

ECONOMIC MODELLING OF ANAEROBIC DIGESTION/ BIOGAS INSTALLATIONS IN A RANGE OF RURAL SCENARIOS IN CORNWALL

- Eight Scenarios were studied; 7 farm based scenario's and 1 community installation.
- 5 of the 7 scenario's were studied using the base case alone (current herd sizes and acreage). In each case there were a number of variables that could have been explored, but this would have warranted a much larger study.
- Scenario 6 and 7 included options in addition to the base case. Scenario 6 studied the base case and then the base case +7,135 t/a energy crops. Scenario 7 has three options; a base case, base + 1000t/a of food waste and base case + 4000 t/a of food waste.
- As scenario 7 originally proved to be the smallest of the installations, we asked IBBK to recalculate the model to explore the amount of food waste required to make the plant viable. This also gave the opportunity to explain the legislative requirements of taking in food waste.



Case study 1: 75kW AD plant using slurry and energy crops

Case study 1 is a dairy farm. Unchopped straw and sand are used as bedding material for the cows. A shortage of straw in the area and ultimately high prices, together with the benefit to acidic soil conditions, is why the farmer uses sand. Miscanthus is not favoured as an alternative, as the farmer sees a risk that it starts degrading and gets warm when used as animal bedding.

The main substrates for biogas production in this scenario are:

- 1,100 t/a dairy cow slurry (Only slurry without high amounts of sand)
- 100 t/a straw
- 500 t/a grass silage
- 650 t/a maize silage

Sand is a common problem in biogas production (sinking layer formation, abrasion of technical material). There is technology available that can cope with high amounts of sand; but due to the high investment costs this is not viable for such a small plant. The economic modelling indicates a high risk of business losses when investing in the planned AD plant. A grant of minimum 90% would be necessary to achieve viability. However it will not be possible to claim 2xROC's when taking a grant, even 100% grant would not enable any profitability.

The modelling is based only on the manure without high amounts of sand. Replacement of sand with straw would require 100 t/a straw and would double both the available amount of slurry for biogas generation and the digested straw. This would increase biogas production by 20% to around 820 m³/d. However, the AD plant would still not be economically viable.



Case study 1: 75kW AD plant using slurry and energy crops

Grants

Total Investment Costs: £506,921	Operation/Main tenance/Capital Costs [£/a]	Revenue [£/a]	Business Profit/Los- ses [£/a]	Return on Invest- ment	Reflux Capital [years]	Payback Period [years]
Without grant:	119,219	69,854	-49,364	-2.7%	83.7	negative
Necessary Grant to achieve a shorter Payback Period. Assumption: 2*ROCs still possible when taking the grant.						
Grant: 89%	£451,515	69,853	69,854	+1	7.0%	9.1
93%	£468,902	67,952	69,854	+1,902	12.0%	6.3
95%	£481,017	66,628	69,854	+3,227	19.5%	4.3
Necessary Grant to achieve a shorter Payback Period. Assumption: 1*ROCs only possible when taking the grant.						
Grant: < 100%		52,159	losses			negative
100%	£506,921	63,796	52,159	-11,637	-	0

The sensitivity analysis shows that at this site, a reduction in the investment cost has the highest potential to increase viability. However, none of the studied parameter variations results in positive Business Profit.

In order to achieve a minimum Business Profit, investment costs would need to be reduced by 64% to £183,000, which is rather unlikely. With regards to the electricity value, a minimum profit would be achieved if electricity was worth 27.1 p/kWh (all other parameters unchanged), which currently is not realistic.



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Case Study 2: 499 kW AD plant with energy crops

Site 2 is a vegetable farm which uses poultry manure from a neighbouring farm as the main fertiliser. Both wet and dry digestion are possible technical options. With dry digestion in batch-operated box-type fermenters.

The main substrates for biogas production are:

Cow slurry	1,500 t/a	Grass silage	1,955 t/a
Poultry Manure 1	1,350 t/a	Stock feed potatoes	500 t/a
Poultry Manure 2	500 t/a	Straw	100 t/a
Maize silage	4,500 t/a		

Dry digestion might be favourable due to the high DM-content of the substrate mix, the high amount of available straw and presence of poultry manure. Digestion of higher amounts of lignocellulosic material is often regarded unsuitable in wet digestion, since phase-separation takes place, with the lignocellulosic material floating on top. Eventually, lignocellulosic material might also form a sinking layer and might cause clogging of the outflow pipes. But with dry digestion such problems do not have to be dealt with.

However, dry digestion was offered at a very high price. Around three times higher investment costs would be necessary compared to the proposed wet digestion solution in the following. Even with high grants, the dry digestion concept was far away from being economically viable. Dry digestion does require higher investment in mainland Europe as well, but the difference to wet digestion is less distinct. As dry digestion needs less maintenance, has lower electricity demand, is more robust than wet digestion and can also treat substrates that need to be excluded in wet digestion. The concrete price is higher in the UK, which might be a key reason for the very high UK offer.



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Case Study 2: 499 kW AD plant with energy crops

Grants

Total Investment Costs:		Operation/Main tenance/Capital Costs [£/a]	Revenue [£/a]	Business Profit/Los- ses [£/a]	Return on Invest- ment	Reflux Capital [years]	Payback Period [years]
£1,364,085							
Without grant:		476,692	505,889	+29,198	9.1%	7.8	10.7
Necessary Grant to achieve a shorter Payback Period. Assumption: 2*ROCs still possible when taking the grant.							
Grant: 19%	£262,450	448,559	505,889	+57,331	12.2%	6.3	8.0
25%	£341,947	440,037	505,889	+65,852	13.4%	5.8	7.3
45%	£611,383	411,156	505,889	+94,734	19.6%	4.3	5.0
Necessary Grant to achieve a shorter Payback Period. Assumption: 1*ROCs only possible when taking the grant.							
Grant: 78%	£1,063,157	362,728	362,729	+1	7.0%	9.3	13.9
85%	£1,161,927	352,141	362,729	+10,588	12.2%	6.3	8.0
90%	£1,225,767	345,298	362,729	+17,431	19.6%	4.3	5.0

The sensitivity analysis points out the decisive influence of the electricity value on the profitability of this project. A 10% higher electricity value (= 16.0 p/kWh) would increase the total Business Profit by £46,130 per year to total £75,328 per year.



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Case Study 3: 190 kW AD plant with slurry and grass silage

Site 3 plans to place an AD plant close to an industrial site with heating, cooling and electricity requirements (offices and light industry, currently in development).

The main substrates for biogas production are:

Cow Manure (Half stackable)	563 t/a
Grass silage	3,600 t/a
Straw	100 t/a

Due to the high DM content of the input mix and especially due to the high amount of lignocellulosic material, dry digestion e.g. in box-type batch fermenters instead of wet digestion would be optimum choice with regards to process technology. Wet digestion has a risk of phase-separation, with lignocellulosic material floating on top of the liquid.

However, as with Scenario 2 of this study, dry digestion was offered at very high cost, making economic viability fully out of reach. While straw would be favourable in dry digestion as it would increase the structure of the substrate stack, only a limited amount should be used in wet digestion, as it further increases stratification risks in the digester.



Case Study 3: 190 kW AD plant with slurry and grass silage

Grants

Total Investment Costs: £953,176	Operation/Main tenance/Capital Costs [£/a]	Revenue [£/a]	Business Profit/Los- ses [£/a]	Return on Invest- ment	Reflux Capital [years]	Payback Period [years]
Without grant:	271,430	240,056	-31,374	3.7	13.6	26.0

Necessary Grant to achieve a shorter Payback Period. Assumption: **2*ROCs** still possible when taking the grant.

Grant:		£294,913	240,054	240,056	+1	7.0%	9.4	14.0
	31%	£294,913	240,054	240,056	+1	7.0%	9.4	14.0
	54%	£513,762	216,771	240,056	+23,284	12.3%	6.3	8.0
	69%	£653,878	201,864	240,056	+38,191	19.8%	4.3	5.0

Necessary Grant to achieve a shorter Payback Period. Assumption: **1*ROCs** only possible when taking the grant.

Grant:		£788,019	187,593	187,594	+1	7.0%	9.4	14.0
	83%	£788,019	187,593	187,594	+1	7.0%	9.4	14.0
	88%	£843,084	181,735	187,594	+5,859	12.3%	6.3	8.0
	92%	£878,351	177,983	187,594	+9,611	19.8%	4.3	5.0

The sensitivity analysis clearly points out the dominant effect of the electricity value. A 19% higher electricity value (= 17.2 p/kWh) would bring this scenario into profitability. This could be achievable at this site, as supplying electricity to the nearby industrial site would generate a higher revenue per kWh. This would however require additional investment into a private electricity wire from the AD plant to the industrial site.



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Case Study 4: 105 kW AD plant with slurry and energy crops

Site 4 is a dairy farm. Cows are kept in three different places and all are kept free range during the summer months. The AD plant would be placed close to the first site where the majority of the cows are kept. The two other sites are 5.6 km and 3.3 km away.

Two options are possible: utilisation of all slurry/ manure from the three sites or utilisation of slurry from the main site only. Despite the additional costs for transport of slurry/ manure from the two further away locations to the AD plant, the economic modelling indicates that digestion of all available substrates can contribute to the economic benefit.

The main substrates for biogas production are:

Cow slurry	4960 t/a	Whole crop wheat silage	500 t/a
Cow manure	350 t/a	Crop silage	100 t/a
Straw	75 t/a		
Sawdust	14 t/a		
Grass silage	500 t/a		

Slurry from the main site could be fed directly into the AD plant. At the other two sites, intermediate slurry storage is already available (around 760 m³ at site B and around 100 m³ at site C). Slurry could be taken out for example once a week in order to be transported to the main site. A 20 m³ tanker is available for transport. There is no slurry pipeline between the three different sites.

A major drawback on the economic viability is the lack of potential heat consumers.



Case Study 4: 105 kW AD plant with slurry and energy crops

Grants

Total Investment Costs: £470,054		Operation/Main tenance/Capital Costs [£/a]	Revenue [£/a]	Business Profit/Los- ses [£/a]	Return on Invest- ment	Reflux Capital [years]	Payback Period [years]	
Without grant:		134,511	112,702	-21,809	2.4%	15.1	32.0	
Necessary Grant to achieve a shorter Payback Period. Assumption: 2*ROCs still possible when taking the grant.								
Grant:	41%	£193,592	112,701	112,702	+1	7.0%	8.9	12.9
	58%	£274,512	103,585	112,702	+9,118	11.7%	6.3	8.0
	72%	£336,465	96,605	112,702	+16,092	19.0%	4.3	5.0
Necessary Grant to achieve a shorter Payback Period. Assumption: 1*ROCs only possible when taking the grant.								
Grant:	< 100%			80,397	losses			negative
	100%	£470,054	81,555	80,397	-1,157	-	0	0

Without grant an AD plant at Site 4 would hardly be economically viable. However, if an electricity value around 17.5 p/kWh could be achieved, the project would be feasible even without grant.

With a higher electricity value, the economic viability would be significantly better. A minimum profit could be achieved by a 21% higher electricity value (17.54 p/kWh), which clearly indicates the significant influence of this parameter.

Reducing the investment costs also has good potential to achieve a more viable AD installation. If the total investment costs could be reduced by 30%, this AD project would result in no losses.



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Case Study 5: 250 kW AD plant with slurry and silage

Site 5 is a dairy farm. Presently, the animal barns are newly established, and integration of a biogas plant could be a further option within the farm concept.

The potential biogas plant would be run mainly on cattle slurry with addition of some left-over potatoes. Less slurry is produced during periods when a part of the herd is kept free range. Around 50% of the animals are out for half of the year. Co-digestion of potatoes is suitable during this time.

However, biogas generation cannot be completely equalized throughout the year; during the summer time the biogas production will be only 71% of the amount in the winter time.

The main substrates for biogas production are;

Cow slurry	16,000 t/a
Straw in slurry	1,170 t/a
Potatoes	500 t/a

This slurry based AD plant would generate a good Business Profit and would result in a fully acceptable Payback Period even without grant. The initial investment sum would be recovered within 8.1 years. The 10-year projection indicates an accumulated Business Profit of £407,270 for the total period. Even in worst case options there is still a buffer for acceptable payback periods.



Case Study 5: 250 kW AD plant with slurry and silage

Grants

Total Investment Costs:		Operation/Main tenance/Capital Costs [£/a]	Revenue [£/a]	Business Profit/Los- ses [£/a]	Return on Invest- ment	Reflux Capital [years]	Payback Period [years]
£822,122							
Without grant:		164,064	204,791	+40,727	12.0%	6.3	8.1
Necessary Grant to achieve a shorter Payback Period. Assumption: 2*ROCs still possible when taking the grant.							
Grant: 1%	£4,111	163,614	204,791	+41,177	12.0%	6.3	8.0
32%	£261,435	135,444	204,791	+69,347	19.4%	4.3	5.0
Necessary Grant to achieve a shorter Payback Period. Assumption: 1*ROCs only possible when taking the grant.							
Grant: 45%	£373,244	123,204	145,792	+22,588	12.0%	6.3	8.0
63%	£514,649	107,724	145,792	+38,068	19.4%	4.3	5.0

Even without any grant the biogas plant would be economically viable. Acceptance of a grant is only advisable if this does not endanger that 2 x ROCs can still be claimed. This slurry based AD plant has only very limited risk of any process imbalance. In addition, the environmental benefit of slurry based AD plants is to be considered.

As mentioned above, the surplus Business Profit of the whole farm would be even higher than the calculated Business Profit of the AD unit, since the AD plant enables cost savings in the dairy unit when establishing the new dairy barns (reduced slurry storage requirement).



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Case Study 6: 250 kW slurry-based AD plant

Site 6 is a pig farm with some beef cattle and some grass silage available. It is one envisaged option at Site 6 to close the beef cattle business and to concentrate on cultivation of energy crops for biogas production. Up to 7,168 t/a of grass silage and 1,759 t/a of maize silage were indicated to be possible if there were no beef cattle kept anymore.

The main substrates for biogas production are:

<u>Option 1</u>		<u>Option 2</u>	
Pig Slurry	17,500 t/a	Pig Slurry	17,500 t/a
Washing water pigs	1,908 t/a	Washing water pigs	1,908 t/a
Beef cattle slurry	1,500 t/a	Straw in pig slurry	100 t/a
Straw in pig slurry	100t/a	Grass silage	1,792 t/a
Straw in cattle slurry	100 t/a	Maize silage	1,759 t/a
Grass silage	1,792 t/a		

The additional energy crops would require investment in extra storage capacity (silage clamps). A much larger AD facility would be necessary. It needs to be taken into account that compared to digestion of slurry longer hydraulic retention times are necessary for efficient digestion of energy crops and higher organic loading rates are achieved. AD processes run on high amounts of energy crops are less stable compared to slurry based processes. Energy crops are substrates with high costs and special attention should be paid not to lose any energy content due to process imbalance or too short retention in the system.



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Case Study 6: 250 kW slurry-based AD plant

Grants

Total Investment Costs: £876,590		Operation/Main tenance/Capital Costs [£/a]	Revenue [£/a]	Business Profit/Los- ses [£/a]	Return on Invest- ment	Reflux Capital [years]	Payback Period [years]	
		208,678	258,272	+49,594	12.7%	6.1	7.7	
Without grant:								
Necessary Grant to achieve a shorter Payback Period. Assumption: 2*ROCs still possible when taking the grant.								
Grant:	30%	£259,471	180,728	258,272	+77,544	19.6%	4.3	5.0
Necessary Grant to achieve a shorter Payback Period. Assumption: 1*ROCs only possible when taking the grant.								
Grant:	17%	£148,451	192,687	192,688	+1	7.0%	9.3	13.8
	44%	£384,823	167,226	192,688	+25,462	12.2%	6.3	8.0
	62%	£540,856	150,418	192,688	+42,270	19.6%	4.3	5.0

Option 1 proves to be the more economically viable, with option 2 showing a payback period of 12.3 years. Closing the beef cattle unit and concentrating on energy crops would result in higher revenues from electricity sales, but the higher necessary investment (including silage storage capacity) and the high substrate costs would not allow higher Business Profit. The results of the economic modelling indicate a significantly longer Payback Period. In addition it needs to be taken into account that when deciding in favour of closing the beef cattle business, the farm will not have revenue from the beef unit anymore. This aspect is not considered in the economic modelling above, but it is relevant regarding the whole farm business.



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Case Study 7: 75 kW slurry-based AD plant (with food waste options)

Site 7 is a farm which is embedded in a larger complex including facilities with educational and research purposes. There are different buildings, kitchens, farm land and animal barns. Presently the dairy cow barns are newly established, which offers the possibility to integrate an AD plant in the concept. In principle the buildings of the affiliated education/ research facilities offer good potential for biogas heat utilisation. There are two possible locations for the biogas plant: close to the affiliated buildings or close to the barns.

It is one option to take in food waste to improve economic viability of an AD plant at Site 7. Higher electricity and heat production together with the incoming gate fees for accepting wastes considerably increase the revenue. Higher heat generation would justify transport of heat to the buildings in the education/ research area. The economic modelling assumes that biogas heat would be transported for 1 km from the plant to the main buildings, where it would replace 62,000 L of oil per year.

However, when accepting food waste, the plant would come under the ABP regulation requiring hygienisation. The necessary hygienisation equipment results in much higher investment costs, details are given in the Annex. A potential amount of 1,000 food waste per year was indicated. This would not bring the AD project into economic viability. With 4,000 t/a food waste, this scenario would be economically viable.

A biogas plant at this site could be of additional benefit for the future development of AD in Cornwall. The affiliated education/ research facilities assure that many visitors get into contact with AD technology which could inspire farmers to decide in favour of a biogas plant at their own farm.



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Case Study 7: 75 kW slurry-based AD plant

The main substrates for biogas production are:

Option 1:

Cattle Slurry	4,066 t/a
Horse manure	360 t/a
Straw (in slurry)	30 t/a
Grass silage	300 t/a
Maize silage	200 t/a
Whole crop cereal	100 t/a

Option 2:

Cattle Slurry	4,066 t/a
Horse manure	360 t/a
Straw (in slurry)	30 t/a
Grass silage	300 t/a
Maize silage	200 t/a
Whole crop cereal	100 t/a
Food waste	1,000 t/a

Option 3:

Cattle Slurry	4,066 t/a
Horse manure	360 t/a
Straw (in slurry)	30 t/a
Grass silage	300 t/a
Maize silage	200 t/a
Whole crop cereal	100 t/a
Food waste	4,000 t/a

In order to achieve a minimum positive Business Profit, the economic modelling indicates that at least 2,800 t/a food waste would be necessary at this site.

Option 1 shows a negative payback period of 39.9 years

Option 2 shows a negative payback period of 103.2 years

Option 3 shows a positive payback period of 7.6 years

Case Study 7: 75 kW slurry-based AD plant

Grants

Total Investment Costs:		Operation/Main tenance/Capital Costs [£/a]	Revenue [£/a]	Business Profit/Los- ses [£/a]	Return on Invest- ment	Reflux Capital [years]	Payback Period [years]
£464,489							
Without grant:		106,331	59,129	-47,202	-3.2%	100.7	negative
Necessary Grant to achieve a shorter Payback Period. Assumption: 2*ROCs still possible when taking the grant.							
Grant:	91%	£423,168	59,128	59,129	+1	7.0%	9.0
	94%	£435,551	57,747	59,129	+1,838	11.8%	6.3
	96%	£444,748	56,721	59,129	+2,409	19.2%	4.3
Necessary Grant to achieve a shorter Payback Period. Assumption: 1*ROCs only possible when taking the grant.							
Grant:	< 100%			42,326	losses		negative
	100%	£464,489	54,519	42,326	-12,192	-	0

In addition to farm substrates, a small quantity of vegetable waste/ kitchen waste from affiliated facilities and from schools in the village might be available. Higher revenue is generated when accepting food waste for digestion, but necessary surplus investment for food waste treatment needs to be taken into account. The economic modelling indicates a minimum of around 3,000 t/a food waste needs to be available on long terms in order to assure a minimum profitability.



Case Study 8: 861 kW waste, slurry and energy crop AD plant

At Site 8, a community based biogas plant is envisaged. Potential substrates are sewage sludge from the municipal water purification plant, fish waste, different food wastes and by-products from food processing, and slurry and energy crops from farms in the surrounding.

In the UK, co-digestion of sewage sludge with food residues from municipal waste was trialled by Thames Waste Management in the late 90's through to 2002. However when the Animal By-Products Legislation came into force, it was decided that mixed sourced food waste was no longer acceptable for application to farmland; source separation was required. The requirement for pasteurisation also presented design difficulties for existing plants. Hence there has been no development of co-digestion of food waste and sewage sludge for the past five years.

Although it is technically feasible to co-digest sewage sludge with food wastes for landspreading to farmland, in practice the plant would have to work under two separate regulatory regimes, the Water Framework Directive for sewage sludge and Environmental Permitting for other wastes. This has not been successfully tried in the UK, and the cost of the administration of such a scheme would be very high in comparison to the value of the energy and nutrients from the sewage sludge.

Food buyers from major retailers are also becoming increasingly reluctant to accept crops grown on land on which sewage sludge has been spread, although this is a marketing issue rather than a real health risk. In conclusion, it is recommended that sewage sludge is not co-digested with other wastes.



Case Study 8: 861 kW waste, slurry and energy crop AD plant

[The main substrates for biogas production are:](#)

Cow slurry	31,200 t/a
Maize silage	7,300 t/a
Meat waste	2,080 t/a
Fish waste	150 t/a
Food waste	300 t/a
Depackaged food waste	1,500 t/a

It is recommended to carry out precise waste analyses before taking key decisions in this project. For the economic modelling of this study waste material characteristics including gas yields are taken into account as they were indicated by Site 8 (according to results of a pre-study).

Sewage sludge was excluded as an AD input. Cardboard was mentioned as a possible additional substrate at a costs of £30/t. Cardboard is not considered in the modelling; as it is not particularly favourable in the AD process.

In addition, availability of some pastry waste at gate fees of £20/t was mentioned; this would be favourable, however it could not be considered in the modelling as it had not been confirmed. For fish waste and meat waste gate fees of £40/t and for food waste and depackaged food waste gate fees of £30/t are considered as revenue in the modelling; gate fees were suggested from the pre-study.



Case Study 8: 861 kW waste, slurry and energy crop AD plant

Grants

Total Investment Costs: £3,157,036	Operation/Main tenance/Capital Costs [£/a]	Revenue [£/a]	Business Profit/Los- ses [£/a]	Return on Invest- ment	Reflux Capital [years]	Payback Period [years]	
Without grant:	934,214	1,009,906	+75,692	9.4%	7.6	10.3	
Necessary Grant to achieve a shorter Payback Period. Assumption: 2*ROCs still possible when taking the grant.							
Grant: 17%	£531,961	876,539	1,009,906	+133,368	12.1%	6.3	8.0
43%	£1,363,524	786,380	1,009,906	+233,526	19.5%	4.3	5.0
Necessary Grant to achieve a shorter Payback Period. Assumption: 1*ROCs only possible when taking the grant.							
Grant: 45%	£1,415,523	780,742	780,743	+1	7.0%	9.2	13.6
63%	£1,973,148	720,285	780,743	+60,459	12.1%	6.3	8.0
74%	£2,346,941	679,758	780,743	+100,986	19.5%	4.3	5.0

Investment cost reduction has potential to further increase the anticipated Business Profit. This community based AD plant would generate additional benefits. Environmental aspects include greenhouse gas reduction by renewable energy generation and valorisation of waste materials together with reduced transport for mostly local waste materials. It also opens an additional market for local farmers.



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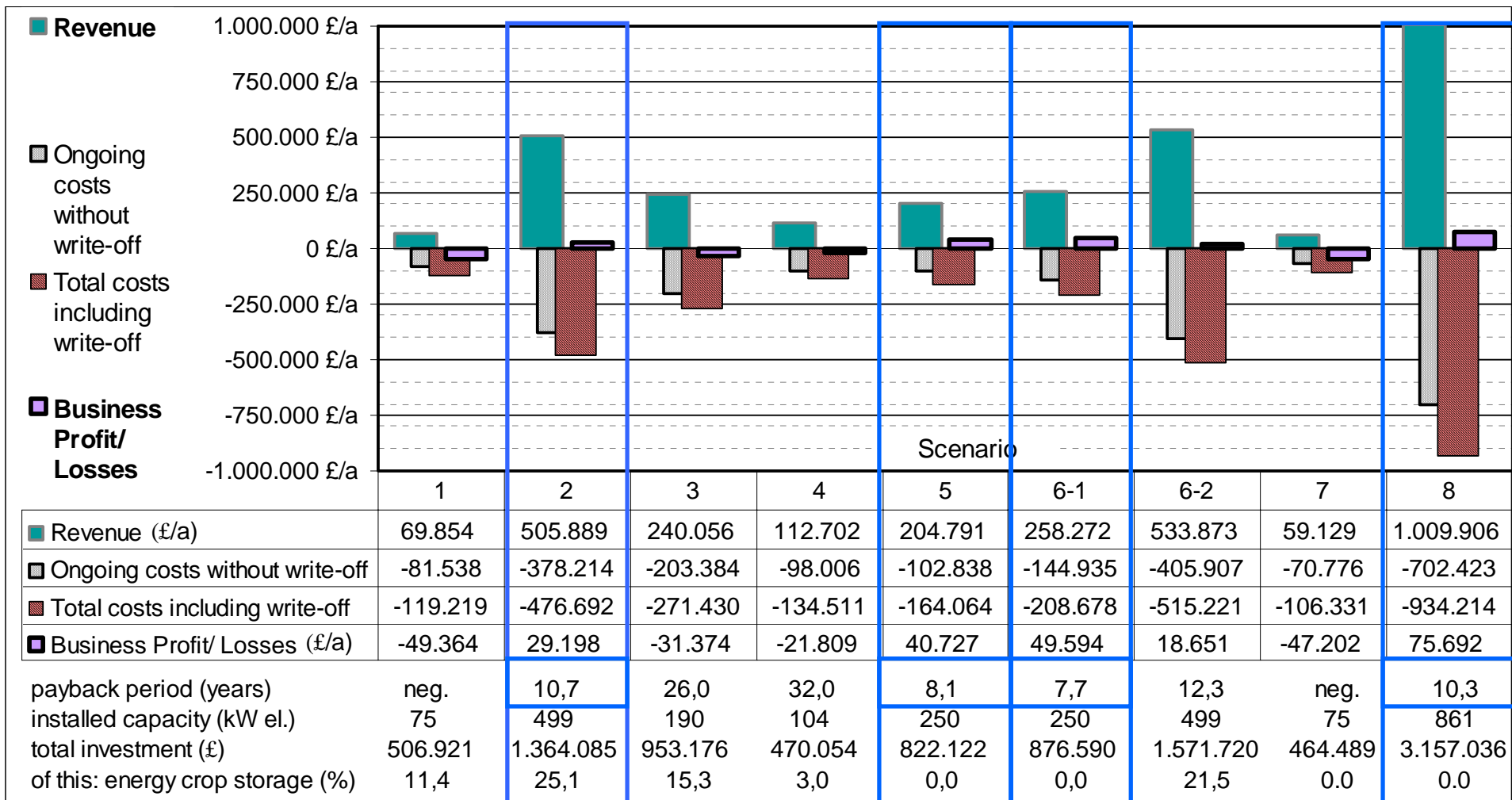


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Conclusions



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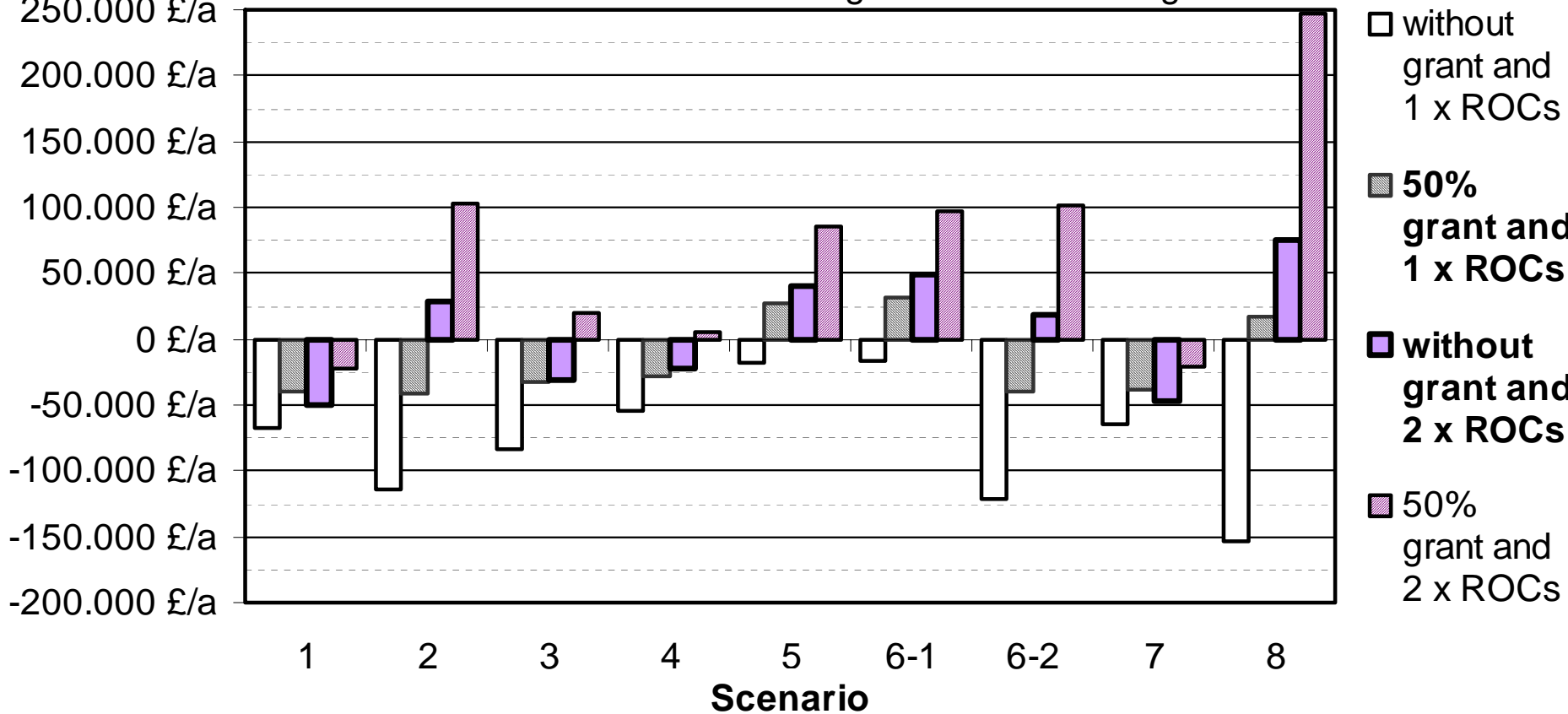
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Conclusions

Business Profit/ Losses without grant and with 50% grant



Summary

Total energy generation and greenhouse gas reduction potential:

- At an installed capacity of 2.30 MW, the 8 CHP units would generate 17,058 MWh/a of electricity. From this 15,345.0 MWh/a could actually be fed into the grid, the rest being self-consumption of the AD facility and energy losses (0.20 MW). This is the annual consumption of almost 4000 average households
- Assumed heat valorisation would substitute 475,000 litres of heating oil per year.
- Reduction of greenhouse gas emissions by approximately 15,000 tonnes CO₂ equivalent per year.
- Better heat utilisation would further improve environmental benefits.



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