# UK Case Study:
# The Greenhouse Gas and Energy benefits of a *Miscanthus* and a wood fuelled heating system.

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June 2004

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## CONTENTS

## Acknowledgements

This work was completed with inputs from Maggie Mann, Robert Matthews, Phil Metcalfe, Nigel Mortimer and Peter Nixon.

I am also grateful to Sam Whatmore (Grascott Farm) and Nick Bristow (RES) for permission to use their heating systems in this case study, and providing information.

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## Introduction

*Background to UK renewable energy policy with respect to heat.*

Following the Kyoto Climate Change Conference, the UK Government agreed to legally binding reductions in greenhouse gas emissions of 12.5% below 1990 levels by 2008-2012. The Government also has a domestic goal to cut $CO_2$ emissions by 20% by 2010 (DTI, 2003). The UK's Climate Change Programme (2000) set out a range of policies for meeting the targets for reducing greenhouse gas emissions (Defra, 2000). Two key policy areas include encouraging the development of renewable energy crops as a form of energy and making more use of combined heat and power. These have been supported by a range of grants, in particular the industry was given a boost in 2003 by a total of £4.2 million to help establish bioenergy projects as a viable source for both industrial and domestic consumers to meet their heat requirements.

*The need for greenhouse gas assessments at a project level*

Bioenergy projects burning wood or energy crops are often described as "carbon neutral" as that $CO_2$ taken in by the crop over it's life is released on burning. However this term does not allow for the $CO_2$ and other greenhouse gas inputs required to manage, harvest and transport and prepare the fuel for burning.

Many studies have been carried out on generic theoretical systems (e.g. Bullard and Metcalfe, 2001; Elsayed, Matthews and Mortimer, 2003; Matthews *et al*., 1994) but few have targeted individual projects. Some studies, such as quantification of Carbon Emissions Reductions (CER's) for carbon trading mechanisms e.g. The World Banks Prototype Carbon Fund, have been carried out using general data and equations (World Bank, 1998) but few in depth case studies can be found.

The carbon and energy budget of projects is often a legal requirement for planning applications, and is also an issue of concern to the general public. It is one of the most frequent queries at seminars and meetings.

The aim of these case studies is to examine in detail the greenhouse gas and energy budget of two actual heat systems and present the data in a manner which the general public can understand.

*Choice of case study*

Biomass heat systems were chosen as there are several examples installed in the UK, with many more planned. There is only one currently fully operational biomass electricity scheme and so it was considered that heat is more representative of the current biomass industry in the UK.

Two systems were examined, an energy crop system and a wood fuel system. There are two fuel types representing the future of biomass heating in the UK. Britain on whole has been 12% under forest (Forestry Commission, 2003a) and this area is increasing each year. The small diameter wood from thinning these plantations is ideal for biomass burning, particularly in areas with heavy afforestation.

In other areas where there is little forestry, but a predominance of arable agriculture, it is more appropriate to grow purpose grown energy crops, such as Short Rotation Coppice Willow and Miscanthus. The government is strongly supporting the planting of energy crops with an establishment grant of between £920 ha$^{-1}$ and £1600 ha$^{-1}$ depending on crop and land type, if the grower can demonstrate an energy end-use.

The Miscanthus system is a medium to high input, high yielding in an arable/urban fringe environment, and the wood fuel case study is a low input system in a rural forested environment.

## Case study one – wood heat system

The first case study is situated in South West England at Grascott Farm. The farm is composed of 90 hectares (ha) of forested land, 12 ha of established broadleaved woodland and the remainder newly planted Douglas fir. The owners are keen to keep income on the estate, and as such grow their own vegetables and shoot deer and sell venison. The heating system was installed in January 2003 and currently heats a 5 bedroom farmhouse and 3 bedroom holiday cottage. Although 150kW, it is running at low capacity at present. There are plans for developing the farm and renovating another holiday cottage (currently on-going) and a large barn for accommodation and training courses. It is anticipated that the heat demand will then rise to 100kw, in approximately 5 years time. There are also plans for a swimming pool in the longer term, hence the sizing of the boiler at 150kw.

As the boiler is not running at full capacity the energy input and greenhouse gas output in plant installation and maintenance are disproportionate in relation to the energy output.

Fuel currently comes from thinning the under managed broadleaved woodland (7.5 oven dry tonnes) and slab wood (22.5 oven dry tonnes) from a local sawmill just 5 km away. Eventually the thinning from the 70 hectares of Douglas fir will be used to fuel the boiler, resulting in a well thinned plantations producing good quality timber.

## Case study two – Miscanthus heat system

Renewable Energy Systems Ltd (RES), a renewable energy company based outside London has acquired former egg farm buildings and a total of 7 ha of land in Hertfordshire, west London. The land abuts the M25 (London circular) motorway. The farm was originally built in the 1930’s by Ovaltine, the manufacturers of the famous malt drink.

The buildings are being developed as offices built to a high sustainable standard, encompassing, in addition to the biomass boiler, a number of renewable energy sources (solar power, a wind turbine, borehole water cooling). The office complex will be largely self sufficient in terms of energy requirement. The project aims to be a cost effective , low energy complex, employing an innovative fully integrated assembly of energy systems.

A 70 kW Miscanthus fired boiler is due to be installed in October 2004. In 2002 4.5 ha of Miscanthus was planted on the land surrounding the complex. The crop is now established and will be used to fuel the boiler. The heating system is capable of replication over a wide spectrum of building sectors throughout Europe. It is also a flagship demonstration of how existing historically valuable buildings can be re-used in a sustainable and educational way.

Both systems are used as education and demonstration of renewable energy technologies, with a purpose built visitor centre at Renewable Energy Systems.

## General Methodology

A “cradle to grave” approach was taken, following the methodology described in Schlamadinger *et al,* 1997; and Gustavsson *et al*; 2000. $CO_2$ from combustion was considered to be part of the closed carbon cycle. Three greenhouse gases were examined ($CO_2$, $CH_4$, $N_2O$). For energy and $CO_2$ direct and indirect inputs were separated wherever possible.

Direct inputs are those from oil burnt or electricity consumed. Indirect inputs arise from the consumption of energy from other operations such as the spares, repairs, maintenance, manufacture and delivery of machinery. For other goods, e.g. fuel oil and diesel, extraction and delivery is also included in the indirect figure.

For $CH_4$ and $N_2O$ less data was available and as the levels were generally negligible, just a total figure was determined. Data was converted to $CO_2$ equivalents, based on the global warming potentials used by the IPCC. This allows one to express all GHG's in terms of $CO_2$ equivalents. The approach taken here is consistent with the IPCC of a one hundred year time horizon, which assumes on a weight for weight basis that methane is 21 times more powerful than $CO_2$, and nitrous oxide is 310 times more powerful (World Bank, 1998). Several data sources were used, all referring to UK work. The results were cross referenced and verified.

*Study boundaries*

The study is based on a rather arbitrary time interval of 25 years. Although it is likely that some changes in the systems would occur, in particular with respect to the fuel supply, it was decided that as this is case study based on actual systems, the current inputs only should be considered. To predict future changes in both biomass and reference systems would introduce a theoretical element to the study. No discounting was carried out, it was assumed that the value of a tonne of carbon in the future is the same as a tonne of carbon now. Future predictions of the value of carbon vary considerably, and to include a discount factor would introduce further artificiality in the case study.

De-commissioning has not been included as it is anticipated that the plant would run for in excess of 25 years, and data for decommissioning the boiler plant is very generic and not available specifically for the systems described here. Restoring land after growing Miscanthus is simple, and the changes to the EU Common Agricultural Policy in the Mid Term Review, may result in Miscanthus being planted as a crop ion long term set-aside. The forest area would not be cut down as UK forest policy does not allow for felling without re-planting.

*Reference systems*

Baseline reference systems were chosen to compare what would happen if the heating system was not installed. In the case of the reference heating system this was fairly straight forward, but the choice of land use system presented more difficulties.

The heating reference systems in both cases was oil heating, with the litres of oil used per year determined by calculating the energy value of the biomass input and efficiency of the biomass boiler, and calculating the equivalent energy required for an oil boiler, with a higher efficiency of 82%.

For the Miscanthus system it was assumed that the land would otherwise be put over to set-aside which would require topping every year.

For the forestry system it was assumed that there would be no difference. The impact of thinning just 15 $m^3$ a year from 12 hectares, is negligible. As the total annual increment for the broadleaved woodland is 96 $m^3$ a year (assumed Yield Class of 8), the removals constitute just 16% of total increase in carbon increment a year. Felling will have no affect on soil carbon stocks as long as the top soil is not damaged by skidding (winching) operations. Natural regeneration takes place in any gaps left after thinning.

The slab wood would otherwise have gone to a board mill approximately 25 km away. The board mill may have to go further a field to obtain this supply, incurring potentially greater energy use and GHG emissions. Examination of forestry volumes in the area (Forestry Commission, 2001) indicated that the nearest sources of woodland were a further 10 km away, or 20 km for a round trip. This was included in the wood fuel spreadsheet, by calculating the substitution of slab wood to the mill with wood from an additional 10 km, or 20 km round trip.

***Table 1 - Description of systems***

| | | **Miscanthus** | **Wood** |
|---|---|---|---|
| **Baseline reference system** | *Energy* | Oil heating | Oil heating |
| | *Land-use* | Set-aside | Remain unthinned |
| **Life cycle analysis** | *Energy* | 70 kW Miscanthus fuelled boiler | 150 kW wood fuelled boiler |
| | *Land-use* | Miscanthus | Low level thinning<br>Slabwood from a further 10 km away |

*Presentation*

Recently transparency and the method of presenting results have become important issues in the field of energy analysis. For this study the general layout of the work by Elsayed *et al*, 2003 was followed.

*Uncertainty and accuracy*

Areas of uncertainty are highlighted in the text below. Most data comes from UK studies so is accurate for UK processes. As far as possible, data is based on the actual measurements and inputs of the individual case studies. For details on errors associated with conversion factors, the original source data is referenced.

## Detailed methodology and system details - Wood heat system.

### *Biomass boiler (Table 2)*

A 150 kW Binder wood fuel stove from Southern Austria was installed in an existing barn, which was over 100 years old and would otherwise have remained empty. An additional 2 ½ $m^3$ of concrete was required for the foundations. The biomass boiler itself and the 15 m of heat main required to link the boiler to the farm house and cottage were included. The boiler had electrical start-up and although it is hard to be precise about the quantities of electricity used as it is not monitored separately, the figures used represent a best estimate after discussions with the owner and heat engineers. The boiler is run continuously which lowers the start –up fuel input. Data on electrical use of ash removal screw, fuel feed augers and controls was obtained from the manufacturers.

### *Wood fuel (Table 3)*

Thinning operations take place in the woodland surrounding the house and cottage, so transport distances are negligible at less than 1000 m, and have been included in the extraction figure. A tractor and skidder are used, with a small trailer adapted for forestry use. The slab wood is transported just 5 km from the local sawmill, in a tractor with 14 tonne trailer. The figure for this was derived from a saw log figure, with allocation of inputs to slab wood determined on market value of the products. The figures for slab wood are slightly lower per oven dry tonne (odt) than for thinning, as part of the energy and GHG input has been allocated to other products, such as saw logs and saw dust. Chipping occurs at the wood store or in the forest. All wood is air dried to 25% before chipping, which overcomes problems of self combustion of wood chip piles. A Lindana TP200 chipper is used to chip the wood. Input data on fuel use came from observations on site supported by technical reports.

*Reference heating system (Table 4)*

It was assumed that one boiler and oil storage tank would be installed in the same barn, rather than individual boilers in each cottage. The quantity of oil used was based on the energy output from the wood fuel boiler calculated as 157250 kWh, equal to 15820 litres of oil a year. The oil storage tank was sized accordingly from measurements of existing installations of this size.

***Table 2 - Biomass heating system, wood fuel case study***

150 kw system, running at lower capacity
Life of plant: 25 years

| **Component** | | **Direct MJ** | **Indirect MJ** | **Total MJ** | **Direct $CO_2$** | **Indirect $CO_2$** | **Total $CO_2$** | **$CH_4$ (kg)** | **$N_2$0 (kg)** | **Note** |
|---|---|---|---|---|---|---|---|---|---|---|
| Foundations | 2.5m$^3$ | - | - | 6325.00 | - | - | 270.25 | - | - | **a** |
| Building | | - | - | - | - | - | - | - | - | **b** |
| Wood store | | | - | 78000.00 | | | 3744.00 | 0.0930 | 0.0015 | **c** |
| Boiler plant | | - | - | 868000.00 | | | 39600.00 | 0.1035 | 0.0016 | **d** |
| Heat main | 15m | | | 2157.21 | | | 95.84 | | | **e** |
| **Plant installation and construction (excluding delivery)** | | | | **954482.21** | **0.00** | **0.00** | **43710.09** | **0.1964** | **0.0031** | |
| **Plant operation** | | | | | | | | | | |
| Electrical start-up | | | - | 1518.192 | 0 | 0 | 703.872 | 18.9212 | 261.0036 | **f** |
| Electrical usage | | | | 38258.925 | | | 17737.8 | 519.4321 | 6.5774 | **g** |
| Maintenance | | - | - | 542500.00 | - | - | 27318.81 | 0.1228 | 0.0019 | **h** |
| Ash disposal | | - | - | - | - | - | - | - | - | **I** |
| **TOTALS:** | | **0** | **0** | **1536759** | **0** | **0** | **89470.57** | **538.6726** | **267.5860** | |

| **Note** | |
|---|---|
| **a** | Concrete foundations, density 2300 kg m$^3$, figures for $CH_4$ and $N_2$0 not available, $CO_2$ and energy from Elsayed and Mortimer, (2001) |
| **b** | Installed into existing building |
| **c** | Wood store softwood poles, with corrugated iron sheet walls and roof of 18 m x 16 m x 8 m high, 20% usage, for 25 years, life span of 40 years. (Matthews et al, 1994), includes construction. |
| **d** | From Elsayed and Mortimer (2001) and Elsayed, Matthews and Mortimer (2003) |
| **e** | Hard polythene 100 MJ kg$^{-1}$, 4.5 kg $CO_2$ kg$^{-1}$; foam insulation 38 MJ kg$^{-1}$, 1 kg $CO_2$ kg$^{-1}$. Energy data from Payet and Joillet, 2003. |
| **f** | 1 kWh a week (3 times 20 minute start-ups), fuel values from BRE (2000) |
| **g** | Average power usage of 1.25 kW/ kWh, for ash screw, fuel feed screw, controls, and fuel extraction auger (fuel store to boiler). Usage data from manufacturer, electricity data from BRE (2000). |
| **h** | Assumed to be 2.5% of plant construction (Elsayed and Mortimer, 2001) |
| **I** | Negligible, approximately 40 kg a year, left in pile by barn, plans for use in pottery glazes in future |

***Table 3 - Wood fuel supply***

25 year full fuel cycle

| | **Direct MJ** | **Indirect MJ** | **Total MJ** | **Direct $CO_2$** | **Indirect $CO_2$** | **Total $CO_2$** | **Total $CH_4$** | **Total $N_2O$** | **Notes** |
|---|---|---|---|---|---|---|---|---|---|
| **Thinning operations** | | | | | | | | | **a** |
| Chainsaw and spares | - | - | **75.00** | - | - | **55.50** | - | - | **b** |
| Fuel | 9104.13 | 1111.62 | **10215.74** | 693.24 | 81.86 | **775.10** | **2.1222** | **0.0596** | **c** |
| Lubricants | 18.21 | 2.22 | **20.43** | 1.48 | 0.16 | **1.64** | - | - | **d** |
| Stump treatment | - | - | **6850.00** | - | - | **123.00** | **0.0045** | **0.0378** | **e** |
| **Extraction and transport** | | | | | | | | | |
| Tractor | 9350.00 | 2660.00 | **12010.00** | 6414.10 | 196.84 | **6610.94** | **0.2522** | **0.0071** | **f** |
| **Slab wood** | | | | | | | | - | |
| Slabwood production | - | - | **44250.00** | - | - | **2345.25** | **0.2928** | | **g** |
| Tractor and trailer | 19950.00 | 6050.00 | **26000.00** | 1368.57 | 49.01 | **1417.58** | **0.5460** | **0.0153** | **h** |
| **Chipping** | | | | | | | | | |
| Fuel | 95699.90 | 11684.97 | **107384.87** | 7287.17 | 860.44 | **8147.61** | **22.3077** | **0.6267** | **I** |
| Lubricants | 180.27 | 22.01 | **202.29** | 14.61 | 1.62 | **16.23** | - | - | **j** |
| Manufacture | - | - | **703.00** | - | - | **37.00** | - | - | **k** |
| **TOTAL** | 134302.52 | 21530.82 | **207711.34** | 15779.17 | 1189.92 | **19529.84** | **25.5253** | **0.7465** | |
| **Thinnings, per odt** | 98.52 | 20.13 | **118.65** | 37.91 | 1.49 | **39.40** | **0.0127** | **0.0006** | |
| **Slab wood, per odt** | 27.05 | 8.20 | **35.25** | 1.86 | 0.07 | **1.92** | **0.0011** | **0.0000** | |
| | | | | | | | | | |
| **Slab wood substitution** | **20080.20** | **6999.65** | **27079.85** | **1376.90** | **394.45** | **1771.35** | **4.2140** | **0.0059** | **l** |
| **TOTAL for Case study** | **154382.72** | **28530.47** | **234791.19** | **17156.07** | **1584.37** | **21301.19** | **29.7393** | **0.7524** | |

**Notes for wood fuel (table 3)**

| | |
|---|---|
| **a** | 7.5 odt a year from 3 hectares, average 2.5 odt a hectare |
| **b** | Elsayed, Matthews and Mortimer (2003). |
| **c** | 1.45 litres per odt, Elsayed, Matthews and Mortimer (2003). |
| **d** | 0.002 litres lubricating oil per each litre diesel used (Elsayed, Matthews and Mortimer, 2003), lubricating oil value from Matthews et al (1994) |
| **e** | Urea ($CH_4N_2O$). General figure for fungicides from Elsayed, Matthews and Mortimer, (2003), assume 1 litre a year |
| **f** | Work rate of 1.24 $m^3$ an hour (Forestry Commission, 2003), and on site data, using tractor from McCormack and Metcalfe (2000) |
| **g** | 29.5 odt a year, 60 MJ $odt^{-1}$; 3.18 kg $CO_2$ and 0.000397 kg $CH_4$.Figures adapted from Elsayed, Matthews and Mortimer (2003). |
| **h** | 10 km round trip with tractor and 14 tonne trailer, five times a year, average speed 30 km $hr^{-1}$ (McCormack and Metcalfe, 2000) |
| **I** | Total of 37 odt a year, 2.9 l oil per odt (from chipper manufacturer). Fuel data from BRE (1996) |
| **j** | 0.002 litres of lubricating oil per each litre diesel used, lubricating oil value from Matthews et al (1994) |
| **k** | Machinery manufacture and spares of 19 MJ per odt, 1 kg $CO_2$ per odt (Elsayed, Matthews and Mortimer, 2003). |
| **l** | Substitution of slab wood to mill with wood from an additional 20km. 29.5 odt (= 49 tonnes at transportation mc of 40%)<br>Values for transport from Mortimer and Elsayed, (2001) and BRE (1996). |

***Table 4 - Wood fuel reference heating system - oil boiler***

150 kW system, running at 157250 kWh a year

Life of plant: 25 years

| **Component** | | **Direct MJ** | **Indirect MJ** | **Total MJ** | **Direct $CO_2$** | **Indirect $CO_2$** | **Total $CO_2$** | **$CH_4$ (kg)** | **$N_20$ (kg)** | **Note** |
|---|---|---|---|---|---|---|---|---|---|---|
| Foundations | 2.5 m3 | - | - | 6325.00 | - | - | 270.25 | - | - | **a** |
| Building | | - | - | - | - | - | - | - | - | **b** |
| Oil tank | | | | 6650.00 | | | 299.00 | | | **c** |
| Boiler plant | | - | - | 10963.00 | - | - | 509.88 | - | - | **d** |
| **Plant installation and construction (excluding delivery)** | | | | **23938.00** | | | **1079.13** | | | |
| | | | | | | | | | | |
| **Plant operation (annual)** | | | | | | | | | | |
| Fuel | | 15118061.46 | 1845917.15 | 16963978.61 | 1225017.75 | 135926.63 | 1360944.37 | 3859.6450 | 100.6864 | **e** |
| Maintenance | | - | - | 14961.25 | - | - | 674.46 | - | - | **f** |
| **TOTALS:** | | **15118061.46** | **1845917.15** | **17002877.86** | **1225017.75** | **135926.63** | **1362697.96** | **3859.6450** | **100.6864** | |

| **Note** | |
|---|---|
| **a** | Concrete foundations, density 2300 kg $m^3$, figures for $CH_4$ and $N_20$ not available, $CO_2$ and energy from Elsayed and Mortimer, (2001) |
| **b** | Installed into existing building, an old stone barn which had no other use |
| **c** | For a cylindrical oil tank of 2 m by 1 m, data from Payet and Jolliet (2003) |
| **d** | Assumed mass of 10 kg .Value for furnace burners from Elsayed and Mortimer, (2001) $N_20$ and $CH_4$ unknown, likely to be negligible |
| **e** | Usage of 15,820 litres a year, oil values from BRE (2000) |
| **f** | Assumed to be 2.5% of plant construction (Elsayed and Mortimer, 2001) |

## Detailed methodology and system details - Miscanthus system

*Biomass boiler (Table 5)*

The fuel store was a low energy design incorporating gabian walls, basically rocks enclosed in mesh . The roof of steel had a high input, although there are plans for solar panels which may change this in the future. A small area of concrete was allowed for on which to site the heavy boiler. Boiler manufacture data from Elsayed and Mortimer, 2001 is based on Talbotts boilers, so the data was considered to be very applicable to this case study/

*Miscanthus fuel (Table 6)*

The energy inputs into rhizome production and establishment have been averaged over the 25 year full fuel cycle. Full inputs into Miscanthus establishment, annual management and harvesting are detailed in table 6. After establishment Glyphosate is applied every year to keep weeds under control, and slurry every three years to maintain nutrient levels. Harvesting is carried out with a mower conditioner, and then baled and transported to the store which is less than 1000 m away. The predicted yields on which the figures are based are shown in table 7 below:

***Table 7 – Assumed yields of Miscanthus***

| **Year** | **Yield (odt $ha^{-1}$ $yr^{-1}$** |
|---|---|
| 1 (planting) | 0 |
| 2 | 5 |
| 3 | 7 |
| 4 | 10 |
| 5 - 25 | 12 |

*Reference heating system (Table 8)*

After discussions with RES it was decided that the gabian walled store would be built anyway, to house other developments. It was assumed that the oil boiler and tank would have been sited in the building, but using only 0.05% of the total area. The quantity of oil used is based on the energy output from the Miscanthus fuel boiler calculated as 43304 kWh, equal to 4356 litres of oil a year. The oil storage tank was sized accordingly from measurements of existing installations of this size.

*Reference land –use system (Table 9)*

Simple set aside was assumed as the reference and use, and would require cutting once a year.

***Table 5 - Biomass boiler - Miscanthus case study***

70 kW system

Life of plant: 25 years

| **Component** | | **Direct MJ** | **Indirect MJ** | **Total MJ** | **Direct $CO_2$** | **Indirect $CO_2$** | **Total $CO_2$** | **$CH_4$ (kg)** | **$N_20$ (kg)** | **Note** |
|---|---|---|---|---|---|---|---|---|---|---|
| Foundations | 2.5m3 | - | - | 6325.00 | - | - | 270.25 | - | - | **a** |
| Building | | - | - | 90702.00 | - | - | 3831.00 | 0.0108 | 0.0002 | **b** |
| Boiler plant | | - | - | 416000.00 | - | - | 19000.00 | 0.0496 | 0.0008 | **c** |
| **Plant installation and construction (excluding delivery)** | | | | **513027.00** | | | **23101.25** | **0.0604** | **0.0009** | |
| | | | | | | | | | | |
| **Plant operation** | | | | | | | | | | |
| Start-up fuel | | 3900.00 | 429.00 | 4329.00 | 202.80 | 22.31 | 225.11 | 0.4848 | 0.0004 | **d** |
| Electrical usage | | | | 12293.60143 | | | 5699.62 | 166.9072 | 2.1135 | **e** |
| Maintenance | | - | - | 320641.88 | - | - | 14438.28 | 0.0377 | 0.0006 | **f** |
| Ash disposal | | 91.20 | 125.00 | 216.20 | 6.26 | 9.25 | 15.51 | 0.0045 | 0.0001 | **g** |
| **TOTALS:** | | **3991.20** | **554.00** | **850507.68** | **209.06** | **31.56** | **43479.77** | **167.4948** | **2.1156** | |

**Notes**

| | |
|---|---|
| **a** | Concrete foundations, density 2300 kg $m^3$, figures for $CH_4$ and $N_20$ not available, $CO_2$ and energy from Elsayed and Mortimer, (2001) |
| **b** | Fuel store built from 200 $m^2$ floor, by 3 m high of gabian walls (total: 9000 MJ, data for steel wire and rock from Elsayed and Mortimer, 2001), with steel roof ( 128428 MJ, data from Elsayed and Mortimer, 2001). Usage 66%. Life span not known, assumed to be 25 years |
| **c** | From Elsayed and Mortimer (2001) and Elsayed, Matthews and Mortimer (2003) |
| **d** | Propane gas start-up, 10 mins a week. Value for propane from Elsayed, Matthews and Mortimer, (2003) |
| **e** | Average power usage of 0.9 kW/ kWh, for ash screw, fuel feed screw, controls, and fuel extraction auger (fuel store to boiler). Usage data from manufacturer, electrical data from BRE (2000) |
| **f** | Assumed to be 2.5% of plant construction (Elsayed and Mortimer, 2001) |
| **g** | Ash disposal onto neighbouring Miscanthus fields, one ha $year^{-1}$, using a 4.5 tonne tractor and trailer, (McCormack and Metcalfe, 2000). |

***Table 6 - Miscanthus Case Study***

| 25 year full fuel cycle | **Rate ha$^{-1}$** | **Direct MJ ha$^{-1}$** | **Indirect MJ ha$^{-1}$** | **Total MJ ha$^{-1}$** | **Direct $CO_2$ ha$^{-1}$** | **Indirect $CO_2$ ha$^{-1}$** | **Total $CO_2$ ha$^{-1}$** | **Total $CH_4$ ha$^{-1}$** | **Total $N_2O$ ha$^{-1}$** | **Note** |
|---|---|---|---|---|---|---|---|---|---|---|
| **ESTABLISHMENT** | | | | | | | | | | |
| **Rhizome Production** | 1000 kg | - | - | 4000.00 | - | - | 296.00 | 0.000477 | 0.000007 | **a** |
| **Herbicide** | | | | | **-** | **-** | | | | |
| Glyphosate | 4 l | - | - | 1096.40 | | | 19.68 | 0.000720 | 0.006040 | **b** |
| Bromoxynil/ioxynil/fluroxpyr | 2 kg | - | - | 548.20 | | | 9.84 | 0.000360 | 0.003020 | **c** |
| **Machinery - cultivation** | | | | | | | | | | |
| Subsoiler | | 1040.06 | 262.00 | 1302.06 | 76.96 | 19.39 | 96.35 | 0.021841 | 0.000104 | **d** |
| Plough | | 1040.00 | 262.00 | 1302.00 | 76.96 | 19.39 | 96.35 | 0.021840 | 0.000104 | **e** |
| Power Harrow | | 272.00 | 179.00 | 451.00 | 20.13 | 13.25 | 33.37 | 0.005712 | 0.000027 | **f** |
| **Machinery - planting** | | | | | | | | | | |
| Planter | | 2038.00 | 946.00 | 2984.00 | 150.81 | 70.00 | 220.82 | 0.042798 | 0.000204 | **g** |
| Roller | | 146.00 | 98.00 | 244.00 | 10.80 | 7.25 | 18.06 | 0.003066 | 0.000015 | **h** |
| **Machinery - Herbicide application** | | | | | | | | | | |
| Glyphosate | | 113.00 | 68.00 | 181.00 | 8.36 | 5.03 | 13.39 | 0.002373 | 0.000011 | **I** |
| Bromoxynil/ioxynil/fluroxpyr | | 113.00 | 68.00 | 181.00 | 8.36 | 5.03 | 13.39 | 0.002373 | 0.000011 | **j** |
| **Fencing** | 1023 m | - | - | 168488.10 | - | - | 8087.84 | - | - | **k** |
| **PRODUCTION (over 25 years)** | | | | | | | | | | |
| Glyphosate | 4 l | - | - | 27410.00 | - | - | 492.10 | 0.018000 | 0.151000 | **l** |
| **Machinery - fertiliser application** | | | | | | | | | | |
| Slurry spreader and tractor | 25 t triennially | 3800.00 | 1318.25 | 5118.25 | 281.20 | 97.55 | 378.75 | 0.079800 | 0.000380 | **m** |
| **Machinery - Herbicide application** | | | | | | | | | | |
| Glyphosate | 24 m sprayer | 2825.00 | 1700.00 | 4525.00 | 209.05 | 125.80 | 334.85 | 0.059325 | 0.000283 | **n** |
| **HARVESTING, STORAGE and TRANSPORT** | | | | | | | | | | |
| Mower conditioner | | 5950.00 | 2725.00 | 8675.00 | 440.30 | 201.65 | 641.95 | 0.124950 | 0.000595 | **o** |
| Baler | | 13375.00 | 12250.00 | 25625.00 | 989.75 | 906.50 | 1896.25 | 0.280875 | 0.001338 | **p** |
| Trailer with grab to transport to store | | 4450.00 | 1350.00 | 5800.00 | 329.30 | 99.90 | 429.20 | 0.093450 | 0.000445 | **q** |
| **TOTALS PER HECTARE over 25 YEARS** | | **35162.06** | **21226.25** | 257931.01 | **2601.99** | **1570.74** | 13078.20 | 0.76 | 0.16 | |
| **TOTALS FOR CASE STUDY (4.5 HECTARE)** | | **158229.27** | **95518.13** | 1160689.54 | **11708.97** | **7068.34** | 58851.89 | 3.41 | 0.74 | |
| Trailer with grab to transport to boiler | | 20025.00 | 6075.00 | 26100.00 | 1481.85 | 449.55 | 1931.40 | 0.420525 | 0.002003 | **r** |
| **GRAND TOTAL** | | **178254.27** | **101593.13** | 1186789.54 | **13190.82** | **7517.89** | 60783.29 | 3.83 | 0.74 | |

**Notes to table 6 - Miscanthus Case Study**

| **Notes** | |
|---|---|
| **a** | From Bullard and Metcalfe, (2001) and Elsayed, Matthews and Mortimer, (2003) |
| **b** | Elsayed, Matthews and Mortimer, (2003) |
| **c** | Elsayed, Matthews and Mortimer, (2003) |
| **d** | From Bullard and Metcalfe, (2001) and Elsayed, Matthews and Mortimer, (2003) |
| **e** | From Bullard and Metcalfe, (2001) and Elsayed, Matthews and Mortimer, (2003) |
| **f** | From Bullard and Metcalfe, (2001) and Elsayed, Matthews and Mortimer, (2003) |
| **g** | From Bullard and Metcalfe, (2001) and Elsayed, Matthews and Mortimer, (2003) |
| **h** | From Bullard and Metcalfe, (2001) and Elsayed, Matthews and Mortimer, (2003) |
| **I** | Elsayed, Matthews and Mortimer, (2003) |
| **j** | Elsayed, Matthews and Mortimer, (2003) |
| **k** | Elsayed and Mortimer, (2001) |
| **l** | Elsayed, Matthews and Mortimer, (2003) |
| **m** | McCormack and Metcalfe, (2000) |
| **n** | Elsayed, Matthews and Mortimer, (2003) |
| **o** | McCormack and Metcalfe, (2000) |
| **p** | McCormack and Metcalfe, (2000) |
| **q** | Source data from McCormack and Metcalfe (2000) Yield assumed to be average annual of 10.48 tonnes a year at 25% moisture content. |
| **r** | McCormack and Metcalfe, (2000) |

***Table 8 - Miscanthus case study reference heat system - oil boiler***

70 kW system running at 43302 kWh a year
Life of plant: 25 years

| **Component** | | **Direct MJ** | **Indirect MJ** | **Total MJ** | **Direct $CO_2$** | **Indirect $CO_2$** | **Total $CO_2$** | **CH4 (kg)** | **$N_2$0 (kg)** | **Note** |
|---|---|---|---|---|---|---|---|---|---|---|
| Foundations | 2.5 m3 | - | - | 6325.00 | - | - | 270.25 | - | - | **a** |
| Building | | - | - | 687.00 | - | - | 29.00 | 0.000082 | 0.000001 | **b** |
| Oil tank | | | | 6650.00 | | | 299.00 | | | **c** |
| Boiler plant | | - | - | 10963.00 | | | 509.88 | - | - | **d** |
| **Plant installation and construction (excluding delivery)** | | | | **24625.00** | | | **1108.13** | **0.000082** | **0.000001** | |
| | | | | | | | | | | |
| **Plant operation (annual)** | | | | | | | | | | |
| Fuel | | 4162722.86 | 508268.97 | 4670991.83 | 337305.77 | 37427.08 | 374732.85 | 1062.74 | 27.72 | **e** |
| Maintenance | | - | - | 15390.63 | - | - | 692.58 | - | - | **f** |
| **TOTALS:** | | **4162722.86** | **508268.97** | **4711007.46** | **337305.77** | **37427.08** | **376533.56** | **1062.744292** | **27.723763** | |

**Notes**

**a** Concrete foundations, density 2300 kg $m^3$, figures for $CH_4$ and $N_2$0 not available, $CO_2$ and energy from Elsayed and Mortimer, (2001)
**b** Fuel store built from 200 $m^2$ floor, by 3 m high of gabian walls (total: 9000 MJ, data for steel wire and rock from Elsayed and Mortimer, 2001), with steel roof ( 128428 MJ, data from Elsayed and Mortimer, 2001). Usage 0.05%. Life span not known, assumed to be 25 years
**c** For a cylindrical oil tank of 2 m by 1 m, data from Payet and Jolliet (2003)
**d** Assumed mass of 10 kg. Value for furnace burners from Elsayed and Mortimer, (2001) $N_2O$ and $CH_4$ unknown, likely to be negligible
**e** Usage of 4356 litres a year, oil values from Elsayed, Matthews and Mortimer, 2003
**f** Assumed to be 2.5% of plant construction (Elsayed and Mortimer, 2001)

**Miscanthus Case Study**

***Table 9 - Reference land-use***

**Conventional Set-aside**
25 year full fuel cycle

| | **Direct MJ ha$^{-1}$** | **Indirect MJ ha$^{-1}$** | **Total MJ ha$^{-1}$** | **Direct $CO_2$ ha$^{-1}$** | **Indirect $CO_2$ ha$^{-1}$** | **Total $CO_2$ ha$^{-1}$** | **Total $CH_4$ ha$^{-1}$** | **Total $N_2O$ ha$^{-1}$** | **Notes** |
|---|---|---|---|---|---|---|---|---|---|
| Mechanical Topping | 7600.00 | 3900.00 | 11500.00 | 562.40 | 288.60 | 851.00 | 0.159600 | 0.000760 | **a** |
| **TOTALS**<br>(4.5 hectare) | **34200.00** | **17550.00** | **51750.00** | **2530.80** | **1298.70** | **3829.50** | **0.718200** | **0.003420** | |

**Notes**

| | |
|---|---|
| **a** | McCormack and Metcalfe, (2000) |

## Results

*Energy input and GHG emission per kWh*

Tables 10 and 11 below present the results in terms of kWh, to allow for comparison between the two systems.

*Table 10 - Energy input per kWh*

| | **Miscanthus** | **Wood fuel** |
|---|---|---|
| **Energy input (MJ/kWh)** | | |
| Landuse Reference system | 0.0478 | 0.0000 |
| Biomass/Fuel production | 1.4566 | 0.0597 |
| Biomass boiler | 0.7857 | 0.3909 |
| Oil boiler | 4.3518 | 4.3251 |
| **TOTAL - Reference system** | **4.3996** | **4.3251** |
| **TOTAL - Biomass system** | **2.2422** | **0.4506** |

*Table 11 - GHG per kWh*

| | **Miscanthus** | **Wood fuel** |
|---|---|---|
| **GHG input (kg CO2 equivalent/kWh)** | | |
| Landuse Reference system (negligible) | 0.0035 | 0.0000 |
| Biomass/Fuel production | 0.0737 | 0.0056 |
| Biomass boiler | 0.0440 | 0.0467 |
| Oil boiler | 0.3764 | 0.3752 |
| **TOTAL - Reference system** | **0.3799** | **0.3752** |
| **TOTAL - Biomass system** | **0.1178** | **0.0524** |
| **Avoided emissions per kWh** | **0.2621** | **0.3228** |

For both case studies the reference systems used similar quantities of energy - 4.35 MJ/kWh for the Miscanthus systems and 4.32 MJ/kWh for the wood fuel system - and had similar GHG emissions, as would be expected for similar oil fired systems This is summarised graphically in figures 1a and 1b, where total energy input and total GHG emissions are presented, combining land use and heating system.

As would be expected the wood fuel production had lower energy inputs and GHG emissions than the Miscanthus fuel production, of 0.3228 kg $CO_2$ equivalent per kWh compared to 0.2621 kg $CO_2$ equivalent per kWh. However the Miscanthus system still demonstrates considerable avoided GHG emission, and was responsible for energy inputs of 50% lower than the fossil system.

*Figure 1a – Total energy input per kWh for both systems*

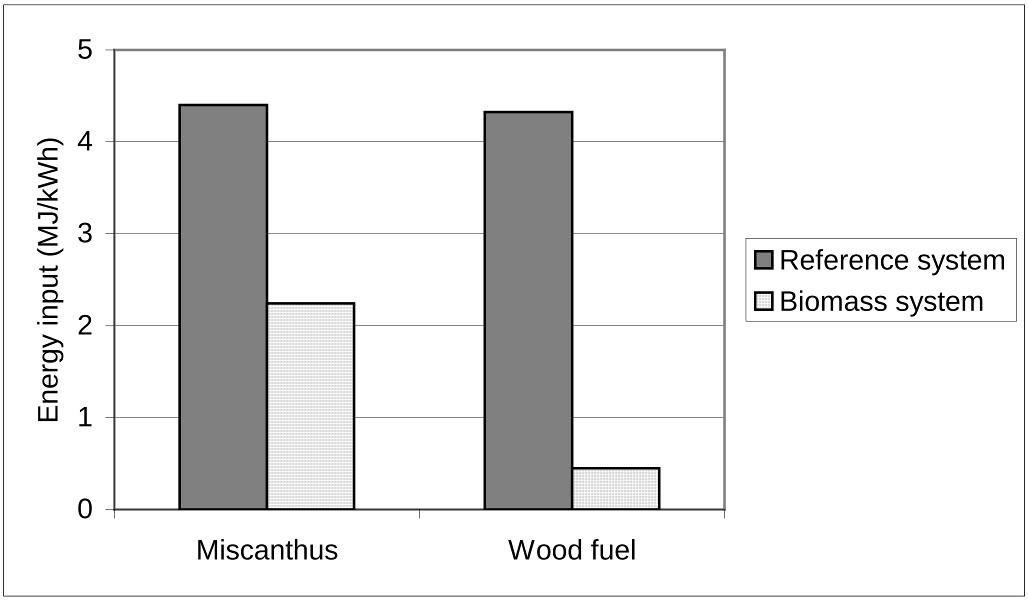
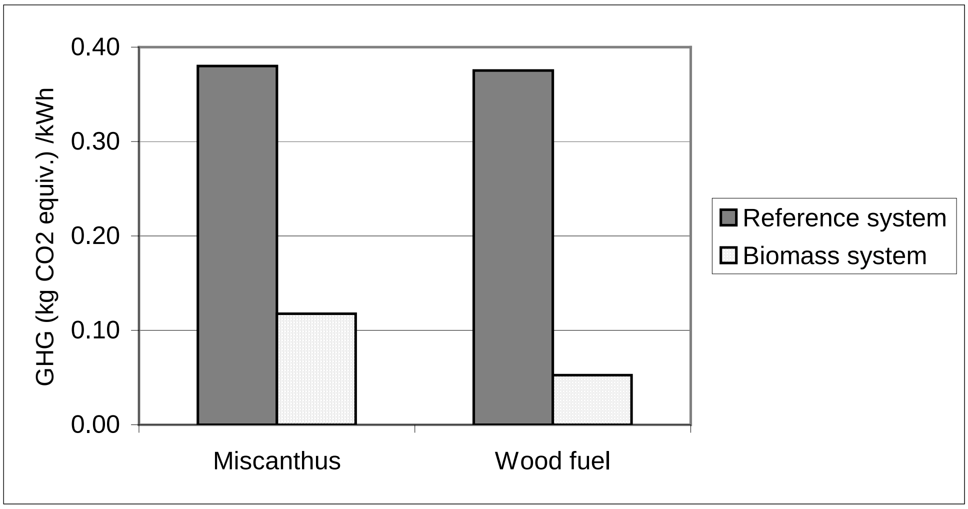


*Figure 1b - Total GHG emissions (kg CO2 equivalent) for both systems*



*Fossil reference systems versus biomass systems*

For both systems the biomass fuel production was responsible for more inputs than the reference land use system, but these inputs were cancelled out by the large savings due to avoidance of oil burning (figure 2).

***Figure 2a – GHG emissions (kg $CO_2$ equivalents) for Miscanthus case study.***

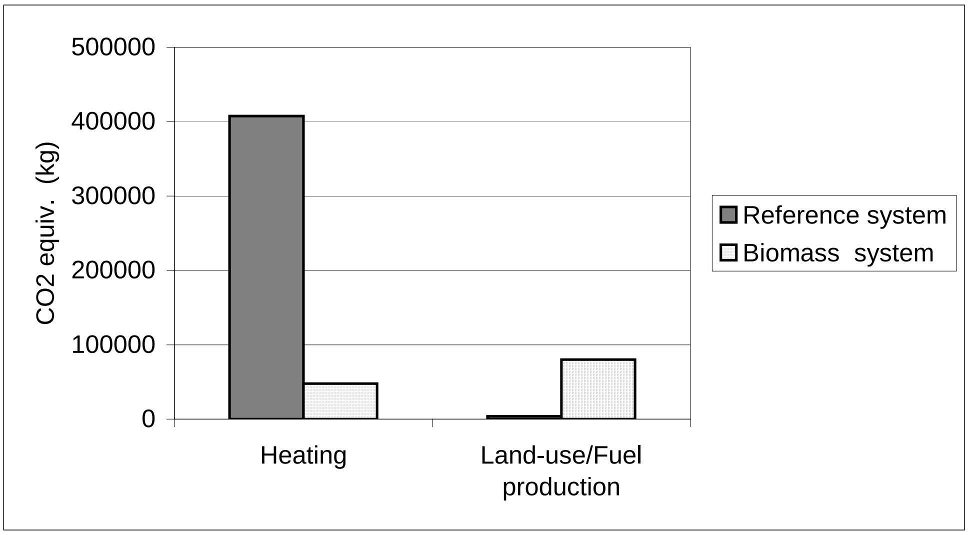
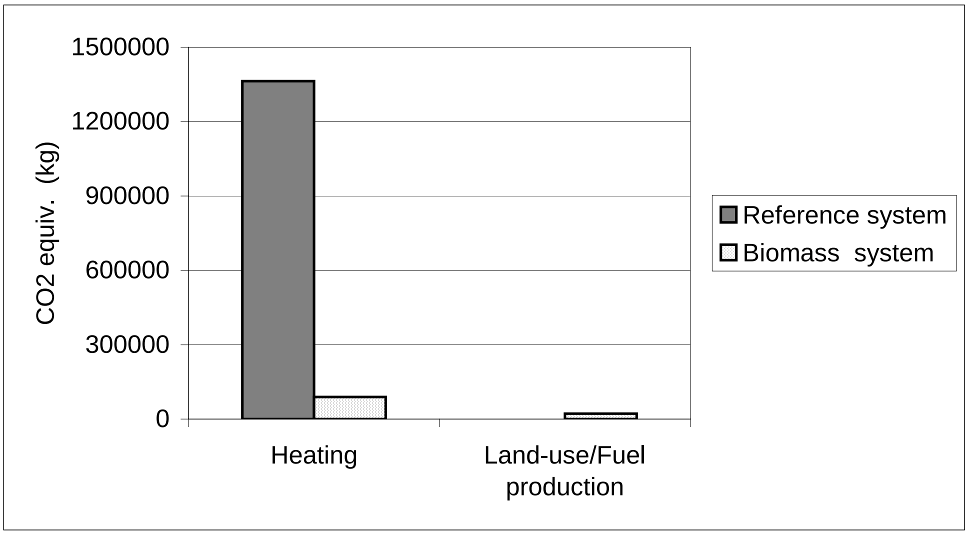


***Figure 2b – GHG emissions (kg $CO_2$ equivalents) for wood fuel case study.***



*Differences between systems*

The differences between the case studies was due to the biomass fuel production and the biomass boiler (shown in tables 12 and 13). The biomass boiler for the Miscanthus system had high inputs due to a large storage barn being erected involving considerable steel and concrete inputs. Although the gabian walls are traditionally seen as low energy input building materials, for the storage barn simpler and lighter materials would have been sufficient , such as the wood and steel construction used in the wood fuel case study.

***Table 12 - Summary of Wood Heat Case Study***

| **Reference system** | **Energy input (MJ)** | **$CO_2$ (kg)** | **Total in $CO_2$ equivalents (kg)** | **$CH_4$ (kg)** | **$N_20$ (kg)** |
|---|---|---|---|---|---|
| Heating | 17002878 | 1362698 | 1474963 | 3860 | 101 |
| Land-use/Fuel production | - | - | - | - | - |
| **Totals** | **17002878** | **1362698** | **1474963** | **3860** | **101** |
| **Annual:** | **680115** | **54508** | **58999** | **154** | **4** |
| **Biomass system** | | | | | |
| Heating | 1536759 | 89471 | 183734 | 539 | 268 |
| Land-use/Fuel production | 234791 | 21301 | 22159 | 30 | 1 |
| **Totals:** | **1771551** | **110772** | **205893** | **568** | **268** |
| **Annual:** | **70862** | **4431** | **8236** | **23** | **11** |

***Table 13 - Summary of Miscanthus Case Study***

| **Reference system:** | **Energy input (MJ)** | **$CO_2$ (kg)** | **Total in $CO_2$ equivalents (kg)** | **$CH_4$ (kg)** | **$N_20$ (kg)** |
|---|---|---|---|---|---|
| Heating | 4711007 | 376534 | 407446 | 1063 | 28 |
| Land-use/Fuel production | 51750 | 3830 | 3833 | 0 | 0 |
| **Totals** | **4762757** | **380363** | **411279** | **1063** | **28** |
| **Annual:** | **190510** | **15215** | **16451** | **43** | **1** |
| **Biomass system** | | | | | |
| Heating | 850508 | 43480 | 47653 | 167 | 2 |
| Land-use/Fuel production | 1576790 | 79503 | 79825 | 4 | 1 |
| **Totals:** | **2427297** | **122983** | **127478** | **172** | **3** |
| **Annual:** | **97092** | **4919** | **5099** | **7** | **0** |

*Installation and running the biomass boilers*

For the Miscanthus boiler systems, the fuel production accounted for 58% of the total energy input, where as for wood this was just 13% (Figure 3). The difference is not due to higher running costs and installation of the wood heat boiler, but by the considerable lower energy into of fuel production for the wood system.

***Figure 3a – Installation and running the biomass boiler –Miscanthus case study***

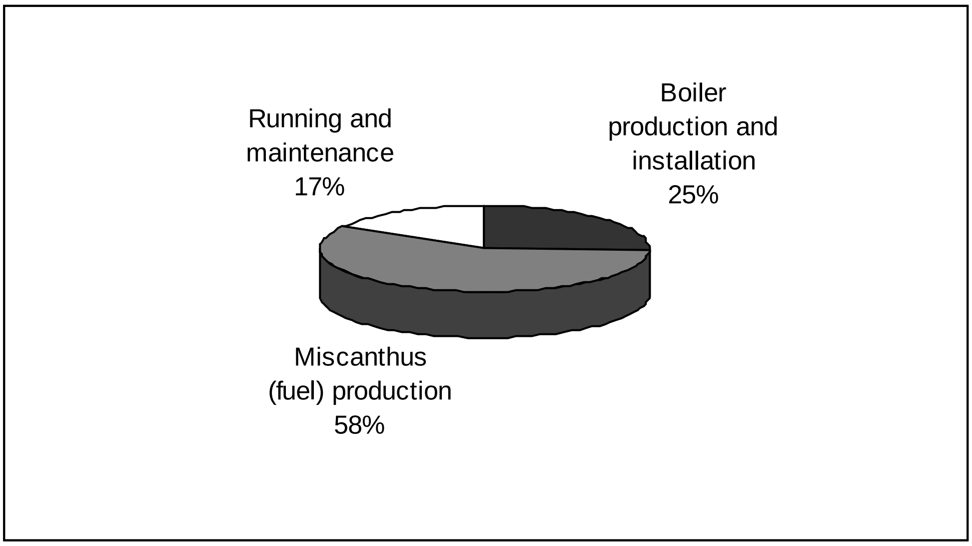
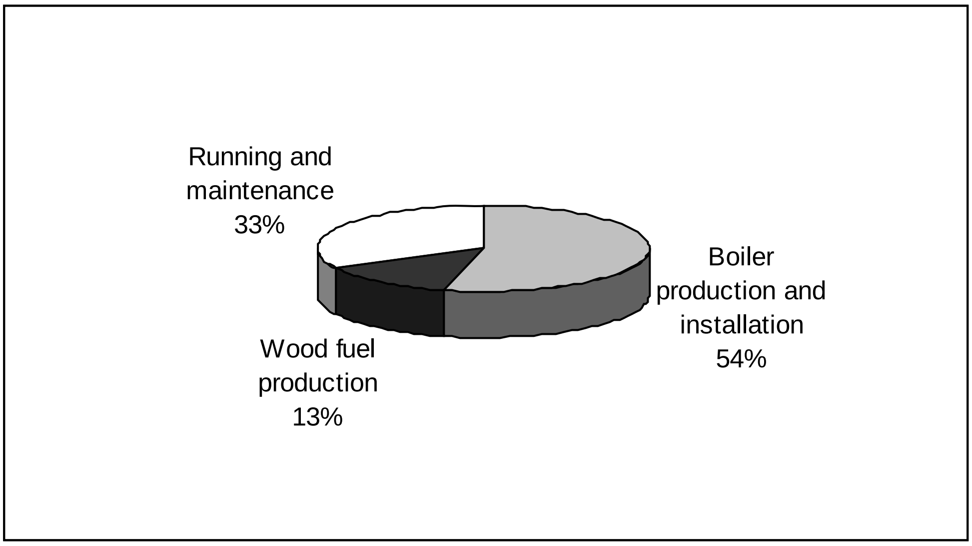


***Figure 3b – Installation and running the biomass boiler –Wood fuel case study***



*Fuel production*

A breakdown of the fuel production for both systems is presented in figures 4a and 4b, showing that for Miscanthus the majority of inputs occur early on at establishment whereas for wood fuel the chipping and extraction are significant.

For the thinnings no allocation due to establishment was included, as the broadleaved woodland had been established over 80 years ago, and much of the thinning material was naturally regenerated.

The slabwood came from managed conifer woodlands and so a small proportion of the establishment inputs was allocated to the slabwood section.

***Figure 4a - Fuel production (miscanthus)***

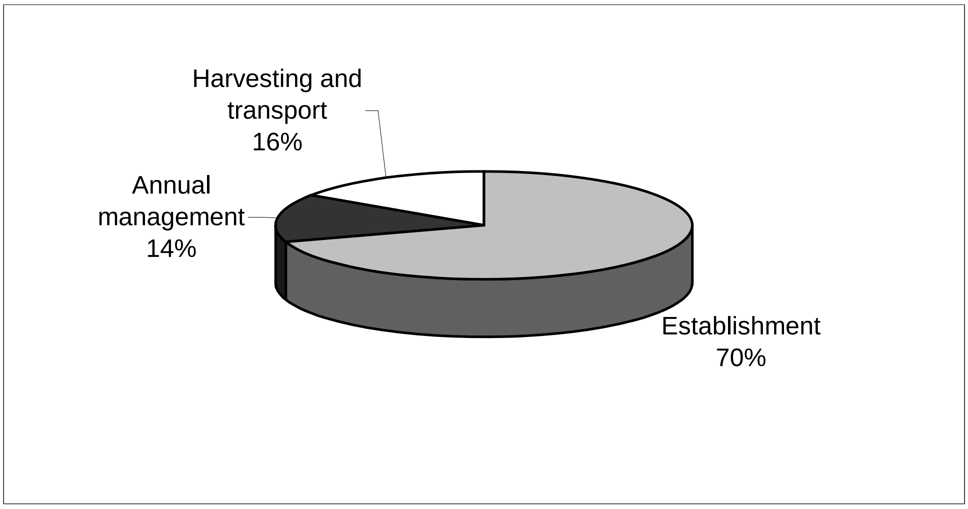
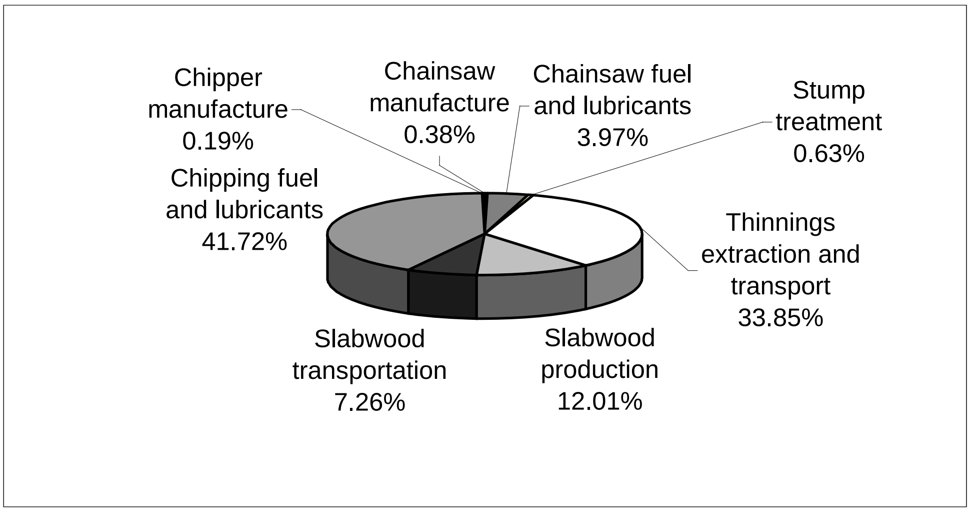


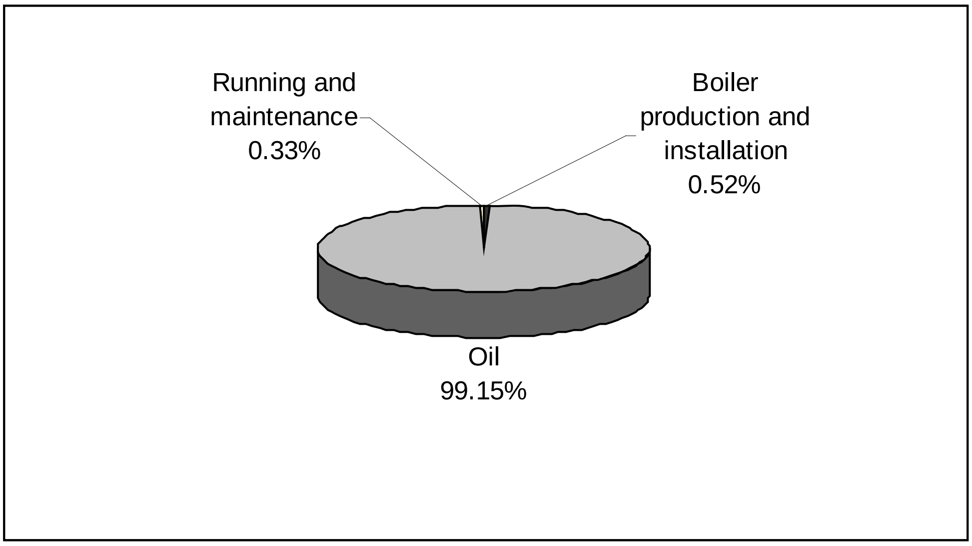
***Figure 4b - Fuel production (wood)***



*Oil reference systems*

For both systems the oil burnt was the main into the reference heating, systems , presented below in figure 5 for Miscanthus.

***Figure 5- Inputs to oil systems (Miscanthus)***



*Annual avoided emissions and sensitivity to nitrous oxide and methane levels*

The annual GHG emissions and the avoided emissions from the biomass system is presented in Table 14. The wood fuel system results in annul savings of 51 tonnes of $CO_2$ equivalent, compared to 11 for the Miscanthus system.

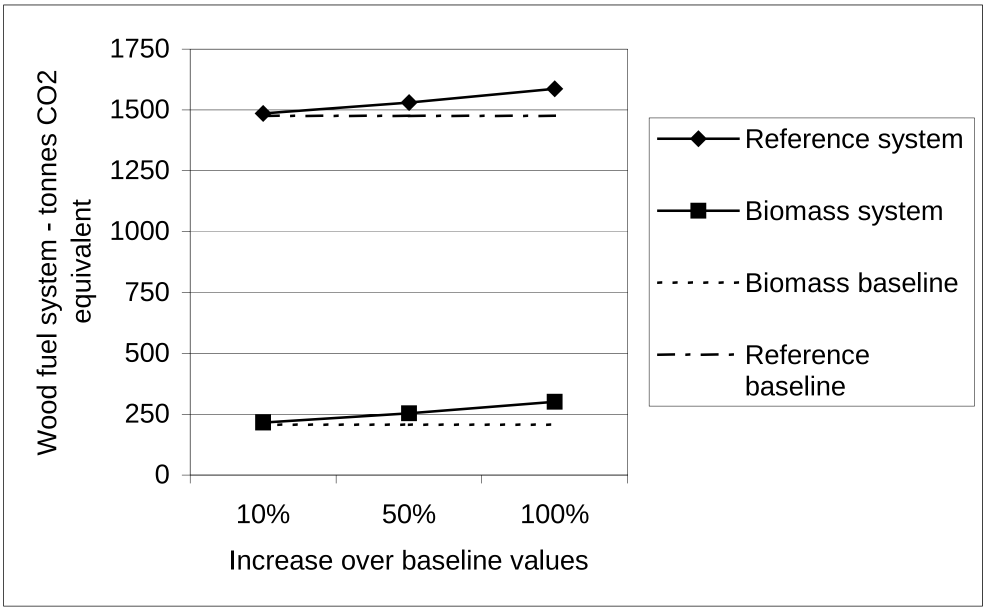
***Table 14 - GHG (CO2 equivalents) tonnes output per annum***

| | **Reference system** | **Biomass system** | **Annual savings** |
|---|---|---|---|
| **Miscanthus** | 16 | 5 | 11 |
| **Wood fuel** | 59 | 8 | 51 |

The GHG figure includes the methane and nitrous oxide data, where available. As this data was scare, and not available for all inputs, a sensitivity analysis was performed to examine the impact of greater nitrous oxide and methane levels. The main cause of concern was $N_20$, which with a global warming potential of 310 small errors in calculation can lead to large errors in emissions.

The wood fuel case study was used for this analysis. Three levels were examined, a 10%, 50% and 100% increase in methane and nitrous oxide levels. The quantities of gas were calculated, and converted to $CO_2$ equivalents. The results are shown below in figure 6.

*Figure 6 – Sensitivity analysis of increasing levels of methane and nitrous oxide*



For the biomass system, the increases were slight, ranging from 1 to 3 tonnes a year, resulting in increases of between 10 (10% level) and 95 (50% level) tonnes over the lifetime of the system. Although these quantities are small, if these small scale systems were to be replicated many times, this inaccuracy may cause significant differences in actual and determined GHG emissions at a national level.

## Discussion and conclusions

The UK government are supporting both wood fuel and energy crop heating systems through several programmes. In England there are incentives to plant Miscanthus under the Energy Crops Scheme, which provides grants for establishment costs for energy end- uses. There are also grants for capital installation of boilers under a government led 'clear skies ' programme (www.clear-skies.org). In Wales, the UK Forestry Commission have launched a Wood Energy Business Scheme (www.woodenergybusiness.co.uk), providing capital support for small scale heating systems, up to 1 MW, and grants for fuel processing companies. In addition wood supply from the state forests can be guaranteed if a private resource is not available. The total grant funding is £7 million pounds (EUR 10 million), and the targets are for 70 installations, and a total of 26 MW thermal installed. Using the data from this case study, of 0.32 kg per kWh, and a load factor of just 50%, approximately 36,500 tonnes of GHG emissions could be avoided per year.

The slowly evolving UK Emissions Trading Scheme (UK ETS), also provides incentives for renewable energy projects. This is currently voluntary, but the EU Emissions Trading Scheme (EU ETS) will impose mandatory limits on emission of greenhouse gases, and in January 2004 the UK Government released its Draft National Allocation Plan. Each installation in the UK ETS is issued with a carbon budget and if they fall short of its target it will be able to buy emissions from other participants. Having to purchase carbon allowances in order to comply with EU ETS could place a significant burden on UK companies. The scheme should establish a cost of carbon that will provide a tangible benefit for switching to bioenergy based systems. The current value of carbon is anticipated to be anything from is £3 to £12 a tonne (Enviros, 2004). It is not yet clear how small projects such as these could benefit, but there is a specific strand under the UK ETS for project led initiatives, and if the emissions reductions could be proven then there is potential to trade the credit.

This would result in a benefit of between £150 and £600 a year for the wood system and £35 a year for the Miscanthus system. The difference in the quantity of emissions per kWh and thus income, could influence the choice of fuel used in projects, with an emphasis on wood projects. However the key factor is in monitoring and verifying the emissions and the rules and systems involved, which may be different to the complete an full accounting used in this case study.

There are uncertainties over several of the data inputs, primarily in running the biomass boiler with maintenance and start up fuel being estimated rather than measured. The sensitivity analysis of methane and nitrous oxide also showed that errors could be introduced if excluding those gases from the analysis. It is unclear yet how small scale projects will be monitored in the UK, but if project monitoring and verification follows the rules set out by the World Bank Prototype Carbon Fund than these gases will be included. The choice of reference baseline is also an area with a high degree of uncertainty, particularly in terms of land use, and changing the reference land use could have impacts on the quantity of avoided emissions determined.

In the wider UK context these case studies represent a small quantity of avoided emissions, but the important element is the replicability of these two systems.

As would be expected the wood system had higher savings of $CO_2$, but there is however a higher degree of replicability with the Miscanthus system in many parts of the UK. The forestry system involved high labour inputs and machinery not commonly available such as the use of specially adapted wood chippers. The Miscanthus system uses conventional farm machinery and is not dependant on forest cover. Wood is also subject to competition from other end-users as demonstrated by the board mill in this case study whereas purpose grown energy crops are not.

The biomass industry in the UK is still in its infancy, and these results support current policy regarding the installation of many small scale heat systems to kick-start fuel supply chains, with the potential for larger CHP schemes in due course which will deliver much greater benefits.

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