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VALORGAS

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D3.4: Baseline mass and energy balance around technical-scale digestion plant

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1 Introduction

Mass and energy balances were conducted for two pilot-scale AD plants. As part of comparative trial of autoclaved and non-autoclaved food waste, Greenfinch Ltd undertook pilot-scale AD trials at their laboratory in Ludlow, Shropshire using source segregated domestic food waste sourced by Aerothermal from the Eco Sustainable solutions site near Bournemouth, UK. Details of these trials are presented in VALORGAS deliverable D3.7. Only the non-autoclaved food waste trial is reported in this study. Around 80% of the waste input to the Andigestion technical-scale plant in Waterbeach, Cambridge, UK was food waste, the other 20% was industrial waste, including depackaging water and sugar-rich water i.e. Coca Cola effluent. The waste was collected by Vertal (later Biocollectors) from London boroughs and pre-processed into a homogeneous form, which was transported by road tanker and pumped to the reception tanks at the Waterbeach site.

The Greenfinch pilot plant was very small with a digester volume of 1.2 m^3. The Andigestion technical-scale plant was much larger with a 500 m^3 digester, comparable to a small-scale commercial operation. This study analyses the material flows of both plants and uses the AD Modelling Tool (VALORGAS deliverable D6.3) to simulate commercial operation with the same feedstock and organic loading rates and estimate usable energy production.

2 Greenfinch Pilot Plant

The Greenfinch plant schematic is shown in Figure 1, and the plant itself in Figure 2.The macerated food waste (stream 2) was fed to the raw waste buffer tank (RWBT) twice per week. The digester was fed 4 times per day (stream 4). The digestate was fed to the digestate storage tank (DST) daily (stream 7) and recycled to the RWBT (from the digester) during the feeding of the macerated food waste into the RWBT. When the DST was at least 85% full the digestate was transferred to external storage (stream 10), around once every 3 weeks. Biogas was collected from both the RWBT and digester, transferred to a gas holder and flared. The RWBT was mixed by mechanical agitation. The digester was mixed by recirculating biogas for 4 minutes out of every 6 minutes. The DST was mixed by an air pump which ran for 1.5 minutes out of every hour. The plant did not use process water input.

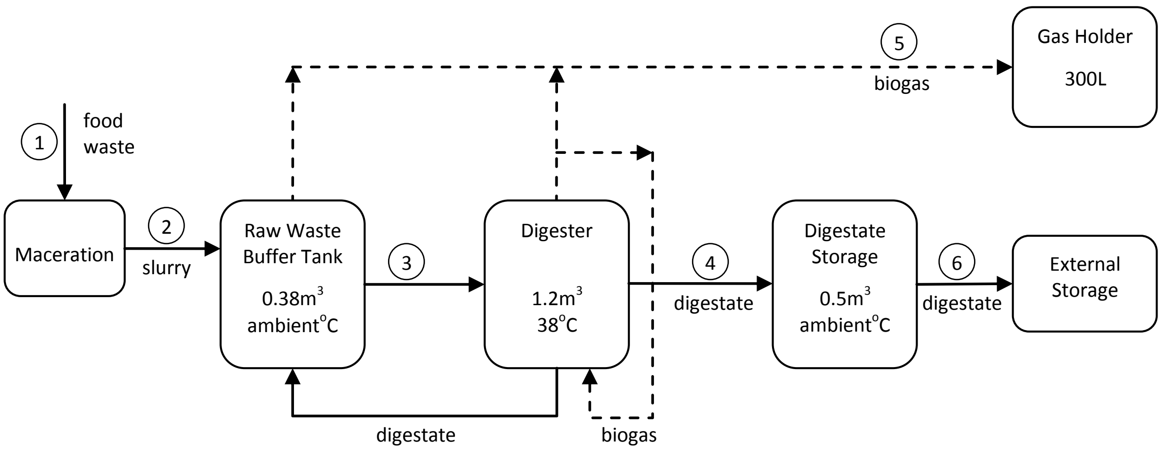

Figure 1. Process flow diagram

(a) Front view showing (L – R) RWBT, control panel, primary digester, storage tank and gas holder

(b) Rear view

Figure 2. Greenfinch pilot-scale digester at Ludlow.

The full trial ran for 560 days during which the OLR was gradually increased from 2.0 to 4.0 kg VS m^{-3} day^{-1}. This study uses the final 13 week period (91 days) commencing on 19/03/2013 (week 1), during which the OLR increased from 3 to 4 kg VS m^{-3} day^{-1} (Figure 3). OLR is based on an average liquid volume of 941 litres i.e. 79% of total digester volume.

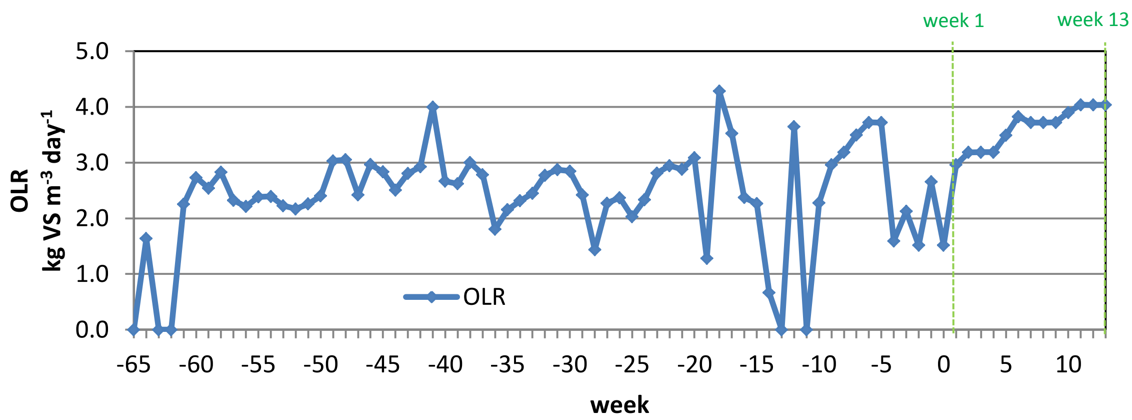

Figure 3. Organic loading rate (based on liquid volume).

2.1 Mass Balance

Mass flows and characteristics of the streams are shown in Table 1.

Table 1. Mass flows and stream characteristics

Basis: 13 weeks		Stream					
		1	2	3	4	5	6
FW	**kg**	1420	1420				
Slurry	**kg**						
Biogas	**kg**					240	
Methane	**kg**					104	
Digestate	**kg**						
TS	**%w/w**		25.0	17.2	10.1		10.3
VS	**% of TS**		88.2	80.8	62.4		63
TS	**kg**		355				
VS	**kg**		313				
P	**mg/kg**		5844		1080		
K	**mg/kg**		10322		3828		
Total Kjeldahl Nitrogen	**mg/kg**		8460		8681		
Ammonium Nitrogen	**mg/kg**				6666		

2.2 Biogas output

Biogas production increased throughout the study period, reflecting the increase in OLR (Figure 4). The average weekly methane fraction was 67.9% (volume) and varied by no more than 3% (Figure 5).

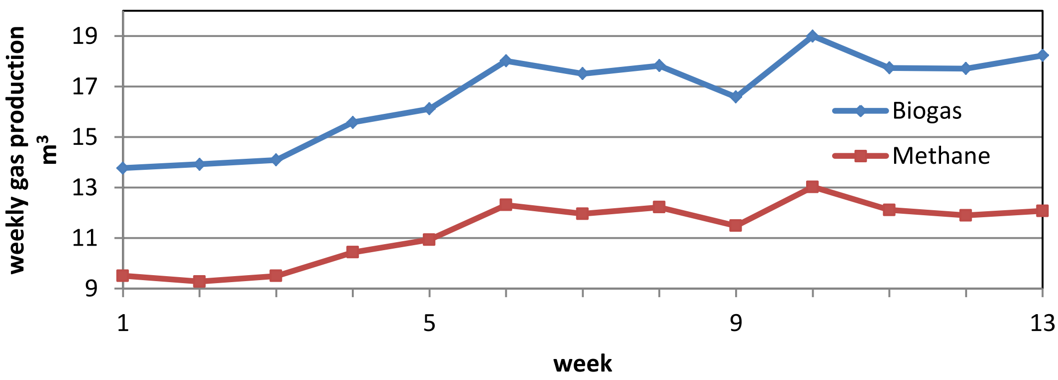

Figure 4. Weekly gas production.

Specific methane production was 0.469 m^3 kg VS^{-1} which is at the high end of what would be expected for food waste (Table 2).

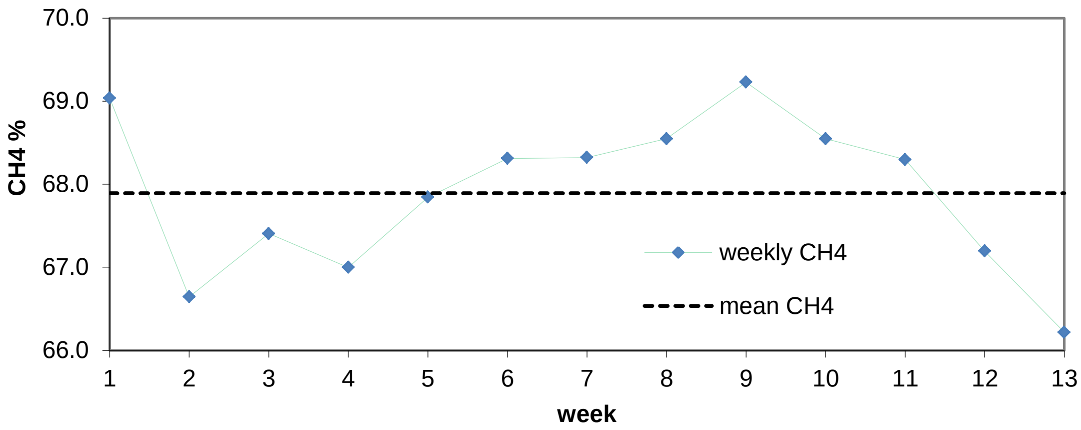

Figure 5. Weekly methane fraction (% volume).

Table 2. Specific and volumetric methane production.

Waste input	**wet kg**	1420
	kg VS	313
Specific methane production	**m^3 wet kg^{-1}**	0.103
	m^3 kg VS^{-1}	0.469
Volumetric methane production	**m^3 m^{-3} digester day^{-1}**	1.36
	m^3 m^{-3} liquid vol day^{-1}	1.71

As a check on the analytical and mass flow data, the VS and TKN content of the digestate was estimated based on biogas production on a mass balance basis (using average values over the study period. For 1 kg of feedstock, the initial VS content is 220 g. It produces 0.691 l g^{-1} VS of biogas with methane content about 67.9% and thus density of around 1.111 kg m^{-3}. This means the 220 g of VS produces about 169.0 g biogas leaving about 51.0 g VS present in (1000 - 169) g of digestate, so the predicted digestate VS concentration is 61.4 g VS kg^{-1} WW. The measured VS content is 63.0 g VS kg^{-1} WW. The predicted digestate TKN based on this amount of breakdown would be 10.18 g N kg^{-1} WW and the measured value is 10.29 g N kg^{-1} WW. These values thus support the validity of the analytical results and mass flows.

2.3 Energy Balance

Actual parasitic energy demand was not seen as relevant for the plant because of its size and configuration as a small-scale replica of the company's larger AD plants elsewhere. The AD modelling tool was used to simulate a simple small-scale mesophilic plant with the same feedstock, an OLR of 3.7 kg VS m^{-3} day^{-1} (the median OLR during the study period) and the following features:

(i) Single digester, working capacity (average liquid volume) = 1000 m^3.

(ii) Digester temperature = 38 ^{o}C.

(iii) Steel digester construction (6 mm steel inner layer, 300 mm thick mineral wool insulation, 3mm thick steel outer layer).

(iv) Post-pasteuriser (6 mm steel inner layer, 300 mm thick mineral wool insulation, 3 mm thick steel outer layer) operated at 70 ^{o}C for 1 hour.

(v) Separate gas holder (214 m^3, stored for 2 hours).

(vi) Digestate not separated into solid and liquid fractions.

(vii) Biogas used on-site by CHP (availability = 95%, electrical efficiency = 35%, CHP/boiler heat efficiency = 50%).

It is a limitation of the spreadsheet version of the AD modelling tool that a working capacity of 90% (volume) is assumed, which is higher than the 79% working capacity of the pilot plant. This does not significantly affect biogas production but does affect total digester volume and thus heating requirements. The software version of the model will allow a user-specified working capacity percentage.

The simulation results are summarised in Table 3.

Table 3. AD modelling tool simulation.

waste	**tonnes year^{-1}**	6976
TS	**% of FM**	22
VS	**% of TS**	88
Specific methane production	**m^3 CH_4 kg^{-1} VS**	0.45
Organic loading rate	**kg VS m^{-3} day^{-1}**	3.7
Methane production	**m^3 year^{-1}**	601672
CHP electrical capacity	**kW**	252
CHP electrical production	**GJ year^{-1}**	7543
CHP/boiler heat production	**GJ year^{-1}**	10776
Parasitic electricity	**GJ year^{-1}**	1552
Parasitic heat	**GJ year^{-1}**	6370
Electricity available for export	**GJ year^{-1}**	5991
Heat available for export	**GJ year^{-1}**	4406

3 Andigestion technical-scale plant

A schematic of the plant is given in Figure 6, and the plant itself is shown in Figure 7. The waste is input to two 80 m^3 reception tanks with re-circulating chopper pumps for mixing. From these tanks the feed is passed through macerators that reduce the particle size to less than 12 mm before being fed into the 40 m^3 pasteuriser, which is heated to 70 ^{o}C for one hour. The slurry is fed to the 500 m^3 digester, a thermally insulated gas mixed-CSTR, operated at an average temperature of 37.7 ^{o}C. The digester radius is 4.75 m and its height is 7 m. The operational height is 4.3 m giving a liquid volume of 305 m^3. Biogas is taken from the headspaces of the pasteuriser and the digester and used for mixing via a gas compressor. The plant does not use process water input to pasteurisation and digestion, and digestate is not recycled. Excess gas is flared as there is no gas storage facility. During the study period the CHP engine was not operated due to unreliable flows, lack of storage bag and lack of a connection to the grid.

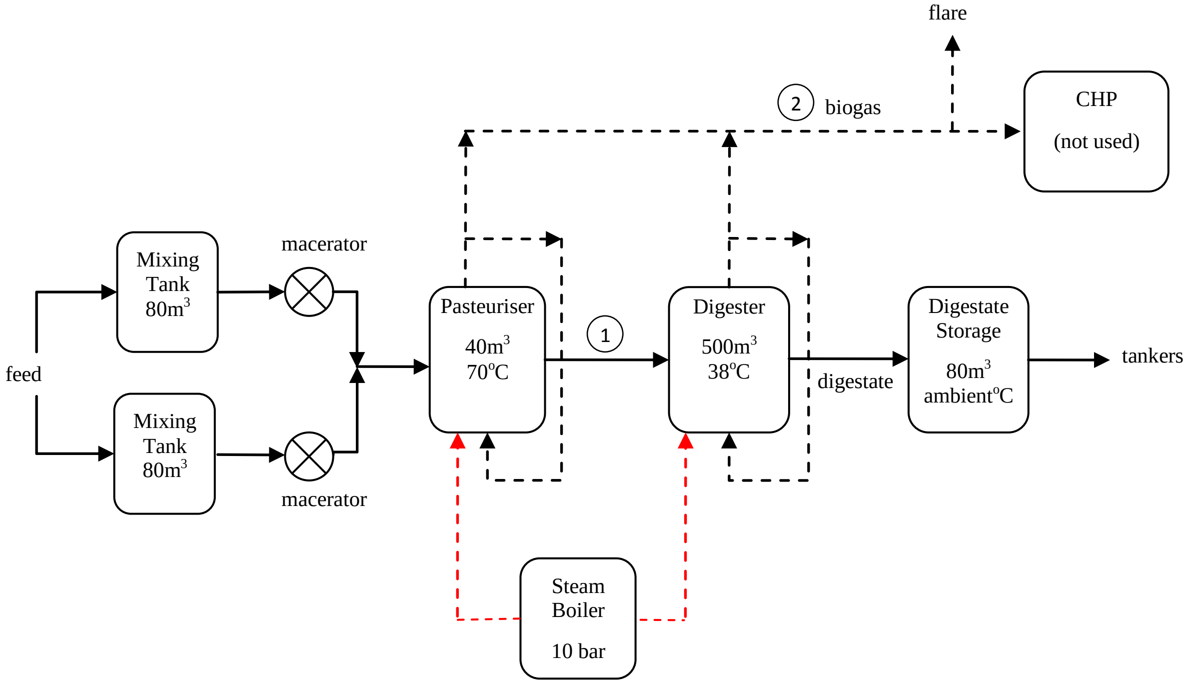

Figure 6. Process flow diagram.

Figure 7. The Andigestion 300 m^3 digestion facility at Waterbeach

This study uses the 19 week (133 days) period commencing on 24/04/2013. During this period the average weekly OLR was 3.7 kg VS m^{-3} day^{-1} (based on liquid volume); however the weekly OLR was highly variable (Figure 8).

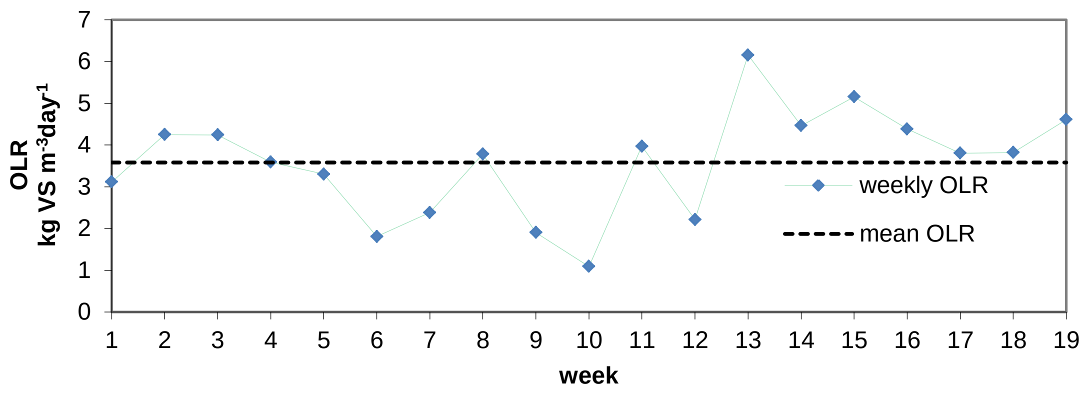

Figure 8. Weekly organic loading rate (based on liquid volume).

3.1 Mass Balance

Table 4. Mass flows and stream characteristics.

Basis: 19 weeks		Stream	
		1	**2**
Feed	**tonnes**	803	
Biogas	**tonnes**		173
Methane	**tonnes**		65
VS	**%w/w**	18.1	
VS	**tonnes**	145	
TKN	**mg l^{-1}**	5444	
NH4-N	**mg l^{-1}**	4423	

3.2 Biogas Output

Biogas production and methane fraction were relatively unstable during the 19-week period, reflecting the variation in organic loading rate (Figures 9 and 10). The average weekly methane fraction was 62.4% (volume) (Figure 10). The total measured VS input during the study period was 145 tonnes which is less than the 173 tonnes of reported biogas production.
Partial solubilisation of solids during the pre-processing and transportation stages may have decreased the feedstock VS measurement. A high specific methane production may also be due to the presence of a higher proportion of fat in the feedstock. A biochemical methane potential (BMP) test carried out at Soton on a sample of the Vertal food waste gave a value of 0.52 m^3 $tonne^{-1}$ VS, slightly higher than typical for domestic food waste but below the value for semi-continuous operation in the Andigestion pilot plant. Another possible source of error is in correction of biogas yield to STP conditions.

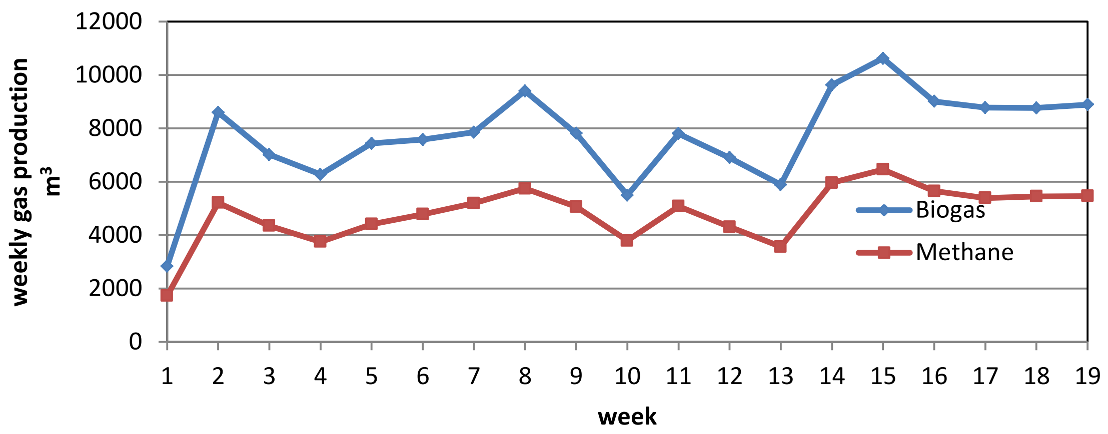

Figure 9. Weekly biogas production

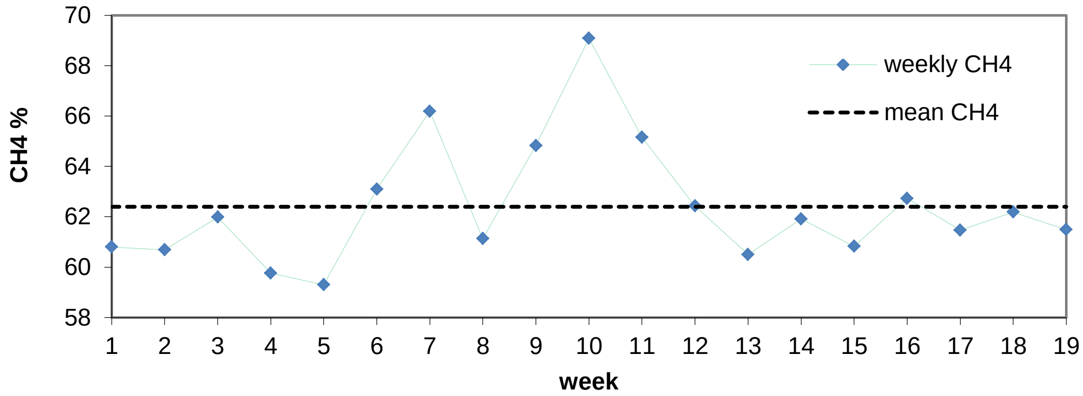

Figure 10. Weekly methane fraction.

Table 5. Specific and volumetric methane yields.

Waste input	**wet tonne**	803
	tonne VS	145
Specific methane production	**m^3 wet tonne^{-1}**	114
	m^3 tonne^{-1} VS	629
Volumetric methane production	**m^3 m^{-3} digester day^{-1}**	1.37
	m^3 m^{-3} liquid vol day^{-1}	2.25

3.3 Energy Balance

The AD modelling tool was used with the following features:

(i) Two identical digesters, each with a working capacity of 500 m^3.

(ii) Digester temperature = 38 ^oC.

(iii) Steel digester construction (6 mm steel inner layer, 300 mm thick mineral wool insulation, 3 mm thick steel outer layer).

(iv) Pre-pasteuriser (6 mm steel inner layer, 300 mm thick mineral wool insulation, 3 mm thick steel outer layer) operated at 70 ^{o}C for 1 hour.

(v) Separate gas holder (291 m^3, stored for 2 hours).

(vi) Digestate not separated into solid and liquid fractions.

(vii) Biogas used on-site by CHP (availability = 95%, electrical efficiency = 35%, CHP/boiler heat efficiency = 50%).

The simulation results are summarised in Table 6.

Table 6. AD modelling tool simulation.

waste	**tonnes year^{-1}**	6976
TS	**% of FM**	22
VS	**% of TS**	88
Specific methane production	**m^3 CH_4 kg^{-1} VS**	0.629
Organic loading rate	**kg VS m^{-3} day^{-1}**	3.7
Methane production	**m^3 year^{-1}**	818241
CHP electrical capacity	**kW**	343
CHP electricity production	**GJ year^{-1}**	10258
CHP/boiler heat production	**GJ year^{-1}**	14655
Parasitic electricity	**GJ year^{-1}**	1624
Parasitic heat	**GJ year^{-1}**	1849
Electricity available for export	**GJ year^{-1}**	8634
Heat available for export	**GJ year^{-1}**	12806