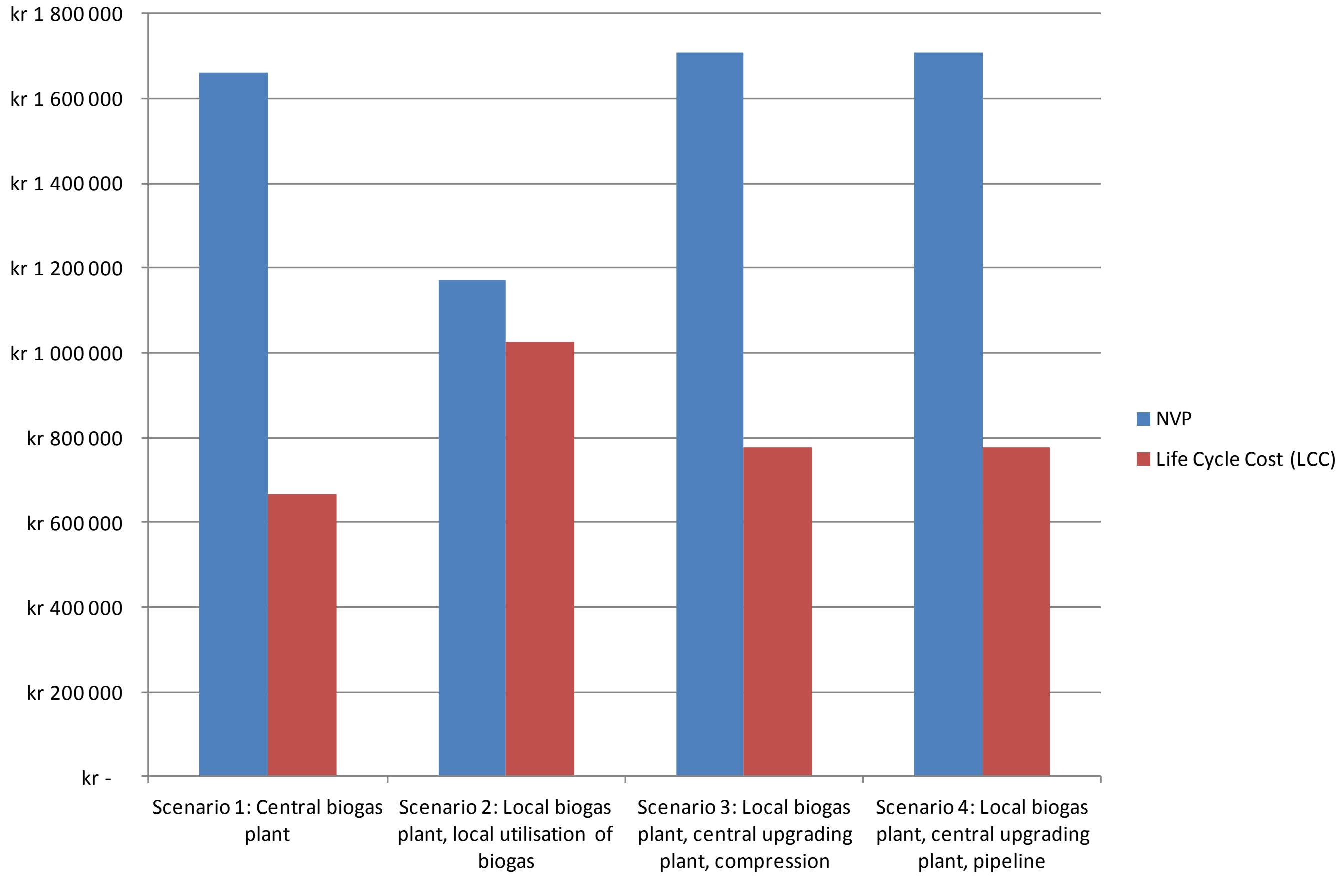


Figure 12: LCC and NPV for the pig manure scenarios

Figure 12 confirms what has already been shown in various tables and figures before this; Scenarios 1, 3 and 4 are the most profitable scenarios in terms of economics. As scenario 2 results in both the highest life cycle costs (NOK 1 027 045) and the lowest net present value of the four analysed scenarios, it can be concluded that this is the least attractive scenario. Scenarios 1, 3 and 4 give similar economic results; scenario 1 has lower life cycle cost (NOK 664 317) and lower net present value, whereas scenario 3 and 4 are more or less identical with slightly higher life cycle costs (NOK 776 121) than scenario 1, but the scenarios also have a higher net present value.

6 Discussion and conclusions - Combining GWP results with economic results

An articulated goal when developing the economic compliment to The Biogas Model was to be able to give decision support regarding biogas production not only on an environmental level, but also on an economic level. To do so the GWP results for treatment of pig manure are combined with the corresponding economic results. An overall picture of the attractiveness of the various scenarios can be found by plotting the environmental and economic results on a single set of axes, as shown in Figure 13. Criteria for preferring one or several scenarios over others are: highest possible NVP and highest possible negative climate emissions. Figure 13 confirms the general trends seen through this analysis and report: The scenarios where biogas is transported and upgraded, regardless of transportation mode, are the most advantageous scenarios, both in terms of GWP and economics. Key points are as follows:

- All scenarios which include a biogas plant are preferable to the reference scenario.
- Use of biogas as a fuel for transport is better than using the biogas for heating.
- A local biogas plant and transportation of biogas to a central upgrading plant is better than transporting manure to a biogas/upgrading plant.
- The difference between Scenarios 3 (transport of compressed biogas by truck) and 4 (pipe line transport of biogas) are negligible both in terms of GWP and economics. However, transportation of compressed raw gas is not an established technology, and the cost estimate has higher uncertainty than pipeline transport.

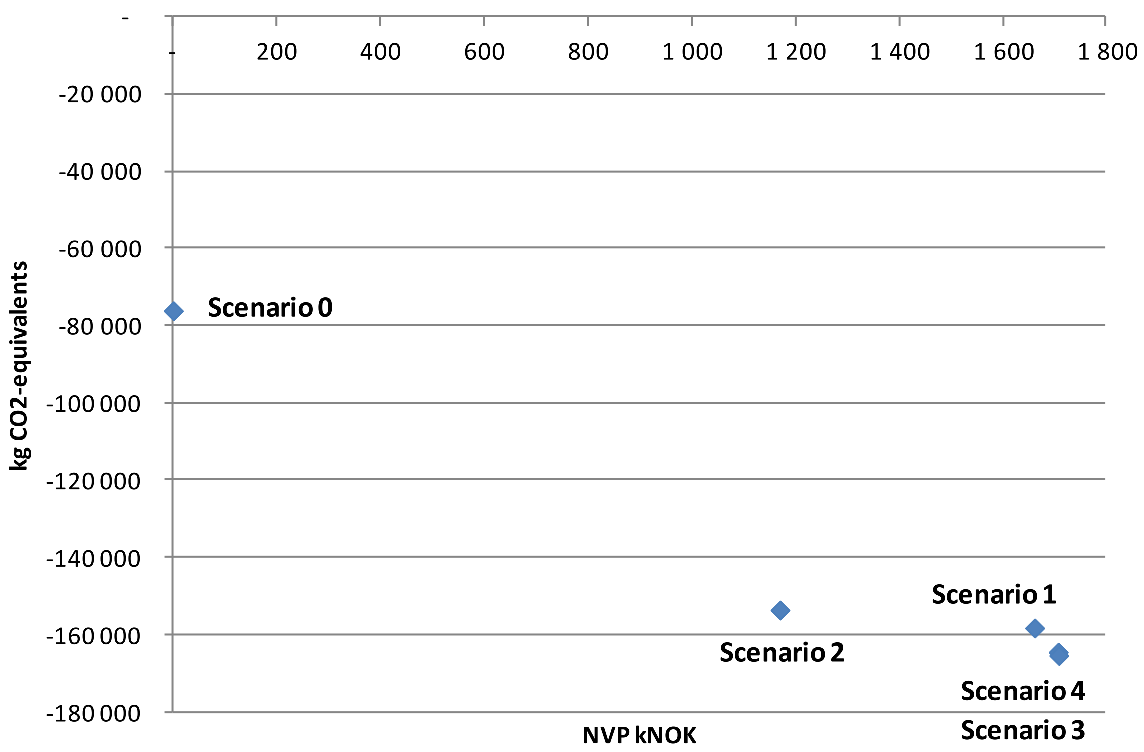


Figure 13: Combined GWP and economic results for pig manure

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Østfoldforskning
SUSTAINABLE INNOVATION

Gamle Beddingvei 2B
N-1671 Kråkerøy
Telephone: +47 69 35 11 00
Fax: +47 69 34 24 94
firmapost@ostfoldforskning.no
www.ostfoldforskning.no

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