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"The Sustainability of Biomass Heating in Scotland"

By

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Executive summary

The Scottish government has target 11% of total heat generation in year 2020 must come from renewables, which biomass is playing an important role to achieve this target. However there is a question about biomass that is it actually a sustainable source. Major concerns of biomass are GHG emission that biomass release when we burn it and the sustainability issue of biomass sources, which the major source is forest. This study is focus on the GHG emission, the availability of biomass and also other environmental impact. The actual GHG emission that biomass gives is less than emission from fossil fuels, however there are some cases that using fossil fuel is better than biomass, the scenarios like cutting down the whole tree just for generating energy or clear-felling the whole forest. The situation like clear-felling might happen because the availability of biomass that Scotland has is not enough to support the 2020 target, Scotland would need 2 million oven dried tonnes at least and it can increase to 10 million tonnes at maximum. The demand is a lot higher than the domestic supply and the pressure will be on the forestry commission who in charge of providing biomass to the market. One solution to support the 2020 demand is to import woody products from overseas, but the source from overseas must be sustainable sources that regulate with the biomass sustainability criteria from the Scottish government or from the EU. Nonetheless, there are some situations that could lead to an unsustainable development from using biomass. So there is possibility that biomass might not be the right answer for reducing the GHG emissions, the result could be totally opposite with what the government aim to achieve.

Acknowledgement

I would like to thank my supervisor Jeremy Cockroft for the help and guidance he has given me. I would also like to thank Neil Phillips for all his help and valuable resources he sent to me.

I would like to take this opportunity to thank all those who have contributed in any way, shape or form to the completion of this project report. Thank the University of Strathclyde for giving me this opportunity and those that give me their advice and support, friends for their ideas and criticisms and my parents for their invaluable support.

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Chapter 1: Introduction

"Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs."

Brundtland Commission, "Our Common Future"

There are probably many definitions of "sustainable", it is used on many occasion in expressions such as "sustainable development", "sustainable living", "sustainability", et cetera. The word "sustainable" itself probably have a general meaning like 1. will not put more strain on human society and on the environment, or 2. to continue doing this for ever. So when we talk about sustainability of biomass the first question must be "Burning biomass releases carbon, how can this not put more strain on the environment and compromise the living of future generations?" Burning biomass is the same as burning fossil fuel in term of carbon emission, but the difference is that burning fossil fuel result in release a stable carbon that has been preserved under the earth surface for millions years into our atmosphere. On the other hand, by the life cycle of trees, biomass emits carbon that has been absorbed and collected from the atmosphere during that tree lifetime. If we consider only carbon released during biomass combustion, it has total zero carbon emission, for the amount of carbon released is the same amount of carbon that was removed and will be removed from the atmosphere by the remaining trees. For instance, see figure 1 below, the comparison between conventional fuels' and biomass' carbon cycle.

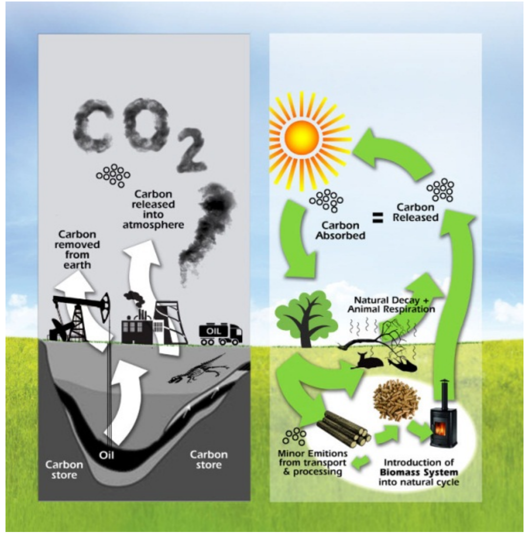


Figure 1 : Carbon-cycle for bioenergy and fossil fuel

Nonetheless, biomass will have to go through many processes before it reaches the end-user, so there will be some considerable amount of carbon released before it can be used. Details of the carbon impact of using biomass will be presented later on in this report.

The second question regarding sustainability of biomass should be "how long can we continue doing this and is there enough available wood fuel?" Biomass fuel use at its simplest means we cut down trees, burn it and turn it into energy. If only deforestation was operated to produce wood fuel and no replanting is encouraged then the resource would be rapidly depleted and the carbon emission would be no different than coal or oil, to put it simply it might be better to leave the tree in forests and burn coal instead. One major topic that must be considered about sustainability of biomass is the management of forest and the management of wood fuel supply, In the UK, Forestry commission is responsible for adopting and implementing forest management and also gathering information of supply on a regular basis.

The urge to reduce greenhouse gas emissions, carbon footprints and leave the world a better place for our children and future generations is currently the most interesting and important issue on the global scale. The Scottish government mandated targets, by 2020, to achieve 100% of Scotland's electricity consumption and 11% of Scotland's heat generation from renewable sources, of which biomass consists around

91% of actual total generation (1, page four section 1.2) and providing the best opportunity to reach the target.

In 2011, The UK Government's renewable heat incentive (RHI) was launched to promote biomass heating, the contract lasts for 20 years and effectively throughout the UK. The Scottish government strongly promotes the installation of biomass heating or combined heat and power schemes, mostly for off gas-grid areas such as Highland and Isles, with the Scottish biomass heat schemes that was announced in late 2010, The Scottish biomass energy supply agreement framework was announced earlier this year and recently approved Grangemouth biomass power plant, A 120MW+200MWth combine heat and power plant. All of this emerging policy and deployment of biomass boilers not only bring a lot jobs to the area but it also would significantly increase demand for wood fuel.

Chapter 2: Objective

The main objective of this project is to studies the sustainability of biomass heating, and in term of sustainability, we considered "The carbon saving from using biomass" and "The total biomass available that can correspond with the government target". The goal of this research is to find the actual carbon saving from switching from fossil fuel to biomass, is it true that we save any carbon from using biomass, and how long can we keep using biomass or what could be the maximum demand that we can still biomass "sustainable". This scope of research can be divided into three parts which are

- To review the sustainability criteria on biomass heating in Scotland, Scotland never have sustainability criteria for biomass heating before, however there are recommendations in the EU level that Scotland could adopt.
- To estimate the total carbon emission and also GHG emission, we will use the existing tool to calculate what are the GHG emissions from various scenarios (ie. Different types of wood fuel, Different types of wood product, Transportation, et cetera).
- To forecast the availability of woof fuel that would be needed and to look for potential supply from domestic products. The assumption for future demand come from the government ambitious goal for the 2020 11% renewable heating target.

Chapter 3: Research design

In this chapter we will look into the methodology that has been used in this project to achieve the objectives, so as you know now what is the meaning behind the word "sustainable" in biomass industry, we will begin from the basic calculation about biomass heating, which is estimate the wood fuel demand, we need a calculation method for changing the heating demand in thermal unit into the volumes or mass unit of biomass.

3.1 Biomass consumption

This method will only express an approximate quantity and volume of biomass demand, due to the variation of biomass quality, moister content, types and boiler efficiency, so it will be just an simple calculation that represent roughly demand of wood fuel.

Before we can convert the heating demand into biomass quantities we need to know the calorific value of that type of biomass first, the table below shows the calorific value of each type of biomass.

Fuel	Net Calorific Value (CV) by mass GJ/tonne	Net Calorific Value (CV) by mass kWh/kg	Bulk density kg/m^3	Energy density by volume MJ/m^3	Energy density by volume kWh/m^3
Wood chips (30% MC)	12.5	3.5	250	3,100	870
Log wood (stacked - air dry: 20% MC)	14.7	4.1	350-500	5,200-7,400	1,400-2,000
Wood (solid - oven dry)	19	5.3	400-600	7,600-11,400	2,100-3,200
Wood pellets	17	4.8	650	11,000	3,100
Miscanthus (bale - 25% MC)	13	3.6	140-180	1,800-2,300	500-650
House coal	27-31	7.5-8.6	850	23,000-26,000	6,400-7,300
Anthracite	33	9.2	1,100	36,300	10,100
Heating oil	42.5	11.8	845	36,000	10,000
Natural gas (NTP)	38.1	10.6	0.9	35.2	9.8
LPG	46.3	12.9	510	23,600	6,600

Table 1 : Typical calorific values of fuels (2)

According from the table above, you can see the percentage of moister content (MC) after some specific type of biomass. Moisture content is a very critical parameter for biomass, because the MC value can affect the efficiency of energy conversion and also some of boilers can only operate in limited range of MC. If the MC is outside the range of that boiler, the converting process might have low efficiency, which lead to increased carbon emission, or might lead to damaging the boiler. And if you consider biomass consumption by its weight, the difference in MC can result in lower energy output, but it will have no significant if you judge the consumption by biomass volume. Here is the link for an example of changing in calorific value of biomass varies with the moisture content (3).

After we know what is the calorific value is, now if we assume that there are 1000 kWh of thermal demand, assume boiler efficiency is equal to 90% then 1000 kWh ÷ 90 % = 1111.11 kWh. Thus we need to input 1111.11 kWh to create a 1000 kWh from a 90% boiler efficiency.

- Wood chips (MC 30%) : 1111.11 kWh ÷ 3.5 kWh/kg = 317.46 kg or 1111.11 kWh ÷ 870 kWh/m^3 = 1.277 m^3 of wood chips
- Wood pellets : 1111.11 kWh ÷ 4.8 kWh/kg = 231.48 kg or 1111.11 kWh ÷ 3100 kWh/ m^3 = 0.358 m^3 of wood chips

Now we can know how much we need for producing the right amount of heat demand we want. We will continue with the methodology that is famous for assessing environmental impact of any products which is the Life-cycle assessment.

3.2 The Life-Cycle assessment method

After we know the volume or mass of biomass that we will needed, next is to find what are the total GHG emissions that cause from using biomass. The most widely accepted technique for assessing environmental impact is the life-cycle assessment (LCA) that I have mentioned in the previous chapter. The technique is promoted to be suited for environmental management and sustainable development, thus every tool for estimating the environmental impact from biomass have been adopted this methodology for calculation. Before we can start using any tool, I believe that we have to understand basic principle of LCA techniques to be able to utilize the tool efficiently. The figure below has shown the life cycle of biomass in general,

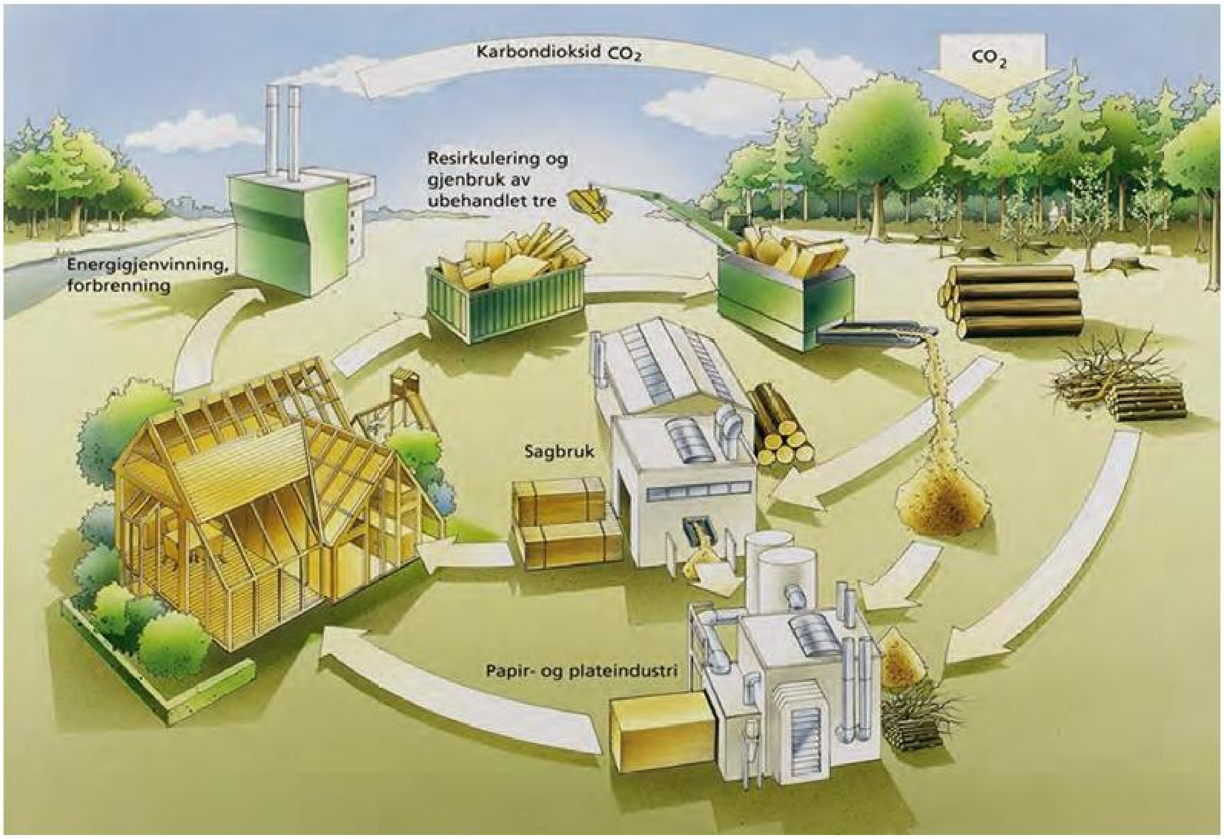


Figure 2: The basic life cycle of Biomass (4)

The basic principle of LCA techniques is to considered and assessed an environmental impact for each and every process involved in the using that product. As you can see from the figure above that there probably around 5-6 steps before the wood fuel has reached the end user. The reason is because the parameter that we interested (carbon emission, GHG emission, environmental impact, et cetera) don’t occur in just combustion of product, as you can see every step include carbon emission whether it come from processing, transportation, or waste wood recovery; thus LCA techniques is intended to estimate the aggregate outcome of interested parameters. The general approaches for LCA are as follow;

- Define what “cradle- to-grave” of the interested system is.
- Set system boundary conditions.
- Identify what are the impacts of interested factor, such as Costs, air pollution, GHG emissions, wastes, resource depletion, et cetera.
- Assess the overall trade off compared with alternative system, and also considering uncertainties of future events.
- Identify major sources of threat and assess any improvement on the interested factor.

These are the general rules or principle for LCA method, if we want to apply this technique to any biomass energy system, the process must be as following;

- Define the major process of biomass; the figure below is a sample of biomass process in LCA assumption from the Scottish government website. The biomass process flow diagram below is for general small-scale biomass production that might be able to view as a representative of how a forest based wood chips production system is operating in Scotland.

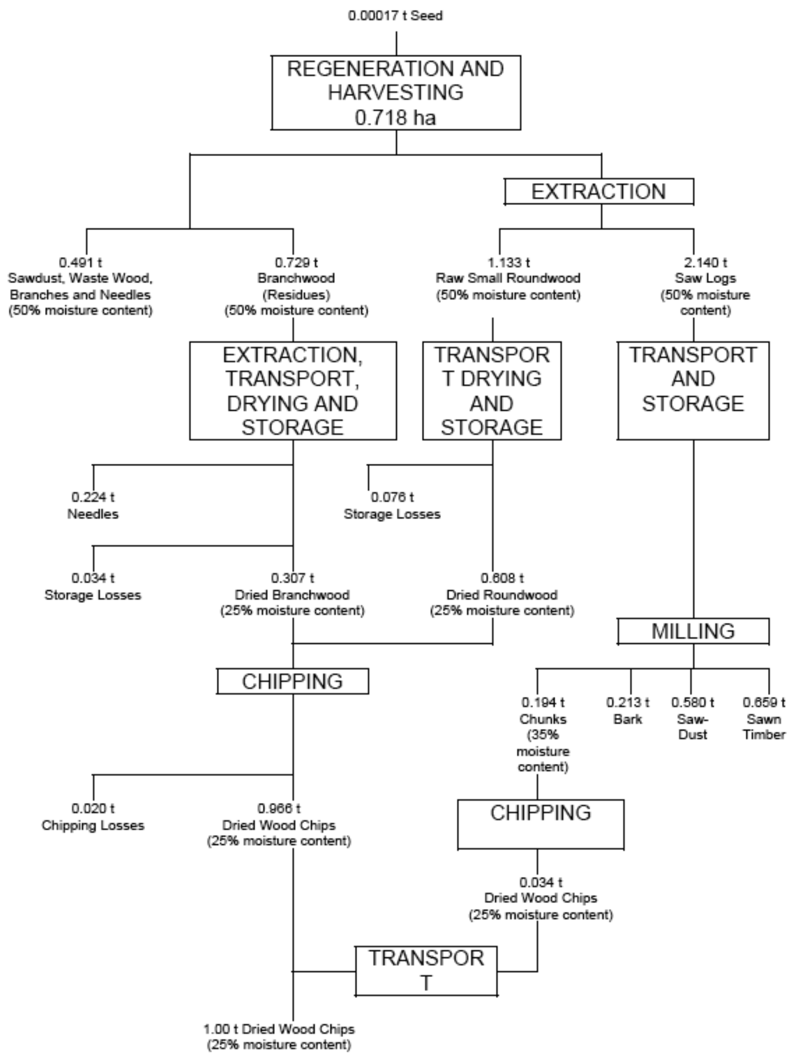


Figure 3: Biomass/process flow diagram for small-scale production of wood chips from woodland management (5)

- Important parameters are emission, useful work, land use change and costs.
- For the system boundary conditions, policy and regulations are the major factors for setting up the boundary.

Although there are a widely recognition of the effect of land use change that could have significant impact on total GHG emission, but there are still no prominent calculation methodology that would be able to give the acceptable results from land use change, due to the limited consensus on various aspect of the calculation and also limited in scientific evidence of appropriated values that should include in the calculation. Hence, the GHG emission from land use change is excluded from system boundaries of this research.

3.3 The BEAT2 (Biomass Environmental Assessment Tool)

After we know the concept of using LCA techniques to assess the environmental impact from using biomass, we can now use the tool efficiently. BEAT2 was used in this report to study the total GHG emission from biomass heating, it is a program in Microsoft Access, and you will need Microsoft Access 2000 or later to run the tool. The tool is UK-based and would only apply to the bioenergy used inside of the UK only; the tool cannot provide the impact of international feed stock. The tool is very simple and you can input your own parameter based on your own LCA assumptions. The example about how to use the tool can be found in Appendix A.

3.4 Availability of biomass supply study approach

The availability of wood fuel for the future demand of biomass are taken from the Woodfuel demand and usage in Scotland 2012 update and the future prediction of wood fuel resources are taking from the study by Wood fuel task force for the Forestry Commission in Scotland and two study, one from CONFOR and another one from the National forest inventory report. Some of information was taken from Renewable heat action plan Scotland 2011.

The first is the estimated biomass demand from the renewable projects in Scotland which was studied by The Forestry commission Scotland, Woodfuel demand and usage in Scotland 2012 update, the demand is forecast by estimated from the proejcts that has been granted in industrial/commercial level. The total heat demand in this report is presented in unit of mass of biomass (oven dried tonnes, odt). The report has separated the level of demand into three levels which are existing major industrial/commercial that using more than 10,000 odt per year, industrial/commercial that using 1,001-10,000 odt per year and other industrial/commercial heat only that using less than 1,000 odt per year.

The second report that has been used is the Supply of wood for renewable energy production in Scotland, by the Wood fuel task force. The report has conducted a research on the existing woody products that are already committed to the existing market and what area the potential of biomass product that are still in the forest. And they also forecast demand using the information from Woodfuel demand and usage in Scotland 2010 combine with the demand from sawlog and wood panel industries to 2021. The report also presented availability of woody products and forecast demand in unit of oven dried tonnes.

The next two reports are from ConFor and the National forest inventory, these two reports are conducted at the UK level, the demand and availability forecast was used to compare with the 2020 target. The ConFor is presented in unit of mass but the National forest inventory is presented in unit of volume (cubic metre), so I decided to just look for the trends of their forecast and did not compared it with the estimated demand because the problem when converting volume of biomass into mass, the moisture content must be known and it difficult to obtain the moisture content of each type of woody products.

Some part from the Renewable heat action plan Scotland 2011 was used to see the possibility of some other alternative that might help reduce the demand of biomass wood fuel. The technologies involved are small scale renewables (solar panel, combined heat and power), heat pumps (water, air and ground source) or biogas. And also the estimated heat output need at the 2020 target which is presented in unit of energy output (Giga watts hours).

Chapter 4: Literature review

I have mentioned in the introduction that sustainability of biomass consists with two elements, first is the true carbon reduction when switching from conventional fuels to biomass, or even compared with leaving trees in the forest, and second is the ability to continue using biomass with the significantly increasing demand. The first thing before we going into details on sustainability of biomass, we should look at where are these demand could come from, the biggest sources of demand in Scotland come from the government policies and schemes that are supporting biomass consumption throughout Scotland. These policies are putting a lot of demand on the biomass market and leading to the question of sustainability of biomass.

4.1 Biomass heating policy in Scotland

The Scottish government aims to create a sustainable, economically viable renewable heat industry in Scotland to support their 2020 renewable target and with this in mind the first Biomass heat scheme was introduced in October 2008 and has continued until the final round that was announced in December 2010. The total support is worth around £3.3 million, funded by forestry commission Scotland, European Regional Development Fund and Scottish Government. The money was distributed between Highland & Island area for £1.3 million and lowlands & uplands Scotland area £2 million. The projects that were awarded by this scheme is said to be producing 14MWth and saving carbon dioxide around 14,000 tonnes annually. According to recent information given in Scottish government website, future biomass heat projects will be supported by The Renewable heat incentive (RHI), which is being introduced at a UK level. The RHI is said to be the world's first long-term financial support programme for renewable heat. The RHI was launched in November 2011, the scheme aims to support non-domestic sector by providing payments to industry, businesses and public sector organization, and The RHI scheme will be available to homeowners by spring 2014.

The current policy now applying across Scotland is the Routemap for Renewable energy in Scotland 2011, The Routemap is an update and extension from the first policy, a Renewable heat action plan that was produced in 2009, in which biomass is playing a big part. Biomass provides around 91% of total renewable heat, from a recent survey by the Energy Saving Trust, which is total of 4.1% of the predicted non-electrical heat demand in Scotland in 2012. This figure is near the target in the Renewable heat action plan for Scotland which is set to have 4.7% of non-electrical heat from renewables in 2014/2015, see figure 2 for the prediction chart. The total forecast of heat demand in 2020 is set to be around 60,089 GWh (60.1 TWh) and 11% of this is 6,420 GWh (2.07 GW installed capacity) which you can see is it need more than 4,146.14 GWh.

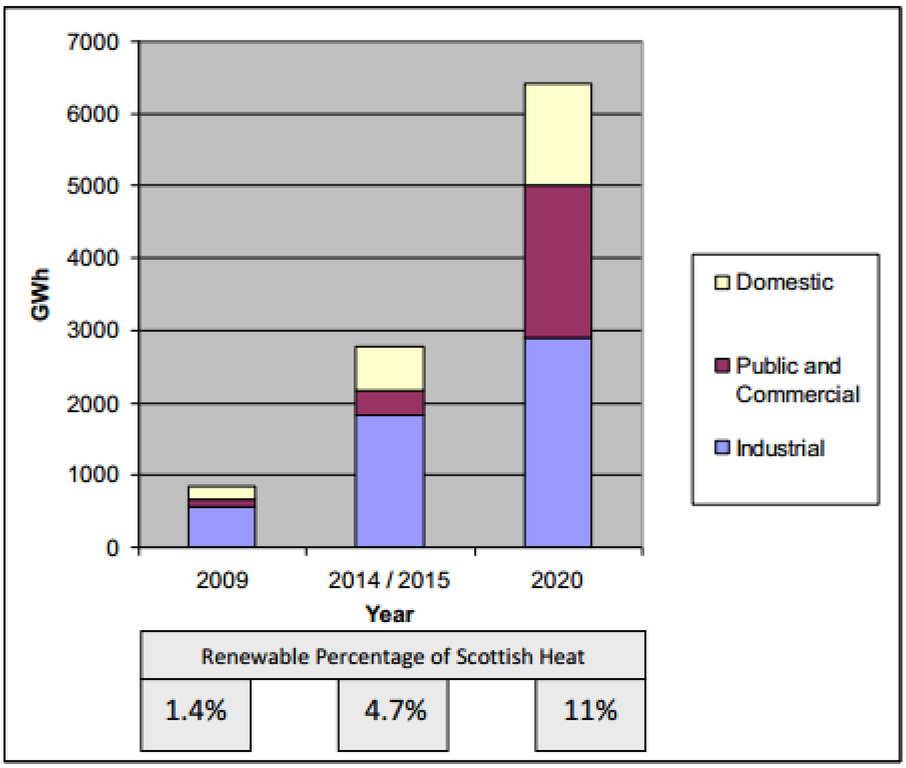


Figure 4: Estimated renewable heat demand to 2020 (1)

After we know what are the policies and the mechanism behind the biomass demand, next thing is to know what the impacts from using biomass are and why biomass is being question on sustainability.

4.2 Carbon impact from using biomass

Biomass is the name for organic material that can produce energy; to understand about carbon emission we need to understand these organic materials first. A Plant absorbs carbon dioxide in the air where it grows. When it dies or is cut down to be used to produce energy it releases the carbon back to the atmosphere. Thus from this simple life cycle, biomass will not increase the total carbon that already existed in the atmosphere; however the carbon is not going anywhere as well. One of the major concerns is that when we burn biomass carbon is released to the atmosphere the same as when we burn oil and gas, so in order to say that biomass is really "sustainable" we need to take into account not only the carbon emission when the fuels is burnt, but also the fuels preparation and transportation need to be considered as well. We have to consider a range of additional emissions such as,

- Emission of Nitrous oxide (a potent greenhouse gas) from fertilizer process.
- Emission from agricultural application such as machinery usage for cutting down or trimming down the tree.
- Emission from transport of biomass from the origin to the final destination and
- Emission from the energy used when processing the biomass (Drying the materials, making wood pellet)

To investigate the total carbon impact or carbon saving from using biomass we need to find some scientific method to be able to cover every possible emission that could occur from tress planting, processing, transporting, until disposal stage. One of the assessments of carbon impact from using biomass was conducted by Forest Research and North Energy Associate; they used LCA method that was mentioned in the previous chapter. Apart from LCA method there are also 2 tools currently available for the UK regarding with carbon assessment from using biomass, the first tool is -The Biomass Environmental Assessment Tool (BEAT2) - , introduced by Defra, the Biomass Energy

Centre and the Environment Agency .Another tool is -The UK Biomass & Biogas Carbon Calculator- that has been introduced by the Office of Gas and Electricity Markets (Ofgem), from the data I have received from the Scottish government is that generator and supplier must show the GHG life cycle of wood fuel used and Department Energy & Climate Change (DECC)has recommend to use the tool from Ofgem, both of these tools are available for freely download from the website below

1. BEAT2 - http://www.biomassenergycentre.org.uk/portal/page?_pageid=74,153193&_dad=portal&_schema=PORTAL
2. The UK Biomass & Biogas Carbon Calculator - http://www.ofgem.gov.uk/Sustainability/Environment/RenewablObl/FuelledStations/bbcc/Pages/bbcc.aspx

4.2.1 The previous studies on sustainability of Biomass

The current state of research about the sustainability of biomass is focus on the actual carbon emission from using biomass. However there are no research that is specifically focused on biomass heating yet and also almost every research does not takes the availability of biomass into account, which is also a major topic of the sustainability of biomass. And the results from current studies are as following;

4.2.1.1 the "UK Bioenergy Strategy supplementary note: Carbon impacts of forest biomass" report (6)

An analysis from the Forest Research and North Energy Associates research has been used in this report, the report investigated a range of forest management scenarios, some are under management and some are unmanaged. There are 710 scenarios that were considered, include managed and unmanaged forest. Thus, this analysis consist with a large variety of possibilities, such as ;using harvested wood for energy only ; using harvested wood for materials ; using harvested wood for energy and materials; and a scenarios that we leave the forest untouched. The "relative GHG emission" for each scenario was assessed on the basis of CO2-equiverlent per hectare per year; the relative GHG emission is defined as

"Relative GHG emissions = Absolute GHG emissions – Counterfactual GHG emissions"

And it was estimated over time horizons of 20, 40 and 100 years.

Absolute GHG emissions were calculated as the sum of:

- The GHG emissions from carbon stock changes in forests
- The quantity of harvested carbon utilised (and hence sequestered) in wood products
- The GHG emissions associated with forest operations
- The GHG emissions associated with wood harvesting and extraction
- The GHG emissions associated with wood transport
- The GHG emissions associated with wood processing
- The GHG emissions associated with disposal of harvested wood products at end-of-life.

Counterfactual GHG emissions were calculated from the event that the UK forest was left unharmed and everything that should be using these woods (for energy and materials) would be supplied by other means instead (Imported wood or non-wood materials). For instance, the power generation that would come from biomass was come from natural gas, oil and coal instead. So, we can see that Relative GHG emission is can be consider as an comparison of total GHG emission from a life-cycle of biomass against other types of fuel.

The result shown in this report stated that using biomass from managed forest result in better GHG benefits from just leaving the trees in forest. However, there are some specific scenarios from the analysis such as; all the wood harvested from forest (almost every part of the trees that above ground) are used for generating energy only, instead of mixing between energy and materials; turn out to have relative GHG emission from using wood to be relatively high, compared to let the trees grow and continue to accumulate carbon absorption. The figure below has shown the result from the analysis of relatively GHG emission from different scenarios and also different time horizons.

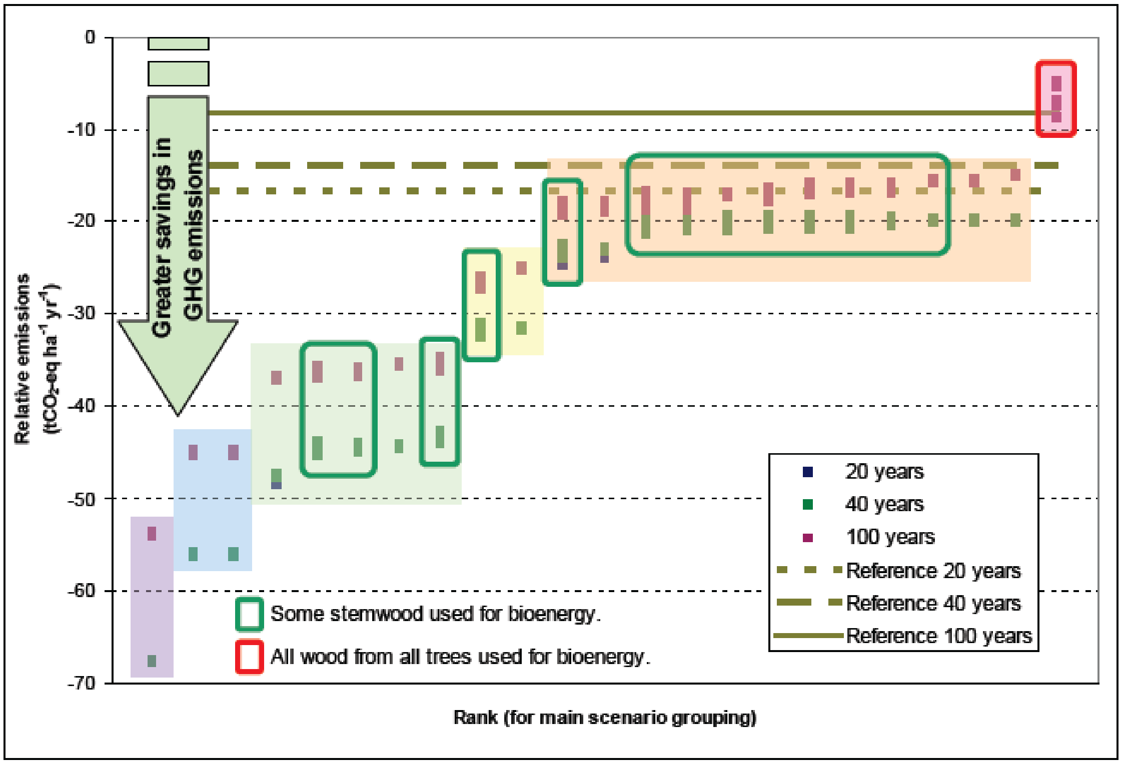


Figure 5: Relative GHG emission

Group No	Mean relative emissions (t CO_2-eq ha^{-1} yr^{-1})		Scenario	Scenario forming group					
	20/40 year time horizon	100 year time horizon		Sawlogs		Small Roundwood		Bark	Branchwood (50%)
				Main	Off-cut	Main	Off-cut		
1	-68	-54	04	Sawn timber	Particleboard	Particleboard		Fuel	Fuel
2	-56	-45	10	Sawn timber	Particleboard	Pallets	Particleboard	Fuel	Fuel
			16	Sawn timber	Particleboard	Fencing	Particleboard	Fuel	Fuel
3	-45	-36	03	Sawn timber	Fuel	Particleboard	Particleboard	Fuel	Fuel
			05	Sawn timber	Particleboard	Fuel	Fuel	Fuel	Fuel
			15	Sawn timber	Particleboard	Fencing	Fuel	Fuel	Fuel
			17	Sawn timber	Particleboard	Fuel	MDF	Fuel	Fuel
			22	Sawn timber	Particleboard	Paper & card	Paper & card	Fuel	Fuel
4	-32	-26	13	Sawn timber	Fuel	Fencing	Particleboard	Fuel	Fuel
			19	Sawn timber	MDF	Fencing	Particleboard	Fuel	Fuel
5	-21	-17	02	Sawn timber	Fuel	Fuel	Fuel	Fuel	Fuel
			06	Sawn timber	Fuel	MDF	MDF	Fuel	Fuel
			07	Sawn timber	MDF	MDF	MDF	Fuel	Fuel
			08	Sawn timber	MDF	Fuel	Fuel	Fuel	Fuel
			09	Sawn timber	Fuel	Pallet	Fuel	Fuel	Fuel
			11	Sawn timber	MDF	Pallet	MDF	Fuel	Fuel
			12	Sawn timber	Fuel	Fencing	Fuel	Fuel	Fuel
			14	Sawn timber	Fuel	Fencing	MDF	Fuel	Fuel
			18	Sawn timber	MDF	Fencing	Fuel	Fuel	Fuel
			20	Sawn timber	MDF	Fencing	MDF	Fuel	Fuel
			21	Sawn timber	Fuel	Paper & card	Paper & card	Fuel	Fuel
			23	Sawn timber	MDF	Paper & card	Paper & card	Fuel	Fuel
6	- 7	-7	01	Fuel		Fuel		Fuel	Fuel

Table 2: Scenario forming

You can see that most of scenarios are having negative value of GHG emission (greater GHG benefits) except the scenarios on the most right of the figure that have less negative value from the reference lines ,in which the reference line is leaving trees in forest for 20, 40 and 100 years horizon. You can see from the figure that these scenarios were put in a red box. In conclusion from this report, if we used every parts of the tree for energy, it will not be sustainable and leaving trees in forest would be better in term of GHG emission.

4.2.1.2 The “Biomass: Carbon sink or carbon sinner?” report (7)

This report is based on the work of AEA for the Environmental agency to carry out the GHG emission from producing and using biomass for heat and electricity generation compared to coal and gas. This report used BEAT2 tool to investigate the environmental impact and the levels of GHG emission from different scenarios of biomass in the UK.

According to the report, biomass are generally has lower GHG emission from those conventional fuels. However, the report said that there are a change of land use occurs, and it might result in a loss of GHG that has been saving from the first place. In this research the found out that the most impact on GHG emission is come from how a fuel is produced, transported and processed or we can say it is how good in overall practices of energy generation from biomass are. See in the figures below on how GHG emission can varies by the difference of practices.

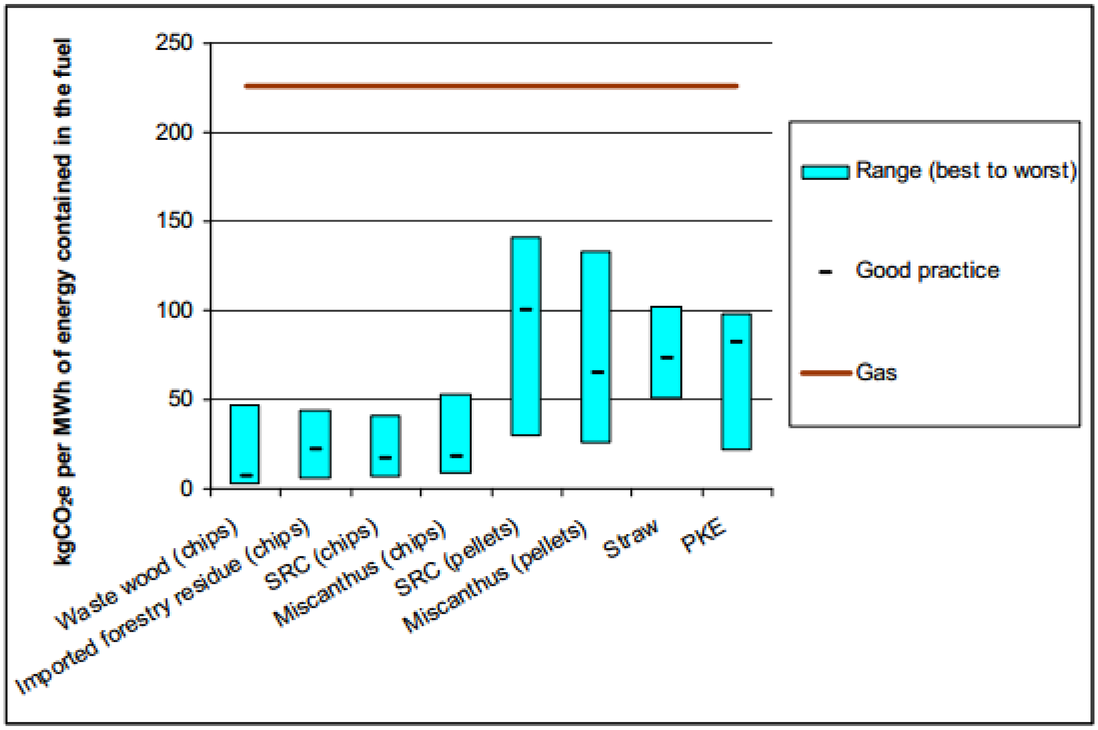


Figure 6: Estimated GHG emission

You can see from the diagram that every types of biomass are vary by some range depended on how good it was produced before turning into a useful materials that can producing heat or electricity. There was some considerable variation in carbon dioxide emission from biomass, but even emission from the worst practice it is still lower than the emission from natural gas, as you can see it is illustrate by the red line in the figure above. The figure below show the overall GHG emission comparison between using biomass in heating application with gas boiler.

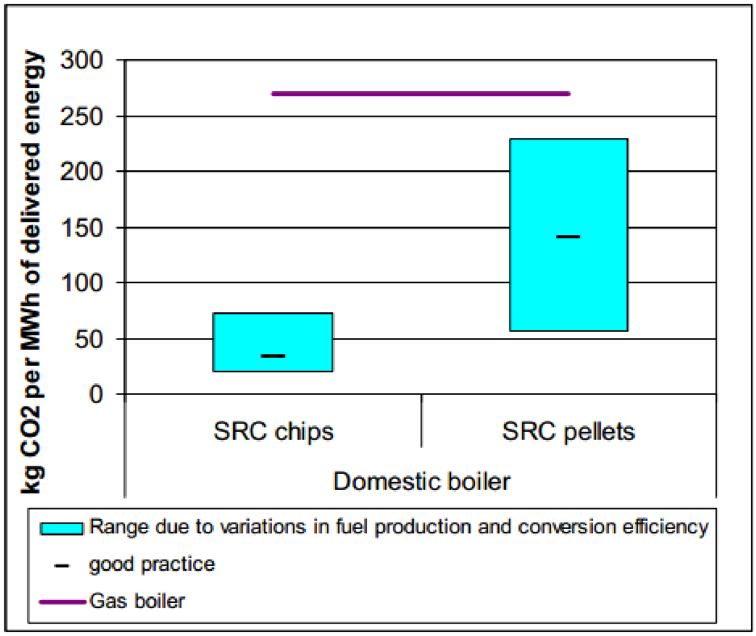


Figure 7: Estimated biomass heating GHG emission

The diagram shows a variation of GHG emission from using SRCchips and pellets (SRC stand for Short rotation coppice) from different type of fuel processing and also the conversion efficiency of boiler, range from best tot worst practice. You can see that when we using SRC pellet, the GHG emission from worst practice is almost reach with the gas boiler line which compared to the range SRC chips that is much lower than those two fuels. Despite from biofuel practices, land use change could possibly affect the sustainability of biomass the most. You can see from the figure below that land use change can cause a negative value of total carbon saving.

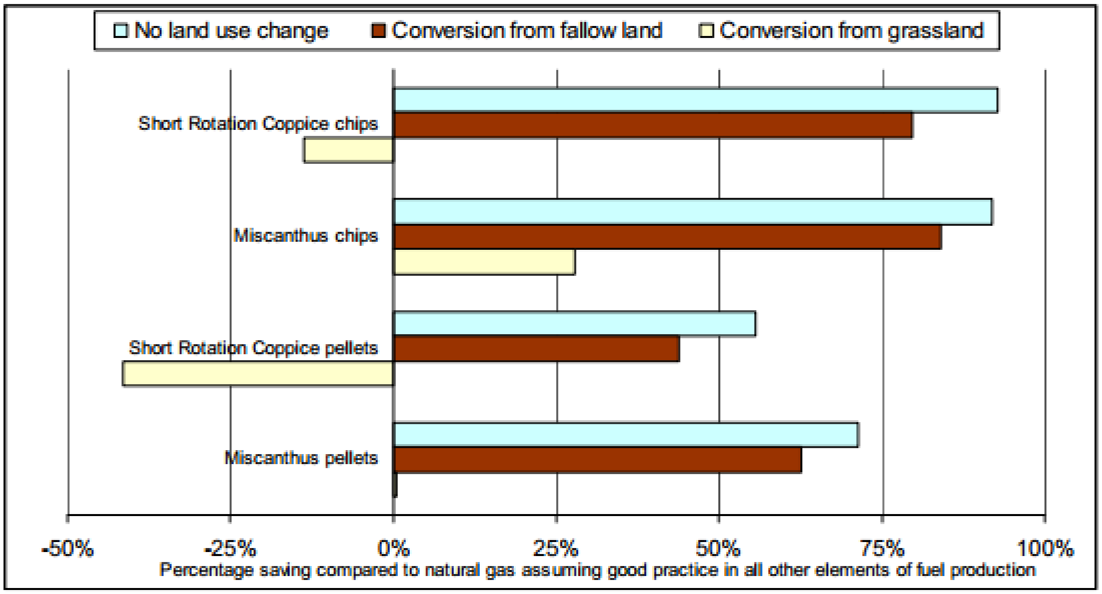


Figure 8: Percentage of saving from Land use change

The bar charts showed an average GHG emission due to land use change for the time period of 20 years which is the typical lifetime of energy crop. According from the diagram, there is small decreased when using fallow land to grow energy crop, however, a significant reduction can be seen when using grassland for plantation. According to the report, there are no evidence that grass land in the UK has been used to grow energy crops, however if demand for biomass is still rising there would be a shift in type of land use to be on permanent grassland.

4.2.1.3 Biomass Energy centre (8)

Biomass Energy centre also published their own carbon emission compared between each type of fuels which you can see from the table below.

Fuel	Net calorific value (MJ/kg)	Carbon content (%)	Approx. life cycle CO_2 emissions (including production) See note 1		Annual total CO_2 emissions to heat a typical house (20,000 kWh/yr)		
			kg/GJ	kg/MWh	kg	kg saved compared with oil	kg saved compared with gas
Hard coal	29	75	134	484	9680	-2680	-4280
Oil	42	85	97	350	7000	0	-1600
Natural gas	38	75	75	270	5400	1600	0
LPG	46	82	90	323	6460	540	-1060
Electricity (UK grid)	-	-	150	530	10600	-3600	-5200
Electricity (large scale wood chip combustion)	-	-	16	58	1160	5840	4240
Electricity large scale wood chip gasification)	-	-	7	25	500	6500	4900
Wood chips (25% MC) Fuel only	14	37.5	2	7	140	6860	5260
Wood chips (25% MC) Including boiler	14	37.5	5	18	500	6500	4900
Wood pellets (10% MC starting from dry wood waste) See note 3	17	45	4	15	300	6700	5100
Wood pellets (10% MC) Including boiler See note 3	17	45	7	26	660	6340	4740
Grasses/straw (15% MC)	14.5	38	1.5 to 4	5.4 to 15	108 to 300	6892 to 6700	5292 to 5100

Table 3: Carbon emission from different type of fuels.

These figures in the table above represent carbon dioxide emission from complete combustion process for each fuel. You can notice the two yellow highlighted columns, which represent the approximate life cycle of carbon dioxide emission. As you can see that if fuel used is from woody products, is result in a significantly less carbon emission than all of conventional fuel. However, the life cycle carbon emission of biomass can be varies depended on how you make assumption and details on supply chain, production techniques, forestry or agricultural practice, transportation, et cetera. The data in this table are from (9) and (10)

4.2 Other environmental impact

Other than a questionable carbon saving from biomass, there are some others impact that could pose treats to the surrounding environment from using biomass. These problems are such as the destruction of biodiversity and ecosystem from land use change; increased in agricultural production, result in more pesticide and fertilizer used which can be affect water quality, heath problem and degradation of soil; food products have been displaced; damaging wildlife and endangered species in some area; et cetera.

According from a report by the House of Commons Environmental Audit Committee; ”Are biofuel Sustainable”, said that land use change issues, especially in tropical zone, are always raised and being the most common concern. There an evidence of the rainforests in Indonesia and Malaysia was completely cleared for palm oil plantation and endanger the Orang-utang specie (11)(12).Not only just the localized environmental issues like biodiversity that is the most important of land use change, but also carbon emission in global scale. The UN has said " Ironically, in the desire to cut CO2 emissions, western markets are driving ecosystem destruction and producing vast and significant CO2 emissions through forest burning and peat swamp drainage. The most effective measure to achieve this is conservation of remaining peatland forests, alongside rehabilitation of degraded peatlands and improved management of plantations and agricultural areas.”(12) So, if we take a look at Government’s policies that try to reduce GHG emission by changing into biomass, it might not always result as they think what they would achieve if we did not research the issue properly. If we look back at Scotland there is possibility of deforestation and lost in biodiversity if the demand of the biomass is still rising, even though the government might have plan for replanting but I believe that clear forest is still not the way of sustainable development and we should avoid any land use change at any cost. If there will be some changing in land use, further studies is a mandatory.

Chapter 5: The sustainability of biomass heating

Before going through investigating the carbon emission and the availability of biomass in Scotland, we will look into what are the sustainability criteria that are currently practices in the EU level to the Scottish level.

5.1 The Sustainability criteria

Even though "biomass" is consider to be sustainable and green energy; however the fast growing bio-energy market that is currently keep demanding more and more will not be truly gain environmental advantage and would turn out to be the source of climate change itself, as you can see from the environmental issue that was raised in the previous chapter of this report. Thus, resolution to forbid the likely event to happen is from the European Commission to the Council and the European Parliament, they have introduced a qualification for sustainability of biomass and the first one is "Sustainability Criteria and Certification Systems for Biomass Production (2008)"(13) and the other one is "Sustainability requirements for the use of solid and gaseous biomass sources in electricity, heating and cooling (2010)"(14). The latter is the one that EU commission is presented as a recommendation for member states to be used at their national level. Beside with the recommendation in the EU level, the Scottish government has published their own obligation for the whole renewables sector, which is called "The Renewable Obligation Scotland (ROS)". This renewable obligation was also introduced at the UK level, but Scotland has their own obligation that is different from England & Wales and Northern Island obligation (15). At first place there are no criteria for biomass when they launch the obligation, it was only just a requirement for sustainability reporting for biomass, however now they are proposing the sustainable criteria for biomass as well (16). These criteria should become affective by April 2013. Another sustainability criteria only for heating is come from the "Renewable Heat Incentive (RHI)" which was introduced in the UK level. We will see what these criteria are and how it affects the sustainability of biomass.

5.1.1 Scotland's biomass sustainability criteria.

At the moment, there still not have any mandatory sustainability criteria for using solid biomass and biogas for heat generation yet; however there already have sustainability criteria for using biomass or biogas for electricity generating. These criteria for electricity generating can be effectively apply to heat generation as well. The proposal of biomass and biogas sustainability criteria was made by DECC on September 2010 and it is intended to be introduce to the UK level, here would be the important details from the proposal, I will only focus on the criteria that based on general biomass using only and will try not to include the criteria that are for electricity generation. The sustainability criteria are as following,

- Sustainable forest management practice in the UK and the rest of the world: In order to meet the UK Government's public procurement policy for sustainable timber purchasing, there will be a requirement to shown the legal and sustainable management of the forest that has been used for processing a solid wood-fuel. This report is very important to ensuring the sustainability of biomass. And this could lead to an improvement of the unmanaged forest in the UK, and the potential forest that it could be brought to active management which would result in increasing of the home grown wood-fuel sources as well as biodiversity benefits.
- A restriction for used raw materials that being harvested from the area contain with high biodiversity, it includes primary forest, high biodiversity grassland and area that been preserved for nature protection.
- A restriction for used raw materials from the area that already has high carbon stock.
- Solid biomass or biogas generators over 50 kW must need to submit a report :
    - The carbon intensity in term of kg CO2/MWh and how much GHG emission they are saving, the report must come from the EU fossil electricity coparator. It is required if you use of the biomass or biogas for electricity generation;

- The origin of biomass or biogas raw materials harvested from whether the area that have high biodiversity value. However there are no criteria and geographical specification to determine which grassland is to be considered as having high biodiversity value, and so they may not be able to include this in the Renewable Obligation (Scotland) Order for 2011;
- The origin of biomass or biogas raw materials harvested from whether the area that have high carbon stock;
- The origin of biomass or biogas raw materials harvested from whether the area that was considered as peat land in January 2008;
- The type, mass or volume, format and country of origin of biomass. It has to meets an environmental standard, and what is that standard, plus all the details of any land use change cause from planting or deforestation.

As we can see that the important criteria that they are focus on is almost for the sourcing process and there are no exact criteria of the GHG emission or carbon intensity for biomass heating. More information on the Renewable Obligation can be found at (17). Now I will move on to look at what are the sustainability criteria that being used at the UK level and then move on to sustainability criteria at the EU level which are suggested by the European commission.

5.1.2 The UK's biomass sustainability criteria

Although there is the Renewable obligation that has been used in the UK level, but Scotland and England use a different one as mentioned before. The criteria that are really use across the UK and focus only for biomass heating is actually from the Renewable Heat incentive scheme (RHI). As mentioned earlier that the sustainability criteria for using solid biomass are made for the purpose of electricity generating and not apply to the biomass heating yet, on the other hand, the sustainability criteria in RHI document are only for heating. In order to receive a full support from the RHI scheme, user must be eligible to complete with these criteria below;

Types of Boilers

- Biomass-only boiler (for both log and chips)
- Biomass pellet stove with back boilers

Air quality

- Every new installation biomass-boilers system must be able to meet the air quality standard of not exceeding 30 grams per gigajoule (g/GJ) of particular matter (PM) and 150 g/GJ for oxide of nitrogen
- Once the system is being accredited on the RHI scheme, there are no need to comply with future change to the emission limits, however user are still need to comply to the future changes of EU or global legislation.

Fuel sustainability

- All of users' biomass fuel must source from a supplier that is registered on the approved RHI list.
- Every RHI user will have to report that they are using only wood-fuel from an approved supplier annually.
- There are two criteria, start from April 2014, for wood-fuel supplier that will make them considered in the list of approved supplier :
    - Complies with the EU fossil fuel heat average to reduce the GHG lifecycle emission at 60% GHG saving, assuming a boiler efficiency of 70%
    - Submit a report on their performance against land criteria for each individual types of fuel from the following list (although compliance with the criteria will not initially be required):
        - For wood-fuel: must comply with the UK public procurement policy on wood and wood products (18).
        - For perennial energy crop: the energy crops that planted under the Energy Crops Scheme for England (19) are

already under the requirement in the scheme, although this scheme is only for farmer in England but I believe the requirements will be suitable for Scotland as well.

- For other types of solid biomass: must be complies with the sustainability criteria set by Renewable Energy Directive (RED) (20).

Even though Scotland is not having the sustainability criteria for biomass heating yet, but The Scottish government already adapt the RHI scheme, thus it is likely that the fundamental requirement in the RHI scheme would applying to every biomass user in Scotland. We are now known what are the criteria that currently being used or about to be uses in the national level, now I will move on to the criteria at European level.

5.1.3 The EU's biomass sustainability criteria

According from the EU website, there is one standard recommended for sustainability of biomass sources using whether in generating electricity, heating and cooling, that is currently applying to the EU level. The report came out in February 2010, the purpose of this report is to fulfill the gap in sustainable criteria for biomass that was left out from the Renewable Energy Directive‘s sustainability scheme; because the EU commission expected biomass to playing significant role to contributing to the EU's 2020 renewable energy target. They are concerned that the expansion from trading biomass among European countries or from third countries could lead to the unsustainable production of biomass; as a result, some of the European countries have developed their own national-level sustainability criteria and led to the certification scheme which in some case are not complementary and compatible and this is why environmental organizations and biomass importing countries have to come into common sustainability scheme in order to limit intra-EU cross-border barriers in setting up bio-energy projects. The EU sustainability scheme is based on the three main following principles:

- Effectiveness in dealing with problems of sustainable biomass use,
- Cost-efficiency in meeting the objectives and

- Consistency with existing policies.

For the next part we will cover what are the main issues for sustainability of biomass heating that has been considered in this report.

Sustainability issue for solid and gaseous biomass in heating

This section is all the main issues that was raised during the public consultation carried out in July-September 2008 and adopted from the Renewable Energy Directive's scheme, here are the issues;

- **Sustainability in production (land management, cultivation and harvesting)**

Sustainability of biomass production is always concern with the biodiversity and carbon stock of the forest, and the issues is always be about whether agricultural production or forest management. The former is regulated through the environmental cross-compliance requirements in the Common Agricultural Policy (CAP) (21) and the latter is regulated through a national-level policy which in Scotland is by the Forestry commission Scotland.

In European and North America, forests are increasing but in other global areas, deforestation and degradation are more common incident. The main cause for deforestation and degradation are from a weak practices on forest management and conversion of forest resources, to be more specific it is in the developing countries that we always seen this incident. There are studies shown that only 8% of forests are certified in the world today compare with 45% in the EU (22). Although in the EU, almost biomass products come from within the EU where the sustainable forest management practices are strong, the sustainability risk is considered to be low. However, with the increasing demand of biomass might lead to importing wood-fuel from a non-EU country which could put biomass sustainability at risk.

- **Land use, land use change and forestry accounting**

GHG emission that cause by land use or land use change for EU countries are need to report to the United Nations Framework Convention on Climate Change (UNFCCC). GHG emission from land use change is best to calculated by a general framework that should be accounts for every activity of land use such as production of food, feed and fibre et cetera. This can be result in increasing carbon stock which would be important to the sustainability of biomass production.

- **Life cycle greenhouse gas (GHG) performance**

As mentioned earlier, to evaluate the true GHG emission from using biomass, the LCA method is considered to be the most appropriate technique. Because there are a lot variable to be consider when relate to the GHG emission from using bio-energy, it is differ depend on type of the feed stock, land use change, harvesting, transportation and processing raw materials. There actually no restriction on methodology of LCA method, thus the choices of methodologies chosen will become the most significant factor affecting the outcome of an analysis. The EU commission has decided to use the same methodologies that have already been established by the Renewable Energy Directive, that are meant for bio-fuel and bioliquid, in order to keep the consistency for all bio-energy. The GHG emission calculation method from RED is stop at when the raw materials are at it final process an ready to be used as a fuel but for whether electricity, heating or cooling there need to assess another step of converse the fuel into energy, so that it can be used to compare with the EU fossil fuel electricity, heating and cooling. After taking the last step of calculation into account, the result of GHG saving produced by different types of solid biomass are available at the figure below

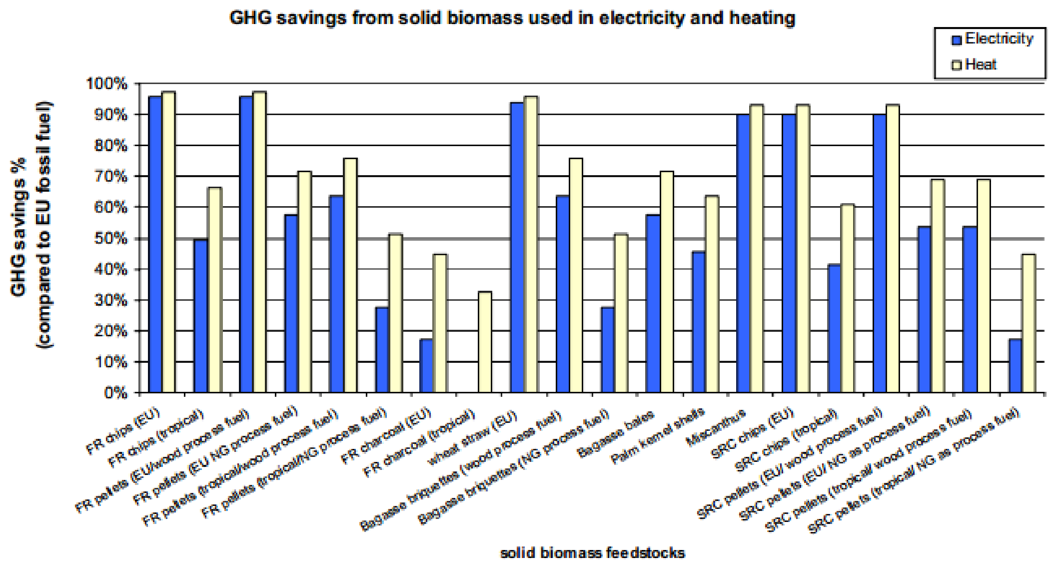


Figure 9: GHG saving from solid biomass used in electricity and heating

The assumptions in the calculation of the above figure are 25% of electrical conversion efficiency and 80% of thermal conversion efficiency. According from the figure above, if the forest or agricultural residues are being used, the GHG emission saving are always more than 80%. Some agricultural crops are result in higher emission due to fertilizer use in agriculture which would not be a problem for biomass from forest.

- **Energy conversion efficiency**

The easiest way for GHG saving is to reduce consumption and increasing conversion efficiency. General biomass stoves and boilers in domestic scale are range from 10%-90%, for larger scale like co-generation, efficiency can be up to 80%-90%. Thus, criteria for new stove or boiler installation regard with conversion efficiency must taking into account and also government must support for high efficiency feed stock.

Hence, from all issues that were raised here, the next question is what should be the sustainability criteria that would correspond with these issues and also an appropriate level of action that must take. The following part is the recommendation of criteria that was introduced by the EU commission.

Recommendations for appropriate action to address sustainability action

It is very difficult to make a harmonised policy or recommendation due to the variety of feed stock available and a different production process. For this reason, the EU commission is not propose any mandatory criteria but they have to minimize the risk of unsustainable. Thus, they purpose varied recommendation of criteria that will be compatible at national level. The EU commission encourages each national to develop their own sustainability scheme by using the following criteria:

- It is very challenging to set up the appropriate GHG saving due to the range of feed stock available; however, according to the report, if the feed stock are waste and residues, the minimum GHG saving must be at least 35%, rising to 50% in 2017 and 60% in 2018. The recommendations here were adopted from the "RED article 17(1) and 17(2)".
- The calculation methodology for the GHG should use the rules in Appendix B, for example and some general calculation by using this methodology can also be found in Appendix B. The recommended methodology here have not concern with the conversion efficiency of the electricity, heating or cooling installation yet, the default values given in Appendix C should be divided by this values before obtain the actual GHG emission.
- All of member states should support the policy or scheme to encourage a higher conversion efficiency process for electricity, heating and cooling. The EU commission is expected to release the minimum standard of conversion efficiency and environmental requirement related with air quality by 2010.

The nature of biomass sector is a combination of a lot of small scale domestic users, by placing sustainability requirements on these small scales would be result only undue administrative burden; still some encouragement should be put on higher performance and efficiency. Thus, the EU commission only recommended that sustainability scheme should apply only to a larger producer of more than 1MW only.

The last recommendation is to keep monitoring and reporting on the latest of a national-level biomass sector. The purpose is to improve the biomass used data, helping to know the situation of the biomass use area and keep improve the statistic record of biomass. The EU commission also suggested that the data collected in national-level should be informed to the EU commission in order to keep tracking for a potential vulnerable area.

In conclusion, as you can see from the criteria of Scottish level to the EU are all connected, the EU make suggestion on the criteria of biomass and each member state develop their own sustainability criteria to suit their own nature. Even though there are no existing criteria of biomass heating in Scotland yet, but the EU commission have placed a recommendation on both electricity and heating together and the Scottish government are already put the biomass heating criteria for electricity out. I believe in a near future the government will publish the criteria only for heating, for now the closet criteria that we can follow would be the criteria in the Renewable Heat Incentive.

5.2 The availability

The Scottish's 2020 target is not only is questionable in term of the actual carbon saving but also the availability of wood-fuel. The Scottish government does not restrict suppliers to use only domestic wood sources, the wood may come from overseas but there is one restriction that it has to come from sustainable sources. Although there might not restricted the source but if the carbon emission that occur during transportation of wood fuel is exceeded the total gain from using biomass, there is no reason to switch to biomass in the first place. So, this research is trying to estimate the availability of wood fuel that Scottish forest can provide and can Scotland relies on their own forests.

The current demand of wood fuel according from "Woodfuel demand and usage in Scotland 2012 update" by the forestry commission (23); there has been around 555,000 odt in the 2011 and increased to 605,500 odt in the 2012 of the demand of wood fuel for major industry and commercial, the historic demand and the future trends can be seen in Appendix D; the demand for a smaller industry and commercial has been around 26,200 odt in 2011, the historic and future trends can also be seen in Appendix D; the demand for the smallest industry and commercial has been recorded at around 31,500 odt in 2011 there is no record for the year 2012 but from the previous evidence that the growth of demand is increased around 4,000 each year from 2009 to 2011, the historic demand can also be seen in Appendix D. The report stated that there is around 4.4% of inaccuracy accounted by the entire small scale industrial and commercial heat only users, the inaccuracy is cause by the large number of different in the contact for each individual user; therefore it has no significant impact on the overall wood fuel used and would not be taken into account in this analysis.

The total demand of wood in 2011 is show in the table below

	2011	
	odt	%
Existing major industrial/commercial (using >10,001 odt/yr)	555,181	90.57%
Industrial/commercial (using 1,001 to 10,000 odt/yr)	26,224	4.28%
Other industrial/commercial heat only <1,000 odt/yr	31,584	5.15%
Totals	612,989	

Table 4: total wood fuel use in 2011 (23)

The figures above are representing only the existing wood fuel usage in industrial, commercial heat and electricity generation sector, you can see there is around 610,000 odt of demand. On the other hand, the total supply material for renewable energy in Scotland was provided by the wood fuel task force, the report “Wood fuel task force 2: the supply of wood for renewable energy production in Scotland” has put together the number of wood fuel that already committed to the existing market. Here is the table from the Wood fuel task force,

Type of material	2009/11 Oven Dry (t)	2012/16 Oven Dry (t)	2017/21 Oven Dry (t)
Hardwood - Logs	20,500	20,500	20,500
Softwood (incl. logs, chips and SRW)	**2,603,000**	**2,603,000**	**2,603,000**
Softwood Brash / Branchwood	20,000	20,000	20,000
Softwood Stumps/roots	0	0	0
Small & Neglected woods	0	0	0
Arboricultural arisings	**120,200**	**120,200**	**120,200**
Short rotation coppice	**0**	**0**	**0**
Short rotation forestry	0	0	0
Recycled and waste wood	**306,000**	**306,000**	**306,000**
Total	**3,069,700**	**3,069,700**	**3,069,700**

Table 5: Material already committed to existing market. (24)

The study from Wood fuel task force concluded that there would be around 3 million of oven dry tonnes of biomass available for the market right now. The supply above is already committed to the market which is not the Scottish renewable sectors, Thus from comparing between these two figures we can see there are about 2.4 million odt of wood fuel available annually up until 2021 if all the supply could lead to the renewable market only.

Hence, the wood fuel task force has assessed the total estimated potential wood fuel resources that can be available to the market. Their forecast is based on the potential estimate volume that private sector can provide if they are on full productive potential of growing stock, not their actual production. Below is the table of potential biomass available from the report,

Type of material	2009/11 Oven Dry (t)	2012/16 Oven Dry (t)	2017/21 Oven Dry (t)
Hardwood – Logs	112,500	110,700	103,400
Softwood (incl. logs, chips and SRW)	**2,819,200**	**3,333,400**	**3,657,300**
Softwood Brash / Branchwood	382,700	395,000	395,000
Softwood Stumps/roots	35,000	35,000	35,000
Small & Neglected woods	50,000	50,000	50,000
Arboricultural arisings	**172,100**	**172,100**	**172,100**
Short rotation coppice	**2,400**	**2,400**	**2,400**
Short rotation forestry	0	0	0
Recycled and waste wood	**602,200**	**602,200**	**602,200**
Total	**4,176,100**	**4,700,800**	**5,017,400**

Table 6: total estimated potential resource.

According from the Wood fuel task force study, there would be around 1,000,000 odt of biomass that can support the renewable sectors and if the demand of wood is still the same there would be up to 2 million odt of biomass available by the year 2021.

From the table above, the soft wood brash/branch wood could be considered to play a significant role for potential source but if we consider the cost from recovering biomass for this type of wood, larger scale plants are the only potential users to take this type of material. The Scottish’s forestry commission is committed to procure and offer the brash contacts on the national forest estate but only there is some market demand. The annual availability of brash volumes is always be dependent on how the forest being harvested. There are also some potential of soft wood stumps/roots harvesting but due to the cost and suitable sites are limited that make it less likely to have a significant potential.

Another potential resource is the arboricultural arisings, there is around 172,100 odt potential from 120,200 odt of already existing source. Thus there are about 50,000 odt that are currently available wood fuel which does not have an existing market and not go to composting in the year 2012.

And the last potential resource that would play a significant role is recycled and waste wood, according from the study by Remade Scotland report, there is over 300,000 odt of recycled and waste wood that is available in Scotland (25). However, they were concerned that the estimated figures were too high due to that most of recoverable waste wood was now being used for either bioenergy or by timber processor. And the actual potential waste wood, which has been study by WARP in the Wood Waste Market in UK (26), can be only just 24,000 odt rather the first figure.

After we can see the picture of what going on for the current demand and supply, now we will look what the future demand is going to be. According from the study by forestry commission, the future wood fuel demand that has been shown in the table below,

	FORECASTS					
	2012		2013		2014	
	odt	%	odt	%	odt	%
Existing major industrial/commercial (using >10,001 odt/yr)	567,998	89.8%	567,998	92.0%	567,998	92.5%
New build major industrial/commercial (using >10,001 odt/yr)	37,500		302,500		424,400	
Industrial/commercial (using 1,001 to 10,000 odt/yr)	32,740	5.5%	32,740	4.7%	32,740	4.6%
New build industrial/commercial (using 1,001 to 10,000 odt/yr)	4,250		11,500		16,500	
Other industrial/commercial heat only <1,000 odt/yr	31,584	4.7%	31,584	3.3%	31,584	2.9%
Totals	674,072	100%	946,322	100.0%	1,073,222	100%

Table 7: future forecast demand

There is a growing demand around 40,000 odt from 2011 to 2012, 300,000 odt from 2012 to 2013 and around 60,000 odt from 2013 to 2014 in the forecast of biomass demand for industrial and commercial projects. Thus, there are around 900,000 odt available from year 2013 onward. From the study, there are 24 projects that are currently in the build, planning or scoping stages. There are 4 electrical generation only projects, 4 heat only projects and 16 CHP scheme that have been identified. According from the study, there will be 104,000 odt/yr of wood fuel needed for electrical generation, 16,500 odt/yr of wood fuel needed for heat only projects and 320,000 odt/yr of wood fuel needed for CHP schemes, all of them are by the year 2014.

But not all, currently in Scotland there are the CHP project that already been granted by the Scottish government which is the Grangemouth biomass station by Forth energy, the plant is said to be use around 1 million odt, if consider all four proposal made by Forth energy for total 600MWe, the plants would require around 3 million odt. And there another high profiles project from Peel energy which is the coal fired power at Hunterston in Ayrshire, and it would demand for around 800,000 odt/yr. you can see that these two project alone are exceeding the available or potential wood fuel. However the Forth energy plants intended to use only 10% from domestic wood or maybe maximum at 30% which would equal to 0.3-0.9 million odt. At the moment, the demand from these two projects is exclude from the future demand forecast shown in this study and assume that these two projects would definitely require wood source from overseas.

In additions to the study from the Forestry commission, there is another forecast done by Wood fuel task force. In the table below is the future prediction from wood fuel task force report on the conservative estimate of future biomass demand.

Type of material	2010/11 Oven Dry (t)	2012/16 Oven Dry (t)	2017/21 Oven Dry (t)
Hardwood - Logs	**92,000**	**90,200**	**82,900**
Softwood (incl. logs, chips and SRW)	**216,200**	**730,400**	**1,054,300**
Softwood Brash / Branchwood	362,700	375,000	375,000
Softwood Stumps/roots	35,000	35,000	35,000
Small & Neglected woods	50,000	50,000	50,000
Arboricultural arisings	**51,900**	**51,900**	**51,900**
Short rotation coppice	**2,400**	**2,400**	**2,400**
Short rotation forestry	0	0	0
Recycled and waste wood	**296,200**	**296,200**	**296,200**
Total availability	**1,106,400**	**1,631,100**	**1,947,700**
LESS forecast additional demand			
Increase in sawlog (less chip) demand	174,000	174,000	174,000
Increase in wood panel demand	190,000	190,000	190,000
Increase in pulp/paper and paperboard demand	Small increase	Small increase	Small increase
Additional biomass demand	170,000	260,000	260,000
Total wood pellet production demand	140,000	140,000	140,000
Net availability	**432,400**	**867,100**	**1,183,700**

Table 8: Less forecast future demand and the total net availability

You can see from the table above that, the actual wood fuel availability would come down to around 400,000 to 1.2 million odt over the year 2021. However, as mentioned earlier about the potential wood fuel that majority are come from soft wood branch and recycled and waste wood, the branch wood is difficult to be used and can only be used by a large scale biomass plant only, and also the recycled and waste wood might only available around 24,000 odt. Hence, if we stick with this figure for recycled and waste wood, there would be around 270,000 odt less for the net availability. We can see only around 160,000 to 900,000 odt over the year 2021.

This forecast is not included any future biomass project that was granted and likely to be commissioned after the year 2010. It is because of the increase in sawlog and wood panel demand does not include in the report from the Forestry commission, hence the net availability that wood fuel task force report is less than from the Forestry commission and the latter is likely to be more accurate.

Considered the 2020 target for renewable heat demand, at the minimum there would need around 1.3 million odt more to meet the 2020 target, if the target is to be meet by maximized production from CHP plant, around 3 million odt would be needed but if the production from CHP is limited, the demand will might be over 10 million odt. For simple calculation I have used the data from "Renewable heat action plan Scotland 2011"(27) that has projected the heat demand according to the 2020 target in the figure below,

Year	Estimated Percentage[8]	Forecast Installed Capacity		GWh Used
Actual 2009	1.4%	0.23	GW	829
2011	2.0%	0.38	GW	1170
2012	3.5%	0.66	GW	2045
2014	5.0%	0.94	GW	2920
2016	7.0%	1.32	GW	4090
2018	9.0%	1.70	GW	5255
2020	11.0%	2.07	GW	6420

Table 9: Interim milestones ambitions to 2020

Use the calculation method from the research methodology section, we got

- Assume the boiler to be at 90% (very optimistic assumption due to 90% efficiency is always for larger size boiler which domestic boiler can be reduce to just 35% efficiency), so from 6420 GWh ÷ 90% = 7133 GWh

- Using wood chips (MC 30%) : 7133 GWh ÷ 3.5 kWh/kg = 2.04 million tonnes or 7133 GWh ÷ 870 kWh/m^3 = 8.2 million m^3 of wood chips

As you can see from this optimistic calculation, the demand for wood chip is around 2 million tonnes which the supply of wood can be only just around 1 million tonnes maximum.

In addition to the data from the Wood fuel task force, the data from ConFor report (28) is stated that the wood fuel demand in Scotland was exceed the supply in year 2011, the figure below show the forecast potential availability and demand for coniferous round wood (soft wood) to 2025 from ConFor report,

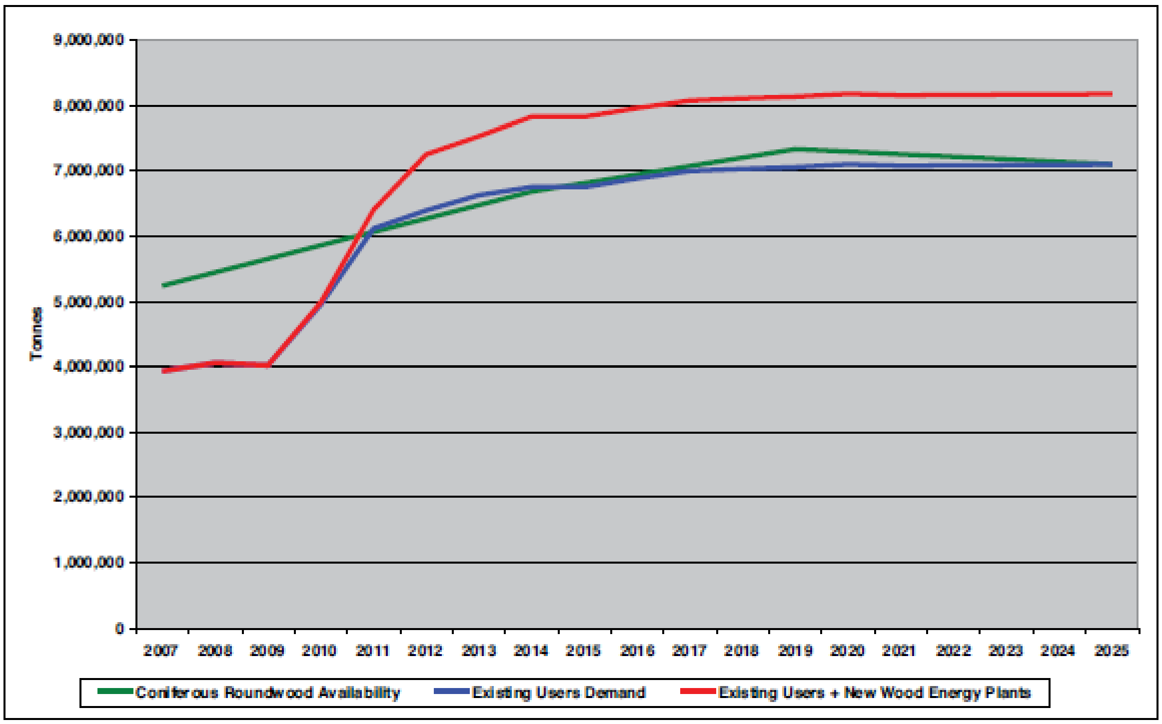


Figure 10: Scotland: Forecast potential availability & demand for coniferous roundwood to 2025

The wood fuel availability shown at the figure above is estimated to be around 5-7 million tonnes to the year 2025 which is around 2 million tonnes more than the forecast made by the wood fuel task force. It was stated in this report that they have some confidential information from private sectors which is why the result shown more wood fuel availability in Scotland. However, even though there are more supply of wood fuel, it is still cannot match with the increasing forecast demand. The report from ConFor was conducted in 2010 and did not cover any possible projects or granted projects that were mentioned earlier or the projects from the Renewable Heat Incentive scheme that would increase a lot of biomass wood fuel demand.

You can see from the current estimated wood fuel availability, it cannot support just the minimum demand for the 2020 target. To look for any possibility to achieve the Scottish government's dream on 2020 renewable target, we need to consider some possibility from imported wood. As you can see from the figure below,

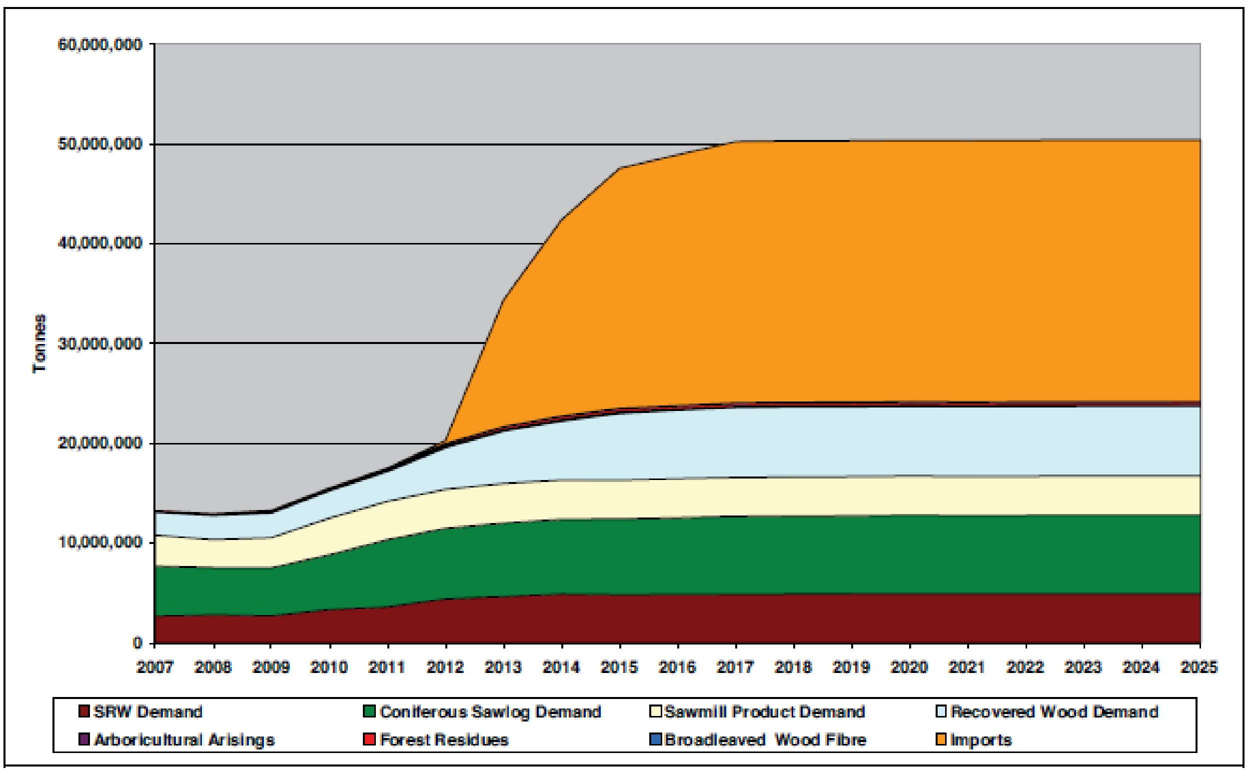


Figure 11: Forecast Total Demand for Wood Fibre in Britain by Type 2007 – 2025

The report from ConFor concludes that from 2012 UK will need to import wood from aboard and the demand would drastically increase. The demand from imported wood fuel in the forecast above amount around 27 million tonnes annually and this forecast excluded any project that was planned after 2010 as mentioned earlier. Thus neither the UK nor Scotland can support their own demand for the biomass wood fuel and still need to import a lot of woody products from oversea. The next challenge for the government would be to control the standard of the wood fuel source and effectively execute the regulation on biomass sustainable criteria for the source from overseas to get a truly sustainable development.

However, the Scottish government has already put up an action plan to the 2020 renewable heat target, the renewable heat would not come from only biomass woody product alone, you can see from the figure below,

Sector	2009	2012	2020
Industrial	Woodchip	Woodchip Energy from Waste Anaerobic Digestion Pellets	Woodchip Energy from Waste Anaerobic Digestion Pellets Ground Source Heat Pumps Air Source Heat Pumps
Commercial and Public	Woodchip	Woodchip Pellets Ground Source Heat Pumps Air Source Heat Pumps Solar Thermal	Woodchip Pellets Ground Source Heat Pumps Solar Thermal Air Source Heat Pumps Biogas (direct injection)
Domestic	Log Woodchip Pellet Ground Source Heat Pumps Air Source Heat Pumps Solar Thermal Biomass District Heating	Log Pellets Ground Source Heat Pumps Solar Thermal Air Source Heat Pumps Biomass District Heating Anaerobic Digestion Biogas (direct injection)	Pellets Air Source Heat Pumps Log Solar Thermal Biomass District Heating Ground Source Heat Pumps Biogas (direct injection) Water Source Heat Pumps Combined Heat & Power

Table 10: Main source of heat to 2020

The market share of heating demand in the 2020 renewable heat target between these three sectors are 45% from industrial sector, 33% from commercial sector and 22% from domestic sector which this sector has the share for actual heating demand around 51%. The industrial and commercial sector are considered as short term target market to achieve the 2020 target. And in this short-medium term, the biomass woody products are likely to be the most frequently employed options across all sectors, even though the possibility of other microrenewables might be employed in the future or some technologies will replaced the biomass boiler with higher efficiency and lower cost, the woody products will be required until that time has come and it is going to be not enough to supply the 2020 target.

Another possibility to increase the supply of wood fuel comes from encouraging private sector to contribute to domestic demand; the figure below is a forecast from the National forest inventory report (29),

Country	2012–16			2017–21			2022–26			2027–31			2032–36		
	FC/FS	Private sector		FC/FS	Private sector		FC/FS	Private sector		FC/FS	Private sector		FC/FS	Private sector	
	000 m³	000 m³	SE %	000 m³	000 m³	SE %	000 m³	000 m³	SE %	000 m³	000 m³	SE %	000 m³	000 m³	SE %
England	1 305	2 184	6	1 183	2 626	7	1 110	2 450	7	1 072	2 804	7	985	2 637	9
Scotland	3 749	4 614	6	3 568	5 917	6	3 417	7 796	6	3 305	9 131	6	2 930	8 213	6
Wales	958	793	19	979	1 025	17	893	1 008	18	795	713	19	927	791	18
GB	6 013	7 591	5	5 730	9 569	5	5 420	11 255	5	5 172	12 648	5	4 841	11 641	5
NI	579	26	-	572	22	-	529	25	-	519	44	-	458	44	-
UK	6 592	7 617	-	6 302	9 591	-	5 949	11 280	-	5 691	12 692	-	5 299	11 685	-

Figure 1 25-year forecast of softwood timber availability for the FC/FS and Private sector estates in the UK.

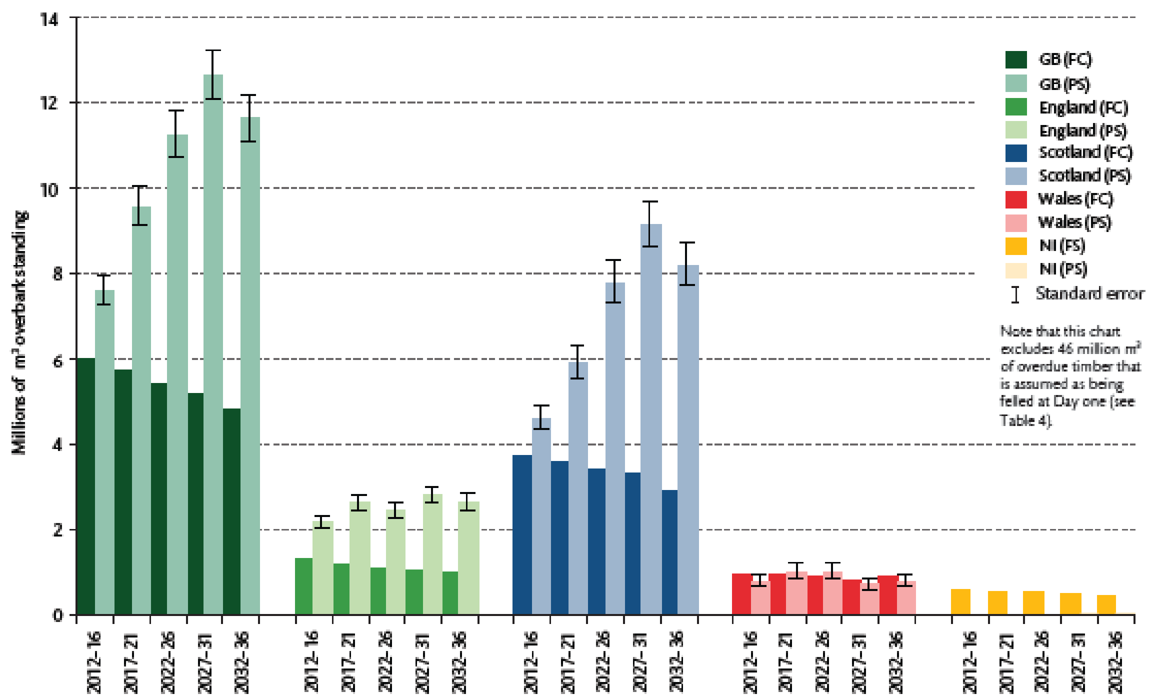


Figure 12: 25-year forecast of softwood timber availability for the FC/FS and Private sector estates in the UK.

As you can see from the figure above, the darker color for each column represents the forecast of timber from Forestry Commission/Forest Service (FC/FS) and the lighter stand for private ownership. The diagram above was using unit of volume (cubic metre; m^3) instead of unit of mass (tonnes) that was used in the other report, because the moisture contents of timber is unknown, thus we cannot know the weight of these biomass and cannot compare the forecast of wood fuel availability with others report.

Nonetheless, we can see the potential from private sector estates in this report. The trend of future availability from private sector is increasing , on the other hand, from the forest commission is decreasing, even though there might be some standard error in the forecast, still it look very promising from the private sector that could help reduce the amount of wood from overseas. Still, sustainability criteria must be strictly regulated.

Another choice for supporting the demand is we push the biomass wood fuel harvesting to its maximum limit, but in this case the biomass scheme can no longer called a sustainable development anymore. We will see why extracting all the biomass resource can result in a negative carbon benefits in the next section.

5.3 The Carbon

As mentioned earlier in the policy section, The Scottish government encourages every Scottish to change from using convention fuel to heat their home in to chosen biomass instead. The Scottish government wants to meet their 2020 target, and we still don't know is biomass really giving us lower carbon emission or not. So, to investigate the sustainable future of biomass in Scotland, this research will conduct an analysis of carbon emission and also other GHG gaseous emission comparison between each type of biomass with difference fossil fuels.

This research has used the LCA technique that was mentioned earlier in the research methodology chapter combined with existing tools which is BEAT2, although the Scottish government recommend in their biomass criteria to use the tool from Ofgem which is "the UK Biomass & Biogas Carbon Calculator", but the BEAT2 come with the same ability with an addition of graphical details which is a lot easier to understand and analyze the data and it can compare with other conventional fuels. The analysis was set up to examine the effects of key factors on unit total GHG emissions from the generation of heat and wood products from different types of woody biomass, including.

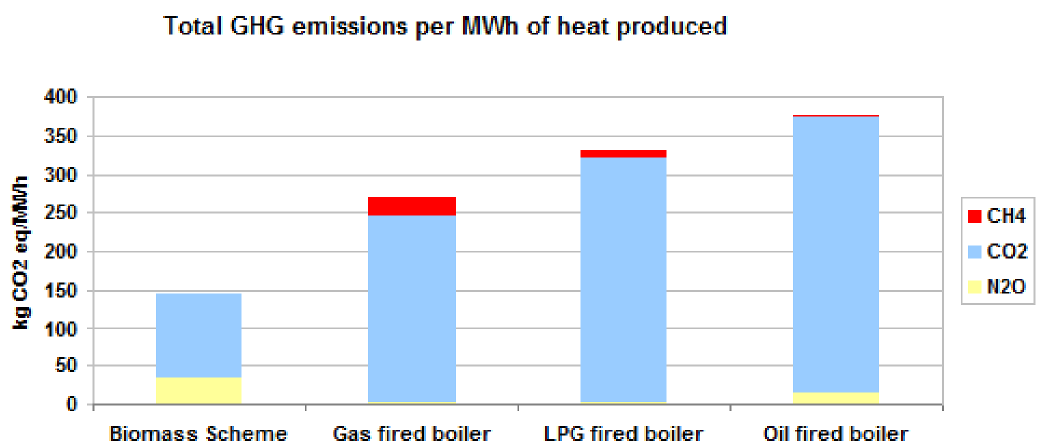
- Type of wood fuel (Shredded, Chips and Pellets)
- Types of wood product (Chipboard, Clean wood waste, Forest residues and Medium density fibreboard waste)

- Types of transport mode (Road, Rail and Ship)
- Location of sources (Scotland and overseas)
- Operational parameters are taking from the default parameters from the tool

The following part will be parts of the GHG calculation that was made. Here is the some result from BEAT2 tool,

5.3.1 1st Scenario

The conditions from the first experiment is Chipboard wood, Pellets, transport by road, the scale of the scheme is industrial/commercial/community size (the reason I chose this size because of the Scottish government try to encouraged biomass scheme in this size in order to accomplish their renewable heat target) and assume to be waste from plant within the UK. The result shown in the figure below is the total GHG emission calculated in term of kilograms of CO2 equivalence per Megawatts hours of heat (kg CO2 eq/MWh)

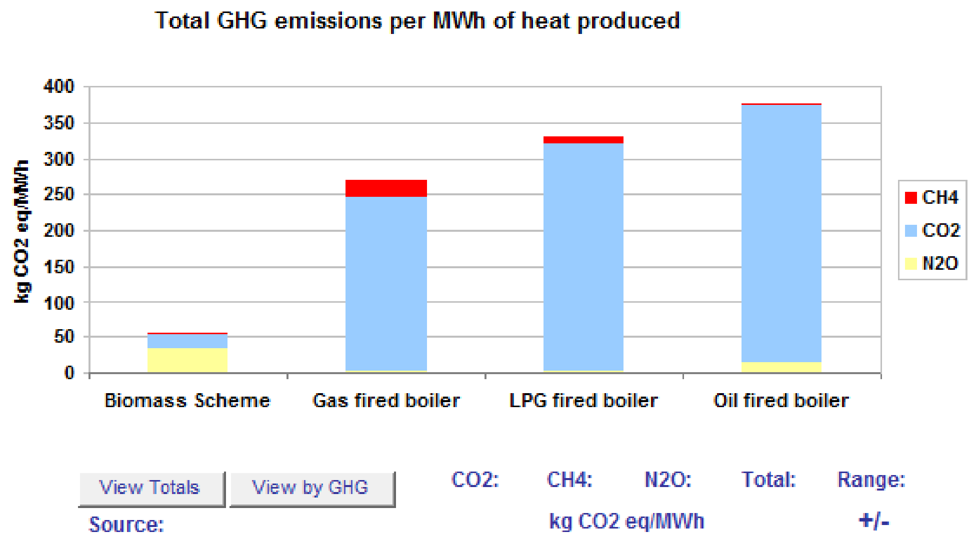


View Totals | View by GHG

Source:	CO2:	CH4:	N2O:	Total:	Range:
		kg CO2 eq/MWh			+/-
Biomass Scheme	109.4	1.9	34.1	-209.1	3.4
Gas fired boiler	242.0	25.3	2.6	269.9	
LPG fired boiler	318.9	8.6	2.6	330.1	
Oil fired boiler	359.8	1.9	13.5	375.2	

Figure 13: Total GHG emission from pellets chipboard.

The GHG emission from biomass scheme in result shown in the figure above come with the smallest value of emission per unit of energy produced. You can see from the table in the above figure that even though there are some GHG emissions from biomass scheme but the total GHG emission was calculated to be -209.1, it is because the tool has taken into account the “Reference system”. The reference system in this tool is referring to the effect from alternatives activities that are being replaced by the investigated event, in which is a very important issue when we considered the biomass schemes. The activities included such as land use, conventional disposal of the feedstock that normally consider as waste and the collection of bio-gas from landfill site that could possibly use in the generation of heat/electricity, GHG emission during the storage of the waste and its decomposition on lands (but it is arguable about the benefit it’s give to the soil as natural fertilizers and reduce the need of synthetic fertilizers) and any loss or waste wood generate during the recovery and processing stages of the biomass energy technology. Thus, from different types of wood products and wood types there is several difference in their reference system and need to choose appropriate reference system according to that particular wood fuel. Hence for the first scenario, the reference system used for pellets chipboard are disposal of waste chipboard to landfill with energy recovery and wood ash used to replace agricultural lime, which you can see in Appendix E. After that I tried to not include the reference system into the calculation, hence the result shown in the figure below,



Source:	CO2:	CH4:	N2O:	Total:	Range:
		kg CO2 eq/MWh			+/-
Biomass Scheme	20.2	1.9	33.2	54.3	3.4
Gas fired boiler	242.0	25.3	2.6	269.9	
LPG fired boiler	318.9	8.6	2.6	330.1	
Oil fired boiler	359.8	1.9	13.5	375.2	

Figure 14: GHG emission from pellets chipboard without reference system.

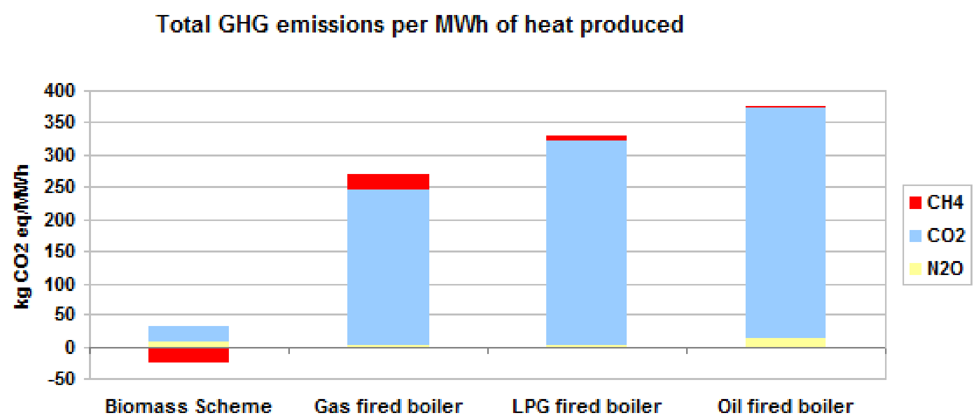
As you can see from the graph, the total GHG emission is now around 54.3 kg of CO2 eq/MWh. Although the real emission is lower than the previous calculation but the absolute emission is a positive value compare to the negative value from scenario where the reference system is included, around 250 kg of CO2 eq/MWh difference. However the CO2 emission from the second calculation is lower than the first calculation because of the chipboard waste that should turn into pellets are treated as waste and put into landfill with energy recovery, hence there is no combustion of the waste and result in lower CO2 emission. But using the chipboard waste as pellets was contribute more to the environment as the total GHG emission is lower.

Nonetheless, both calculation result in biomass has more benefit to the environment than others three competitors, but the result shown here is still questionable due to the fact that some factor does not concern in the calculation methodology in this tool, thus we will moved to the next scenario where the source of wood fuel come from the forest.

Summary report and detailed parameter can be found on Appendix F and Appendix G respectively.

5.3.2 2nd scenario

The condition in this experiment are Forest residues, Chips, Road transport, the scale of the scheme is industrial/commercial/community size and assume to be from forest in the UK, all parameters are taking by the default value from the tool. The figure below shows the total GHG emission calculated from the tool,



View Totals | View by GHG

Source:	CO2:	CH4:	N2O:	Total:	Range:
		kg CO2 eq/MWh			+/-
Biomass Scheme	24.6	-26.2	6.5	4.9	0.8
Gas fired boiler	242.0	25.3	2.6	269.9	
LPG fired boiler	318.9	8.6	2.6	330.1	
Oil fired boiler	359.8	1.9	13.5	375.2	

Figure 15: Total GHG emission from forest residues chips.

The figure above is represent the second scenario with the reference system , which is disposal of waste wood chunks to landfill with energy recovery, wood ash used to replace agricultural lime. The total emission is turn out to be very low but the question is remains, the figure below shown how the tool calculate the total GHG emission, GHG emissions per MWh generated

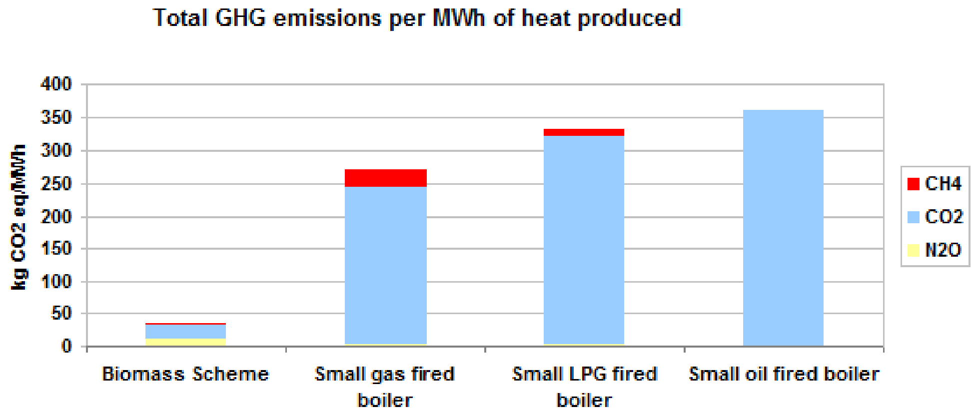
Description:		CO2: (kg CO2 eq/MWh)	CH4: (kg CO2 eq/MWh)	N2O: (kg CO2 eq/MWh)	total GHG: (kg CO2 eq/MWh)	Total GHG (range):	Primary energy required MWh/MWh:
Supply of forestry residues (uk) (chips)	Cultivation and harvesting	2.9	0.0	0.0	2.9	0.8	0.0
Supply of forestry residues (uk) (chips)	Processing of feedstock	-22.0	95.7	-0.2	73.4	0.5	-0.1
Supply of forestry residues (uk) (chips)	Transport of feedstock	7.6	0.1	0.5	8.3	0.3	0.0
Supply of forestry residues (uk) (chips)	Reference system	31.2	-123.3	0.3	-91.8	0.0	0.2
Heat production	Conversion of feedstock to heat	4.9	1.2	5.9	12.0	0.5	0.0
Heat production	Ash disposal	0.0	0.0	0.0	0.0	0.0	0.0
TOTAL		24.6	-26.2	6.5	4.9	0.8	0.1

Figure 16: Detail of GHG emission

As you can see from the figure above, the cultivation and harvesting return with a very small amount of CO2 released, the question is have they taken into account the harvesting procedure or not?. As mentioned earlier in the literature review section that land use change and deforestation are very critical aspect for biomass scheme, the fact that the origin and their cultivation and harvesting practice for both chipboard and forest residues wood fuel could change the whole carbon emission oppositely from the result shown here. It might not clear from the first two scenarios here, so we will move on to the next scenario.

5.3.4 3rd scenario

The condition in this experiment are Logs, Road transport, the scale of the scheme is domestic size and assume to be from forest in the UK, all parameters are taking by the default value from the tool. The figure below shows the total GHG emission calculated from the tool,



View Totals | View by GHG

Source:	CO2:	CH4:	N2O:	Total:	Range: +/-
	kg CO2 eq/MWh				
Biomass Scheme	21.6	2.5	10.4	34.4	1.8
Small gas fired boiler	242.0	25.3	2.6	269.9	
Small LPG fired boiler	318.9	8.6	2.6	330.1	
Small oil fired boiler	359.8	0.1	0.0	375.2	

Figure 17: Total GHG emission from domestic logs

The result shown above is emphasis the previous result from the first two experiments; biomass scheme has a significantly lower GHG emission from the others three. And from the figure below showed that, GHG emissions per MWh generated

Description:		CO2:	CH4:	N2O:	total GHG:	Total GHG (range):	Primary energy required MWh/MWh:
		kg CO2 eq/MWh					
Supply of logs	Cultivation and harvesting	9.1	0.0	0.0	9.1	2.5	0.0
Supply of logs	Processing of feedstock	0.9	0.0	0.0	1.0	0.0	0.0
Supply of logs	Transport of feedstock	6.0	0.1	0.4	6.5	0.2	0.0
Supply of logs	Reference system						
Heat production	Conversion of feedstock to heat	5.6	2.3	9.9	17.8	0.5	0.0
Heat production	Ash disposal	0.0	0.0	0.0	0.0	0.0	0.0
TOTAL		**21.6**	**2.5**	**10.4**	**34.4**	**1.8**	**0.1**

Figure 18: Details of GHG emission

The cultivation and harvesting the wood logs is very low and the reference system is completely ignored. The alternative event such as leaving the tree in the forest has not taken into account which that event might possible to revoke the result shown here. Another possible alternative event is how many parts of the tree used solely for producing energy, as mentioned earlier in the literature review section that if we used from tip-to-root of the tree for energy purpose, we will not gain any GHG emission benefits and we eventually increasing carbon intensity in the atmosphere. Not to mentioned the practice of biomass harvesting by the source of biomass wood fuel, some practices could have put more tension to the environment such as destroying a high bio-diversity forest or clear-felling which can be reduce the ability of carbon absorption in that particular area for more than 25 years (for coniferous wood which is Scotland's dominated tree species).

Even though there are questions of the sustainability of biomass, the Scottish government has clearly put out a regulation and the criteria that would define that wood fuel is come from the sustainable sources, the criteria of biomass was mentioned earlier in the literature reviews section. Hence, if the regulations have been strictly mandated by the government, the questionable GHG emission results that we have seen earlier might be the actual GHG emission. The Forestry commission Scotland's report stated that wood fuel projects currently operating in Scotland are saving around 884,000 tonnes of CO2 eq per year (23).

In conclusion, the result from the tool gave a definitive understanding of GHG emission benefit from every types of biomass used, with regulations and criteria to control the supply of woody products, the biomass could play a significant role in reducing GHG emission and help the global environmental problems.

Chapter 6: Conclusion

From the result of this study, the availability of woody products for use as biomass will not be enough to support with the government 2020 target, both UK and Scotland will have to find overseas source of biomass. Not only there are not enough wood from domestic production, the question on the actual carbon emission from domestic product is still questionable. Even though the result from the BEAT tool show that biomass always give better GHG emission saving than fossil fuel but there are some concerns of the result from the tool such as, the tool did not include how biomass has been harvested, or any land use change that happens from the wood fuel source, it can have lot of difference from the result that we have here. Some other concern on the sustainability of biomass is such as, if Scottish government push the production of domestic biomass to support the 2020 target it will not be sustainable and would be intensify the level carbon dioxide and other GHG gaseous in the atmosphere. From literature review, we know that if we use every part of tree just for producing energy, it will give less carbon benefit than leaving that tree in forest, so if there are really not enough wood for biomass, maybe this situation might occurs and the government 2020 target will become non sustainable development. And the unknown effect from land use change that will occur if the government decided to grow trees on grassland or replace existing food products. The imported wood will also having effect on the actual carbon saving that government has target, because the transportation of these wood would emit a lot of carbon dioxide. Not only the emission from transportation but the question of sustainability of biomass origin, if the wood came from unmanaged forest by clear-felling practices that would not give any carbon saving benefit in the global scale. Deforestation from overseas sources will make the global environmental issue worse and that would make Scotland or UK have an opposite result from their intention. But this issue can be minimize by the sustainability criteria, the criteria that was mention in the previous chapter must be strictly regulate by the Scottish government. This will not be an easy task for the government, as you can see that Scotland in worst case would need to imported around 10 million tonnes of biomass annually and the UK have to import around 27 million tonnes per year. This amount of biomass will come from many different locations around the world and it will come from developing countries where forest management practices is not very good or even unmanaged, thus the whole situation on greenhouse gas or climate change will become even worse than it already are.

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Appendices

Appendix A: BEAT2 tool

In this part is the step from BEAT2 tool to create a project of any biomass to for GHG emission. This will be a guideline for anyone that will use this tool to assess their biomass project. For any project in Scotland, the GHG emission report is mandatory to present to the government every year of their project life.

Look at the figure below for the interface of BEAT2,

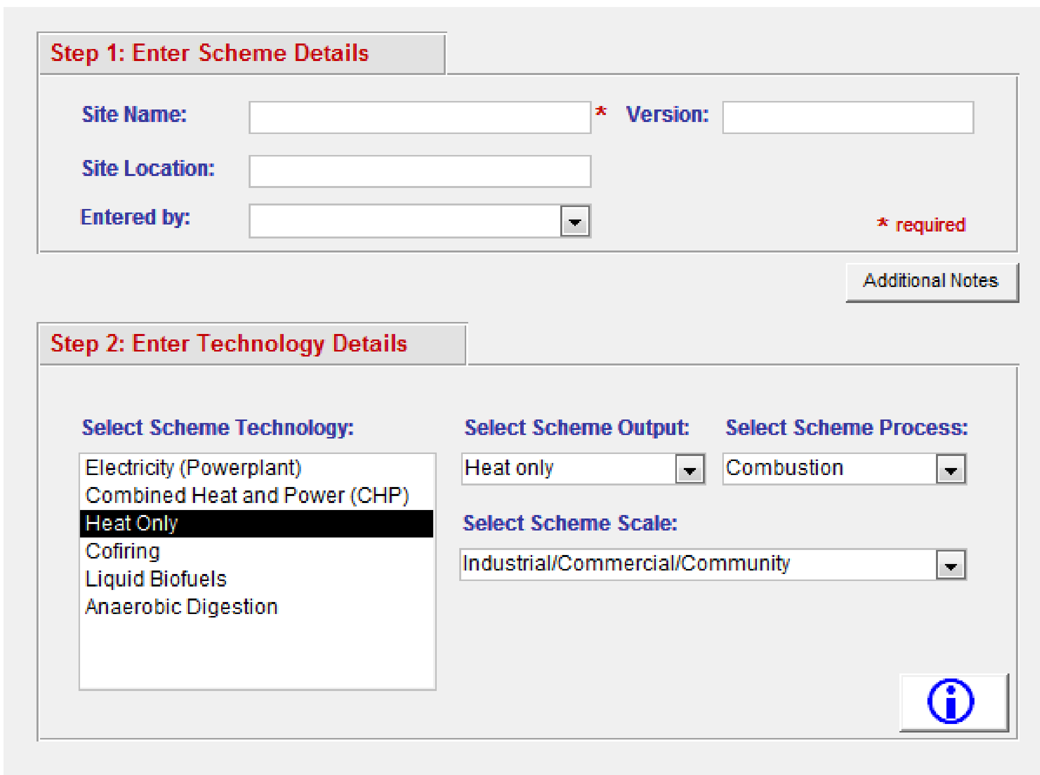


Figure 11: Scheme and Technology selection.

The tool allow user to input information on different categories of wood fuel, conversion and feedstock. The parameters involve with the calculation are already setup as default parameter but user can also customise the parameter is correspond with their project, the figure below illustrated the feed stock selection and parameters that can be customise,

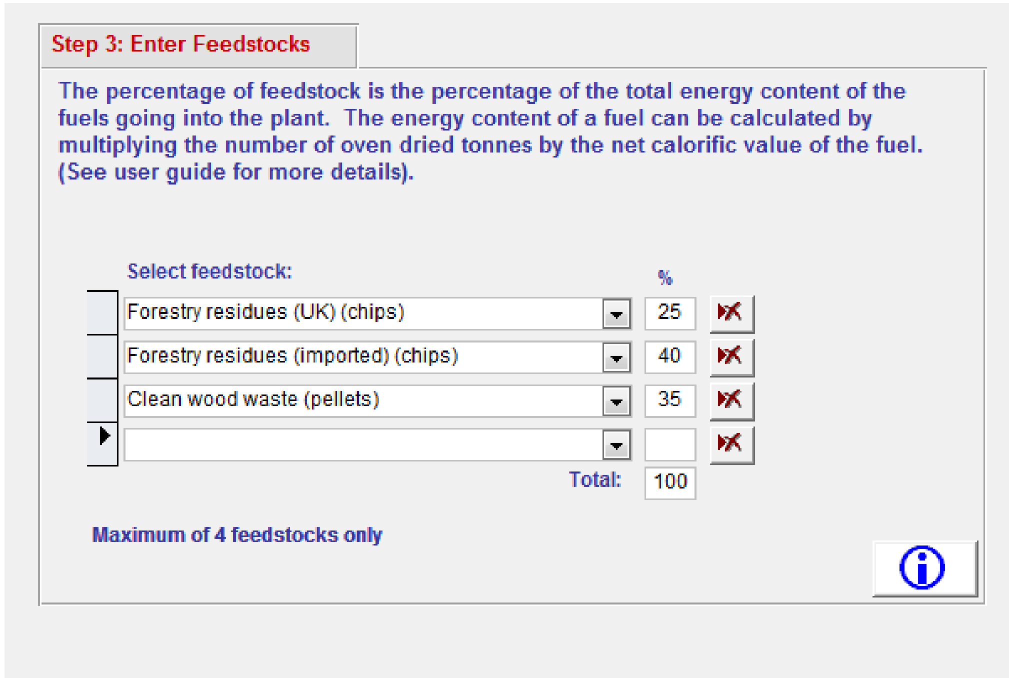


Figure 12: Feed stock and Types selection

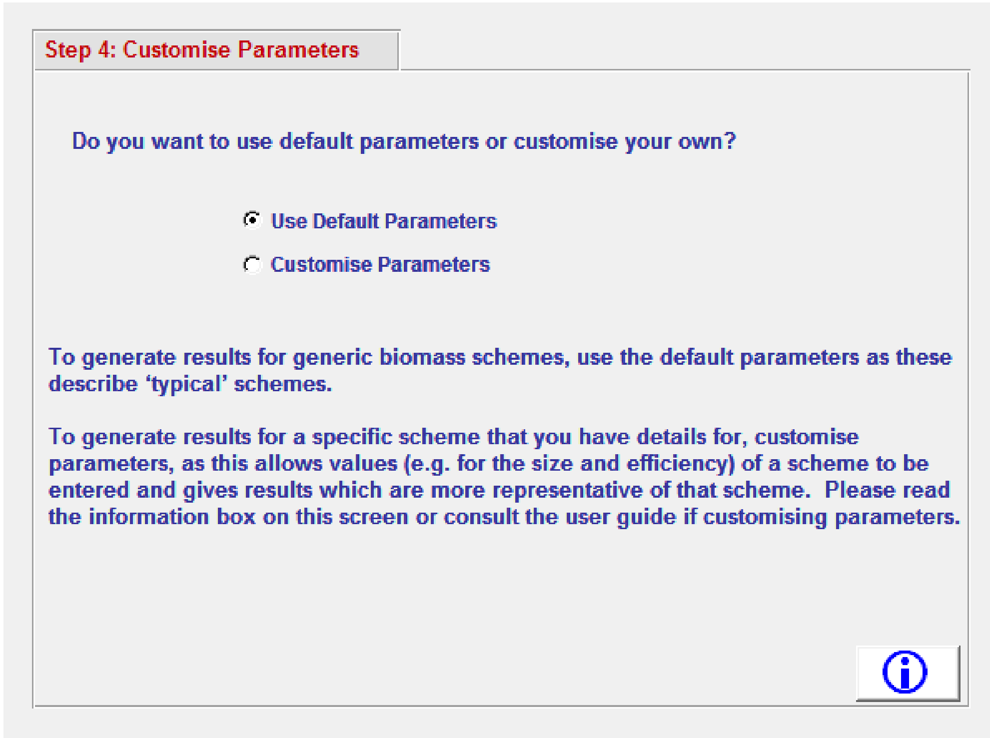


Figure 13: Parameters selection

The user can choose from using default parameter or customize their own parameters. The parameters they can customise can be from the selected technology (here we used the heat only scheme) which are site access, ash disposal and boiler; another parameter can be the characteristic of feed stock such as cultivation and harvesting, transport or drying as you can see in the figure below,

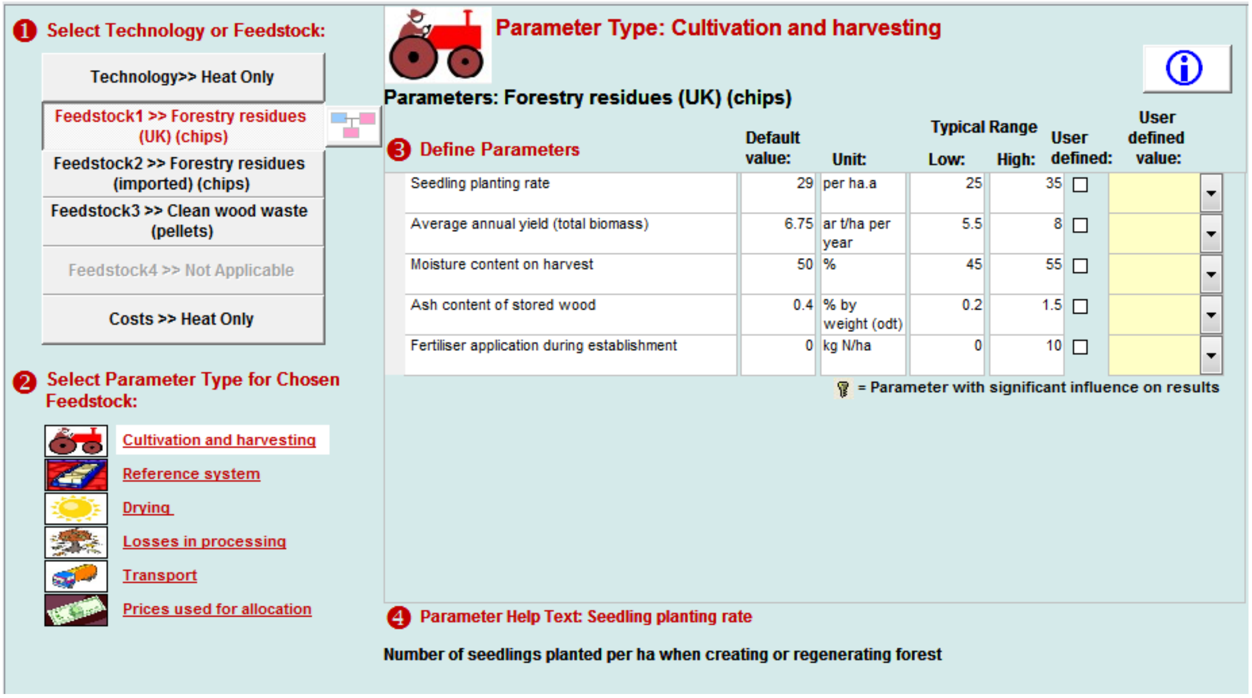


Figure 14: Customise parameters

You can see from the figure above that this tool also include the costs calculation in it, you can customise the cost of feed stock, scheme or you can input any supporting mechanism from the government. The tool is very useful in its own and covered up almost every aspect that need to be concern of a biomass project.

Result from the tool provided graphical detail and numerical detail on the GHG emission compare between biomass scheme, oil, gas and LPG. As you can see from the figure below,

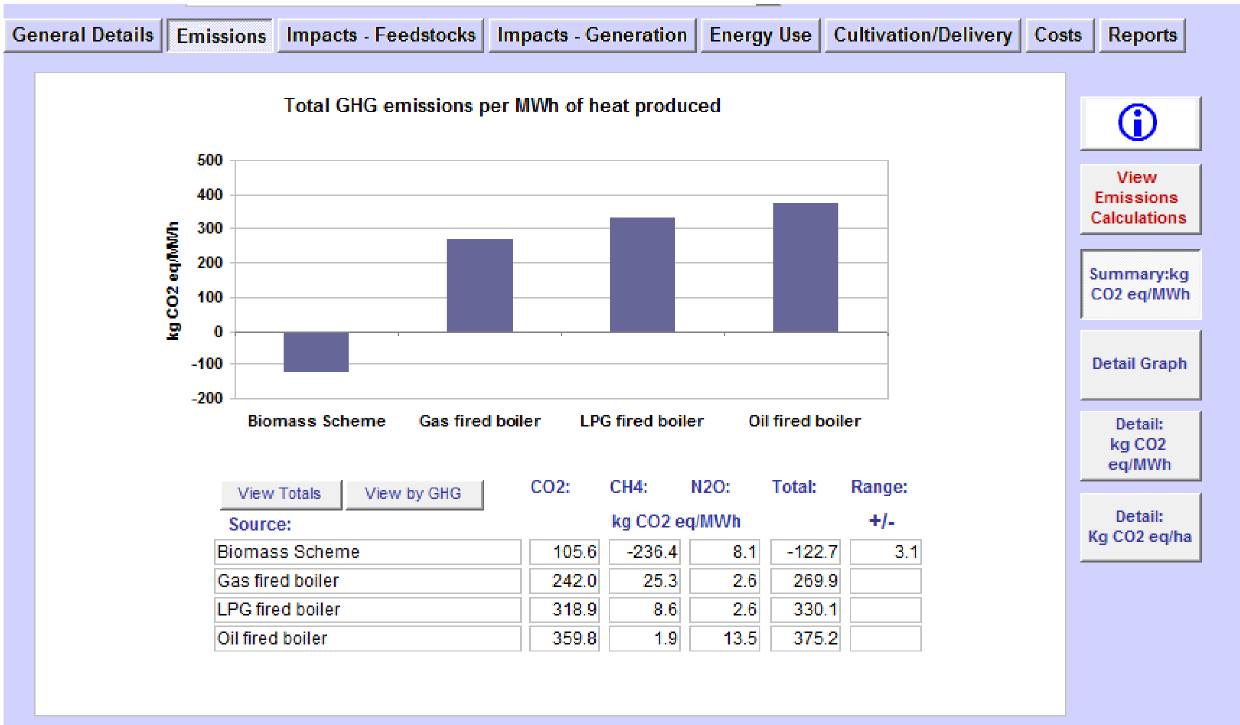


Figure 15: GHG emission result

The result are shown in summary of the GHG emission but you can also see details of the GHG gaseous from the selection panel on the right hand side, the tool also provide the details of calculation in spreadsheet. You can see from the selection panel in the top of the tool that this tool give information about impact of feedstock, impact from generation technology (in here is combustion for heat only generation), the energy use for the biomass scheme (ie. Diesel for tractor, et cetera), the land require to cultivate feed stock and also the delivery time of that feed stock, the estimated cost report for each MWh produced and other report about the biomass scheme, see in the figure below for the report concern with biomass scheme,

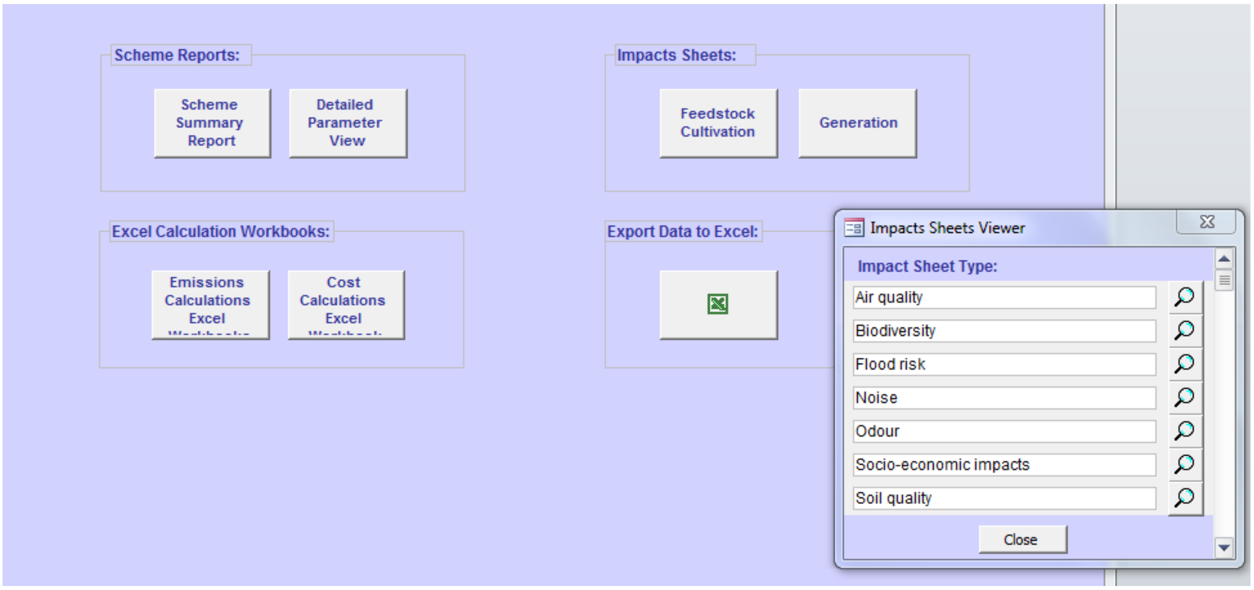


Figure 16: Report on biomass scheme

The scheme report are details of parameter used to calculate such scheme and present in pdf file, the impacts sheets are general impact that cause from using biomass scheme and the impact are shown in the little box in the figure above. You can also export the calculation data to excel spreadsheet which you can look for any details made for calculate the GHG emission. The outputs also highlight where values have been changed from the default setting.

Appendix B: **Methodology for calculating greenhouse gas performance of solid and gaseous biomass used in electricity, heating and cooling**

1a. Greenhouse gas emissions from the production of solid and gaseous biomass fuels, before conversion into electricity, heating and cooling, shall be calculated as:

$E = e_{ec} + e_l + e_p + e_{td} + e_u - e_{sca} - e_{ccs} - e_{ccr}$,

Where

E = total emissions from the production of the fuel before energy conversion;

e_{ec} = emissions from the extraction or cultivation of raw materials;

e_l = annualised emissions from carbon stock changes caused by land use change;

e_p = emissions from processing;

e_{td} = emissions from transport and distribution;

e_u = emissions from the fuel in use, that is greenhouse gases emitted during the combustion of solid and gaseous biomass;

e_{sca} = emission savings from soil carbon accumulation via improved agricultural management;

e_{ccs} = emission savings from carbon capture and geological storage, and;

e_{ccr} = emission savings from carbon capture and replacement.

Emissions from the manufacture of machinery and equipment shall not be taken into account.

1b. Greenhouse gas emissions from the use of solid and gaseous biomass in producing electricity, heating or cooling including the energy conversion to electricity and/ or heat or cooling produced shall be calculated as follows:

For energy installations delivering only useful heat:

$$EC_h = \frac{E}{\eta_h}$$

For energy installations delivering only electricity:

$$EC_{el} = \frac{E}{\eta_{el}}$$

For energy installations delivering only useful cooling:

$$EC_c = \frac{E}{\eta_c}$$

Where:

EC_h = Total greenhouse gas emissions from the final energy commodity, that is heating.

EC_{el} = Total greenhouse gas emissions from the final energy commodity, that is electricity.

EC_c = Total greenhouse gas emissions from the final energy commodity, that is cooling

η_{el} = The electrical efficiency, defined as the annual electricity produced divided by the annual fuel input.

η_h = The thermal efficiency, defined as the annual useful heat output, that is heat generated to satisfy an economically justifiable demand for heat, divided by the annual fuel input.

η_c = The thermal efficiency, defined as the annual useful cooling output, that cooling generated to satisfy an economically justifiable demand for cooling, divided by the annual fuel input.

Economically justifiable demand shall mean the demand that does not exceed the needs of heat or cooling and which would otherwise be satisfied at market conditions.

For the electricity coming from energy installations delivering useful heat:

$$EC_{el} = \frac{E}{\eta_{el}} \left(\frac{C_{el} \cdot \eta_{el}}{C_{el} \cdot \eta_{el} + C_h \cdot \eta_h} \right)$$

For the useful heat coming from energy installations delivering electricity:

$$EC_h = \frac{E}{\eta_h} \left(\frac{C_h \cdot \eta_h}{C_{el} \cdot \eta_{el} + C_h \cdot \eta_h} \right)$$

Where:

C_{el} = Fraction of energy in the electricity, or any other energy carrier other than heat, set to 100 % (Cel = 1).

C_h= Carnot efficiency (fraction of energy in the useful heat).

Carnot efficiency, C_h, for useful heat at different temperatures:

$$C_h = \frac{T_h - T_0}{T_h}$$

Where:

T_h = Temperature, measured in absolute temperature (kelvin) of the useful heat at point of delivery as final energy

T_0 = Temperature of surroundings, set at 273 kelvin (equal to 0 °C)

For T_h < 150 °C (423 kelvin), C_h is defined as follows:

C_h= Carnot efficiency in heat at 150 °C (423 kelvin), which is: 0.3546

2. Greenhouse gas emissions from solid and gaseous biomass fuels for electricity, heating and cooling purposes, EC, shall be expressed in terms of grams of CO2equivalent per MJ of final energy commodity (heat, cooling or electricity), gCO2eq/MJ.

3. Greenhouse gas emission savings from heat, cold and electricity being generated from solid and gaseous biomass shall be calculated as:

SAVING = $(EC_{F\ (h,el,c)} – EC_{h,el,c})/EC_{F\ (h,el,c)}$,

Where

$EC_{h,el\ ,c}$ = total emissions from the heat, cooling or the electricity; and

$EC_{F\ (h,el,c)}$ = total emissions from the fossil fuel comparator for heat, cooling or electricity.

4. The greenhouse gases taken into account for the purposes of point 1 shall be CO2, N2O and CH4. For the purpose of calculating CO2 equivalence, those gases shall be valued as follows:

CO2: 1

N2O: 296

CH4: 23

5. Emissions from the extraction, harvesting or cultivation of raw materials, eec, shall include emissions from the extraction, harvesting or cultivation process itself; from the collection of raw materials; from waste and leakages; and from the production of chemicals or products used in extraction or cultivation. Capture of CO2 in the cultivation of raw materials shall be excluded. Certified reductions of greenhouse gas emissions from flaring at oil production sites anywhere in the world shall be deducted. Estimates of emissions from cultivation or harvesting may be derived from the use of

averages calculated for smaller geographical areas than those used in the calculation of the default values, as an alternative to using actual values.

6. Annualised emissions from carbon stock changes caused by land-use change, el, shall be calculated by dividing total emissions equally over 20 years. For the calculation of those emissions the following rule shall be applied:

$e_l = (CS_R – CS_A) \times 3{,}664 \times 1/20 \times 1/P – e_B$,

Where

e_l = annualised greenhouse gas emissions from carbon stock change due to land-use change (measured as mass of CO2-equivalent per unit solid and gaseous biomass energy);

CS_R = the carbon stock per unit area associated with the reference land use (measured as mass of carbon per unit area, including both soil and vegetation). The reference land use shall be the land use in January 2008 or 20 years before the raw material was obtained, whichever was the later;

CS_A = the carbon stock per unit area associated with the actual land use (measured as mass of carbon per unit area, including both soil and vegetation). In cases where the carbon stock accumulates over more than one year, the value attributed to CSA shall be the estimated stock per unit area after 20 years or when the crop reaches maturity, whichever the earlier;

P = the productivity of the crop (measured as solid and gaseous biomass energy per unit area per year); and

e_B = bonus of 29 g CO2eq/MJ solid and gaseous biomass if biomass is obtained from restored degraded land under the conditions provided for in point 7.

7. The bonus of 29 g CO2eq/MJ shall be attributed if evidence is provided that the land:

(a) Was not in use for agriculture or any other activity in January 2008; and

(b) Falls into one of the following categories:

(i) Severely degraded land, including such land that was formerly in agricultural use;

(ii) Heavily contaminated land.

The bonus of 29 g CO2eq/MJ shall apply for a period of up to 10 years from the date of conversion of the land to agricultural use, provided that a steady increase in carbon stocks as well as a sizable reduction in erosion phenomena for land falling under (i) are ensured and that soil contamination for land falling under (ii) is reduced.

8. The categories referred to in point 7(b) are defined as follows:

(a) "Severely degraded land" means land that, for a significant period of time, has either been significantly salinated or presented significantly low organic matter content and has been severely eroded; EN 15 EN

(b) "Heavily contaminated land" means land that is unfit for the cultivation of food and feed due to soil contamination.

Such land shall include land that has been the subject of a Commission decision in accordance with the fourth subparagraph of Article 18(4) of Directive 2009/28/EC.

9. In accordance with Annex V.C point 10 of Directive 2009/28/EC, the Commission guidelines for the calculation of land carbon stocks adopted in relation to that Directive, drawing on the 2006 IPCC Guidelines for National Greenhouse Gas Inventories — volume 4, shall serve as the basis for the calculation of land carbon stocks.

10. Emissions from processing, e_p, shall include emissions from the processing itself; from waste and leakages; and from the production of chemicals or products used in processing. In accounting for the consumption of electricity not produced within the fuel production plant, the greenhouse gas emission intensity of the production and distribution of that electricity shall be assumed to be equal to the average emission intensity of the production and distribution of electricity in a defined region. By

derogation from this rule, producers may use an average value for an individual electricity production plant for electricity produced by that plant, if that plant is not connected to the electricity grid.

11. Emissions from transport and distribution, e_{td}, shall include emissions from the transport and storage of raw and semi-finished materials and from the storage and distribution of finished materials. Emissions from transport and distribution to be taken into account under point 5 shall not be covered by this point.

12. Emissions from the fuel in use, e_{u}, shall be taken to be zero for solid and gaseous biomass.

13. Emission saving from carbon capture and sequestration, e_{ccs}, that have not already been accounted for in e_p, shall be limited to emissions avoided through the capture and sequestration of emitted CO2 directly related to the extraction, transport, processing and distribution of fuel.

14. Emission saving from carbon capture and replacement, e_{ccr}, shall be limited to emissions avoided through the capture of CO2 of which the carbon originates from biomass and which is used to replace fossil-derived CO2 used in commercial products and services.

15. Where a fuel production process produces, in combination, the energy carrier for which emissions are being calculated and one or more other products ("coproducts"), greenhouse gas emissions shall be divided between the energy carrier or its intermediate product and the co-products in proportion to their energy content. For the accounting of useful heat as co-product, the allocation between the useful heat and other co-products shall be made using the Carnot efficiency (C), where all other co-products than heat has a C equal to 1.

$$A_i = \frac{E}{\eta_i}\left(\frac{C_i \cdot \eta_i}{C_i \cdot \eta_i + C_h \cdot \eta_h}\right)$$

Where:

A_i = Allocated GHG emissions at allocation point to (co-)product i

E = Total GHG emissions up to allocation point

η_i = The fraction of co-product or product, measured in energy content, defined as the annual amount of co-product or product produced divided by the annual energy input.

η_h = The fraction of heat produced together with other co-products or products, defined as the annual useful heat output divided by the annual energy input.

C_i = Fraction of energy in the energy carrier (else than heat), equal to 1

C_h = Carnot efficiency (fraction of energy in the useful heat).

Carnot efficiency, C_h, for useful heat at different temperatures:

$$C_h = \frac{T_h - T_0}{T_h}$$

Where:

T_h = Temperature, measured in absolute temperature (kelvin) of the useful heat at point of delivery.

T_0 = Temperature of surroundings, set at 273 kelvin (equal to 0 °C)

For T_h < 150 °C (423 kelvin), C_h is defined as follows:

C_h = Carnot efficiency for heat at 150 °C (423 kelvin), which is: 0.3546

16. For the purposes of the calculation referred to in paragraph 15, the emissions to be divided shall be e_{ec} + el, + those fractions of e_p, e_{td} and e_{ee} that take place up to and including the process step at which a co-product is produced. If any allocation to coproducts has taken place at an earlier process step in the life-cycle, the fraction of

those emissions assigned in the last such process step to the intermediate fuel product shall be used for this purpose instead of the total of those emissions.

In the case of solid and gaseous biomass, all co-products, including electricity that does not fall under the scope of paragraph 14, shall be taken into account for the purposes of this calculation, except for agricultural crop residues, including straw, bagasse, husks, cobs and nut shells. Co-products that have negative energy content shall be considered to have an energy content of zero for the purpose of the calculation.

Wastes, secondary biomass and primary forest and agricultural crop residues, including tree tops and branches, straw, bagasse, husks, cobs and nut shells, and residues from processing, including crude glycerine (glycerine that is not refined), shall be considered to have zero life-cycle greenhouse gas emissions up to the process of collection of those materials.

In the case of fuels produced in refineries, the unit of analysis for the purposes of the calculation referred to in paragraph 15 shall be the refinery.

17. For solid and gaseous biomass, for electricity production, for the purposes of the calculation referred to in point 4, the fossil fuel comparator ECF(el) shall be 198 gCO2eq/MJ electricity.

For solid and gaseous biomass used for heating production, for the purposes of the calculation referred to in point 4, the fossil fuel comparator ECF(h) shall be 87 gCO2eq/MJ heat.

For solid and gaseous biomass used for cooling through absorption heat pumps, for the purposes of the calculation referred to in point 4, the fossil fuel comparator ECF(c)shall be 57 gCO2eq/MJ cooling.

Appendix C: Typical and default values for solid and gaseous biomass if produced with no net carbon emissions from land use change

Primary solid and gaseous biomass pathways	Typical greenhouse gas emissions (gCO_{2eq}/MJ)	Default greenhouse gas emissions (gCO_{2eq}/MJ)
Wood chips from forest residues (European temperate continental forest)	1	1
Wood chips from forest residues (tropical and subtropical forest)	21	25
Wood chips from short rotation forestry (European temperate continental forest)	3	4
Wood chips short rotation forestry (tropical and sub-tropical e.g. eucalyptus)	24	28
Wood briquettes or pellets from forest residues (European temperate continental forest) – using wood as process fuel	2	2
Wood briquettes or pellets from forest residues (tropical or subtropical forest) – using natural gas as process fuel	17	20
Wood briquettes or pellets from forest residues (tropical or subtropical forest) – using wood as process fuel	15	17
Wood briquettes or pellets from forest residues (European temperate continental forest) – using natural gas as process fuel	30	35
Wood briquettes or pellets from short rotation forestry (European temperate continental forest) – using wood as process fuel	4	4
Wood briquettes or pellets from short rotation forestry (European temperate continental forest) – using natural gas as process fuel	19	22
Wood briquettes or pellets from short rotation forestry (tropical and sub-tropical e.g. eucalyptus) – wood as process fuel	18	22

Wood briquettes or pellets from short rotation forestry (tropical and sub-tropical e.g. eucalyptus) – natural gas as process fuel	33	40
Charcoal from forest residues (European temperate continental forest)	34	41
Charcoal from forest residues (tropical and sub-tropical forest)	41	50
Charcoal from short rotation forestry (European temperate continental forest)	38	46
Charcoal from short rotation forestry (tropical and sub-tropical e.g. eucalyptus)	47	57
Wheat straw	2	2
Bagasse briquettes – wood as process fuel	14	17
Bagasse briquettes – natural gas as process fuel	29	35
Bagasse bales	17	20
Palm kernel	22	27
Rice husk briquettes	24	28
Miscanthus bales	6	7
Biogas from wet manure	7	8
Biogas from dry manure	6	7
Biogas from wheat and straw (wheat whole plant)	18	21
Biogas from maize as whole plant (maize as main crop)	28	34
Biogas from maize as whole plant (maize as main crop) – organic agriculture	16	19

Appendix D: Wood fuel usage

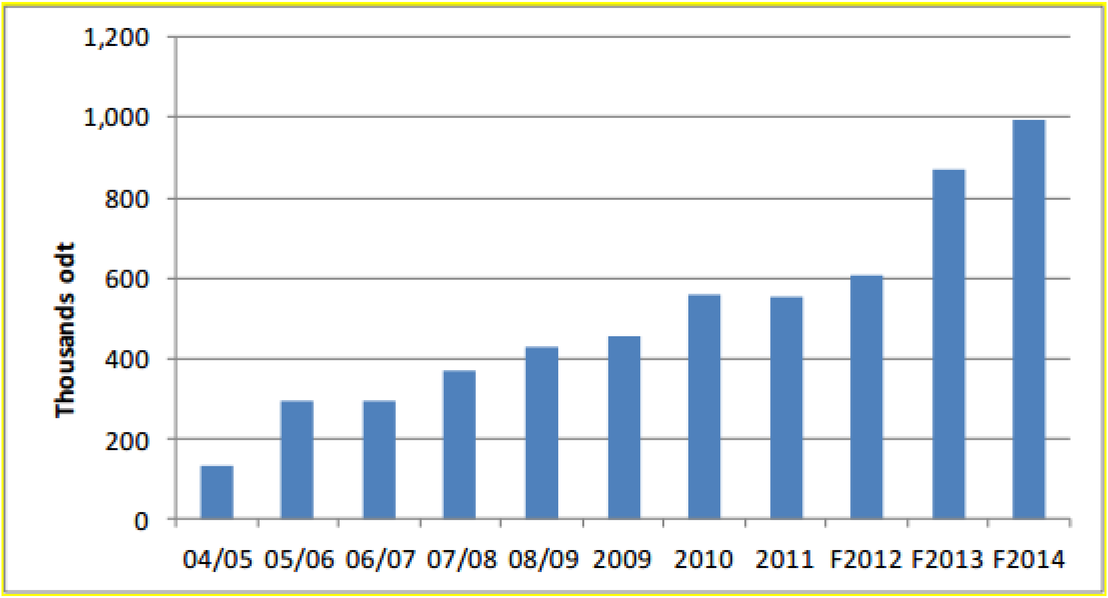


Figure 1: Wood Fuel Usage - Major Industry/Commercial (using >10,001 odt/yr)

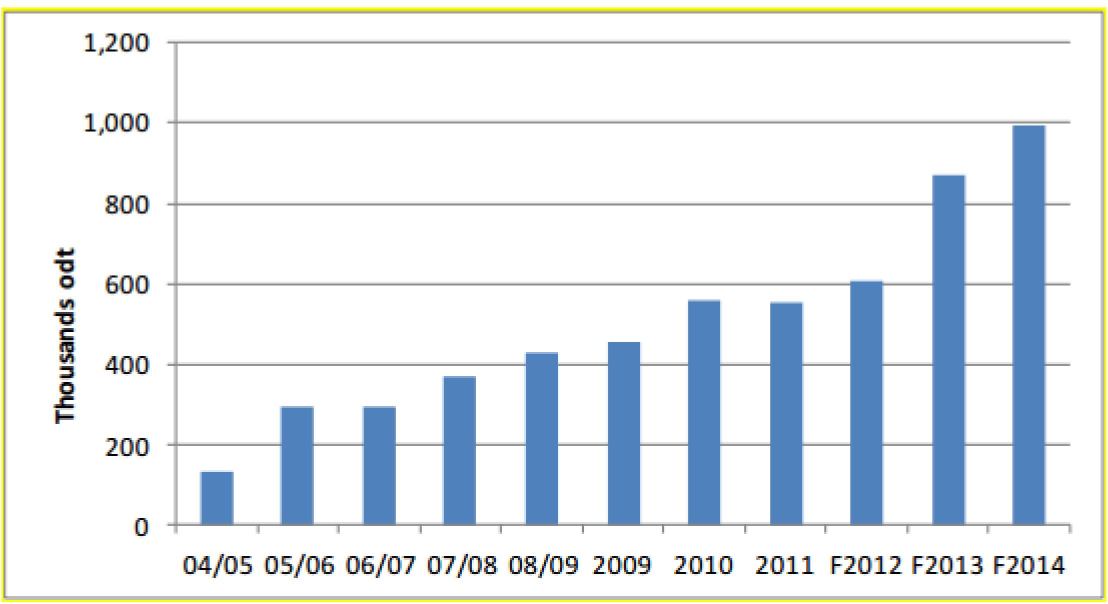


Figure 2: Wood Fuel Use - Industry/Commercial (using 1,001 to10,000 odt/yr)

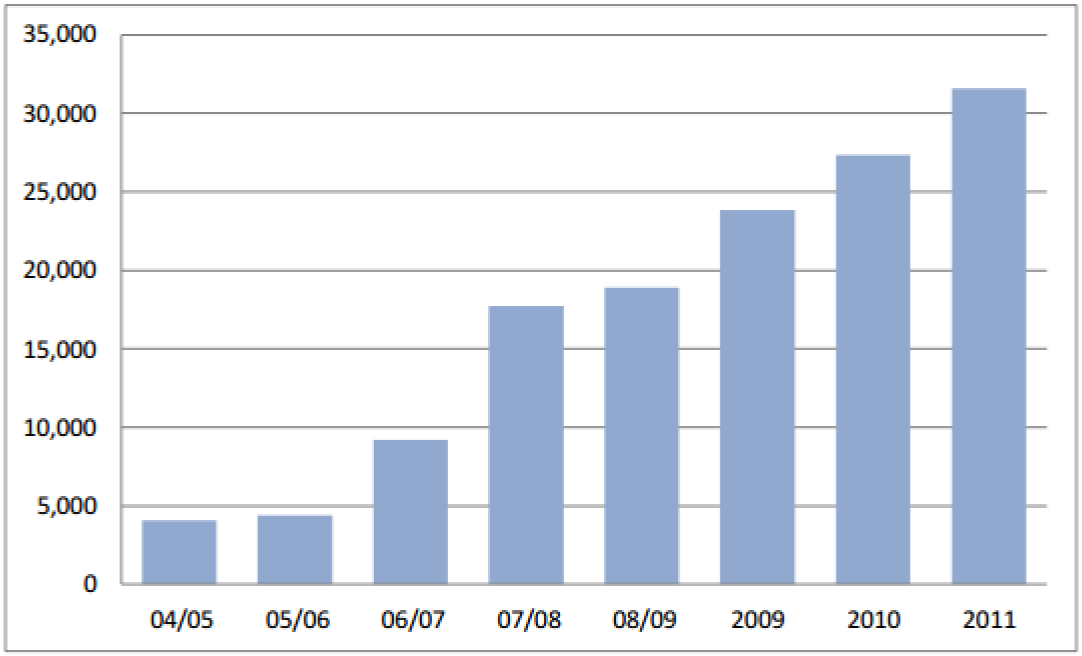


Figure 3: Wood Fuel Use - Other Industry/Commercial (using up to 1,000 odt/yr)

Appendix E: the reference from BEAT2 manual

Reference system from 1st scenario

chb_p_cb_h.xls	Chipboard off cuts and sawdust	Collection	Pellets	Combustion	Heat (industrial)	Disposal of waste chipboard to landfill with energy recovery, wood ash used to replace agricultural lime	None	Biomass source treated as a waste, laminate and glue treated as fossil fuel, and option for Waste Incineration Directive compliance	None but theoretical assumption about direct emissions for laminate and glue

Figure 1: reference system for chipboard pellets

Appendix F: Scheme summary report

Scheme Name: **1st scenario**

Scheme Version:

Bioenergy Environmental Assessment Tool (BEAT)

BEAT was developed for DEFRA and the Environment Agency by AEA. It provides:

A) Estimates of the greenhouse gas emissions associated with bioenergy schemes and a comparison with conventional fossil fuel technologies,
B) Identifies potential environmental impacts associated with the scheme
C) Estimates land area required for cultivation of feedstock and lorry movements to deliver feedstock to scheme
D) Estimates the cost of energy produced by the scheme and the value of support mechanisms

This report is prepared to enable informed discussion about the potential impacts of bioenergy schemes; it is not an authoritative statement of expected impacts. The results below are based on a number of assumptions which are detailed at the end of the report. Where assumptions have been changed by the user to better reflect individual scheme characteristics, this is clearly indicated (SECTION D)

GENERAL DETAILS **This report was generated on 04/09/2013**

Scheme Name:	**sc**
Scheme Version:	
Scheme Technology:	**Scheme Process:**
Heat Only	Combustion
Scheme Output:	**Scheme Scale:**
Heat only	Industrial/Commercial/Community

Feedstock name	%
Chipboard (pellets)	100

GENERAL DETAILS

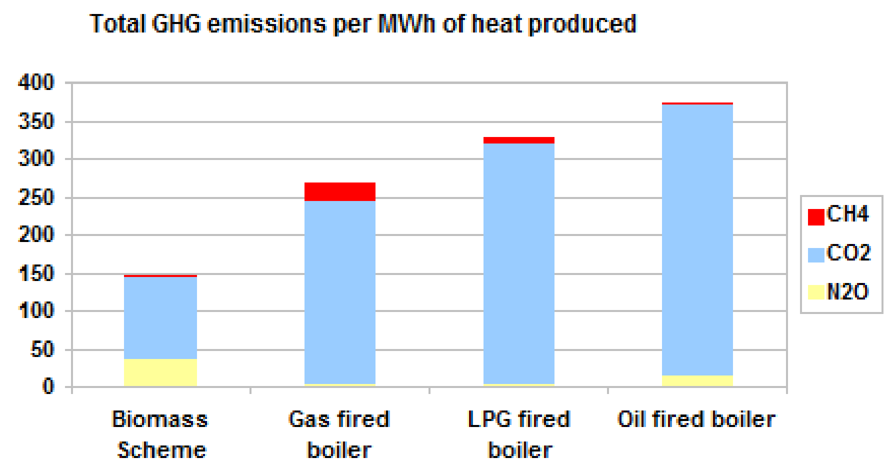
Scheme Name: **1st scenario**

Scheme Version:

Scheme Technology:	**Scheme Process:**
Heat Only	Combustion
Scheme Output:	**Scheme Scale:**
Heat only	Industrial/Commercial/Community

Feedstock name:	%
Chipboard (pellets)	100

SECTION A: Summary of lifecycle greenhouse gas emissions



Source:	CO2	CH4	N2O	Total:	Range:
		kg CO2 eq/MWh			+/-
Biomass Scheme	109.4	1.9	34.1	-209.1	3.4
Gas fired boiler	242.0	25.3	2.6	269.9	
LPG fired boiler	318.9	8.6	2.6	330.1	
Oil fired boiler	359.8	1.9	13.5	375.2	

Figure 1: Total GHG emission

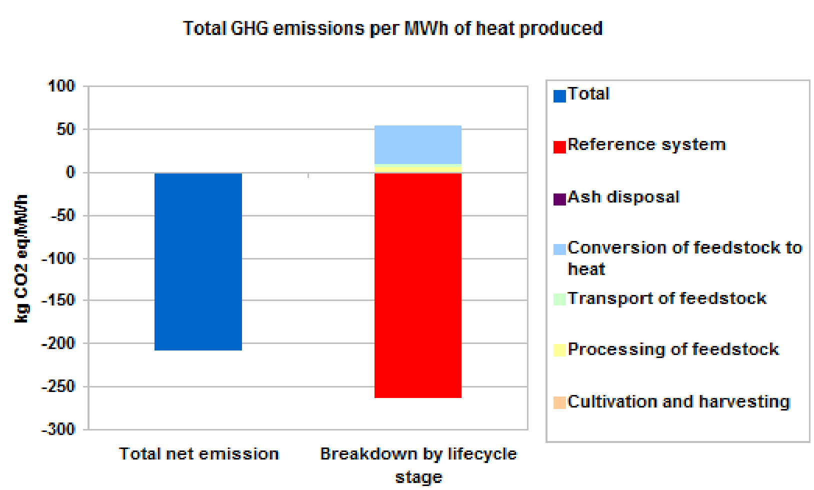


Figure 2: Breakdown GHG emission

GHG emissions per MWh generated								
		kg CO2 eq/MWh			**total GHG:**	**Total GHG (range):**	**Primary energy required MWh/MW**
Description:		**CO2:**	**CH4:**	**N2O:**			
Supply of chipboard (pellets)	Reference system	89.2	1.0	0.9	-263.4	0.1	0.5
Supply of chipboard (pellets)	Transport of feedstock	4.0	0.1	0.3	4.4	0.1	0.0
Supply of chipboard (pellets)	Processing of feedstock	6.0	0.3	0.1	6.4	0.6	0.0
Supply of chipboard (pellets)	Cultivation and harvesting						
Heat production	Ash disposal	0.0	0.0	0.0	0.0	0.0	0.0
Heat production	Conversion of feedstock to heat	10.2	0.5	32.9	43.5	3.4	0.0
TOTAL		**109.4**	**1.9**	**34.1**	**-209.1**	**3.4**	**0.6**

SECTION B: Summary of potentially significant impacts

Fuel	Impact	Description	Mitigation Option
N/A		NO SIGNIFICANT IMPACTS	

Generation Type	Impact	Description	Mitigation Option
Combustion	Noise	Soundproofing of plant should reduce noise to acceptable levels. High speed chipping/shredding equipment for fuel processing can be very noisy.	Soundproofing and landscaping features can reduce noise at site boundary. Use low speed equipment for any chipping/shredding.
Combustion	Release to air	Potentially significant impact; detailed determination of impacts is complex and site specific.	Pollution abatement technologies can reduce emissions of pollutants if required.
Combustion	Release to water	Detailed determination of impacts is complex and will be covered by IPPC authorisation, with contaminated process water likely to be discharged to sewer.	Features such as lagoons for water storage, efficient land drainage, oil separators (interceptors), silt traps wet balancing ponds and reed beds can help to reduce the impact on nearby water courses.
Combustion	Visual Impact	Visual impact will depend on size of plant and building and stacks and surrounding landscape but can be significant in rural areas	Avoid siting in high quality landscape. Landscape to match surrounding topography, paint buildings appropriate colour and landscape with local flora.

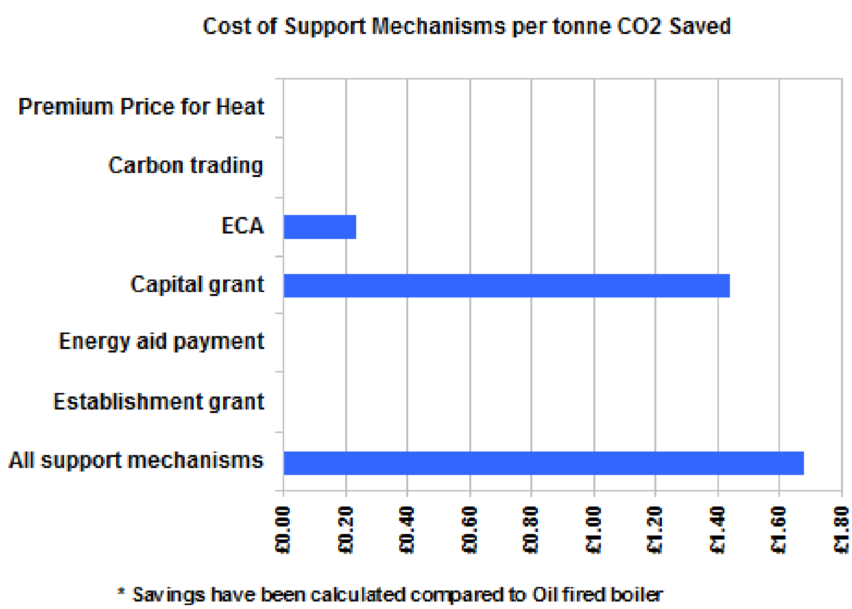
SECTION C: Fuel use, cultivation and delivery

	Fuel Type	Hectares for	Delivery
	cultivation	lorries per week	
Chipboard (pellets)	0	1.2	

SECTION D: Estimated cost of energy produced and value of support mechanism

Estimated net price of elecricity from biomass scheme: £/MWh

Average price of grid electricity for comparison: £40.00 £/MWh



*** Savings have been calculated compared to Oil fired boiler**

All support mechanisms	£1.68
Establishment grant	£0.00
Energy aid payment	£0.00
Capital grant	£1.44
ECA	£0.24
Carbon trading	£0.00
Premium Price for Heat	£0.00

Value per tonne of CO2 based on comparison of lifecycle emissions with those from gas fired electricity and heat generation for all dedicated

biomass and anaerobic digestion schemes, coal fired generation for cofiring and conventional petrol and diesel for liquid biofuels

Appendix G: Detailed parameter

Scheme Name: 1st scenario

Scheme Version:

Assumptions in Tool

Feedstock Or	LifeStageName:	Parameter:	Default	Units:	Lower Range:	Upper	User Defined
Technology:	Value:	Range:	Value:				
Chipboard (pellets)	Feedstock characteristics converted to N2O	Fraction of N in melamine resin	10	% by weight	0	20	
Chipboard (pellets)	Feedstock Characteristic converted to N2O	Fraction of N in urea formaldehyde resin	10	% by weight	0	20	
Chipboard (pellets)	Feedstock characteristics	Calculate calorific value based on composition?	yes	yes/no			

Chipboard (pellets)	Feedstock characteristics	Fraction of melamine resin in waste	0	% by weight	0	20	
Chipboard (pellets)	Feedstock characteristics waste	Fraction of urea formaldehyde resin in	8	% by weight	0	20	
Chipboard (pellets)	Feedstock characteristics	Net calorific value of chipboard waste	18	GJ per odt	17	19	
Heat Only	Site access Location	Description of Site	Rural / Isolated				
Heat Only	Site access Access	Description of Site	Average				
Chipboard (pellets)	Reference system for alternative use/disposal	Include reference system	yes	yes/no			
Chipboard (pellets)	Reference system distance if chipboard waste were disposed of	Reference round trip	100	km	0	200	

	to landfill						
Chipboard (pellets)	Losses in processing	Losses during shredding	5	%	0	10	
Chipboard (pellets)	Losses in processing	Losses at milling	2	%	0	5	
Chipboard (pellets)	Losses in processing	Losses during pelletisatio n	2	%	0	5	
Chipboard (pellets)	Transport factory to pelleting plant (stage 1)	Transport mode - From barge/ship	road	road/rai l/			
Chipboard (pellets)	Transport distance - From factory to pelleting plant (stage 1)	Average round trip	100	km	0	400	
Chipboard (pellets)	Transport pelleting plant (stage	Losses - From factory to	3	%	0	5	

	1)						
Chipboard (pellets)	Transport Factory to pelleting plant (stage 2)	Transport mode - barge/ship	road/rail/				
Chipboard (pellets)	Transport distance - Factory to pelleting plant (stage 2)	Average round trip	0	km	0	400	
Chipboard (pellets)	Transport pelleting plant (stage 2)	Losses - Factory to	0	%	0	5	
Chipboard (pellets)	Transport pelleting plant to heating plant (stage 1)	Transport mode - From barge/ship	road	road/rail/			
Chipboard (pellets)	Transport distance - From pelleting plant to	Average round trip	100	km	0	400	

	heating plant (stage 1)						
Chipboard (pellets)	Transport plant to heating plant (stage 1)	Losses - From pelleting	3	%	0	5	
Chipboard (pellets)	Transport pelleting plant to heating plant (stage 2)	Transport mode - From barge/ship	road/rail/				
Chipboard (pellets)	Transport distance - From pelleting plant to heating plant (stage 2)	Average round trip	km	0	400		
Chipboard (pellets)	Transport plant to heating plant (stage 2)	Losses - From pelleting	0	%	0	5	
Heat Only	Ash disposal ash disposal	Round trip distance for	100	km	0	200	

Heat Only	Ash disposal application of lime to land	Allow for ash displacing	yes	yes/no			
Heat Only	Boiler (input rating)	Size of plant (thermal)	0.8	MWth	0.1	1.5	
Heat Only	Boiler boiler	Net thermal efficiency of	80	%	75	92	
Heat Only	Boiler drying?	Include high temperatur e	no	yes/no			
Heat Only	Boiler	Annual load factor	65	%	65	90	
Heat Only	Boiler	Lifetime of plant	25	years	20	30	
Heat Only	Boiler up and feed	% energy used for start	1.1	%	0.5	2	
Heat Only	Boiler	Cost of boiler	256	£/MWt input	133	247	
Costs	Scheme costs	Capital cost	319136	£/MW th	28722 3	35105 0	

Costs	Scheme costs maintenance costs as £ per year	Annual operating &	0	£ / year	0	0	
Costs	Scheme costs maintenance costs as % of capital costs	Annual operating & costs	2	% of capital	1.8	2.2	
Costs	Scheme costs	Ash disposal costs	0	£ / tonne ash	0	0	
Costs	Scheme costs costs	Insurance costs (annual)	1.25	% of capital	1.125	1.375	
Costs	Scheme costs	Other (annual)	0	£ / year	0	0	
Costs	Scheme costs	Cost of Capital	10	%			
Costs	Feedstock costs	Cost of Feedstock 1	60	£/odt	54	66	
Costs	Feedstock costs	Cost of Feedstock 2	£/odt				

Costs	Feedstock costs	Cost of Feedstock 3	£/odt				
Costs	Feedstock costs	Cost of Feedstock 4	£/odt				
Costs	Support mechanisms	Establishment grant - Miscanthus	£/ha				
Costs	Support mechanisms	Energy Aid Payment	£/ha				
Costs	Support mechanisms	Capital grant costs	30	% of capital			
Costs	Support mechanisms	Enhanced capital allowance	5 costs	% of capital			
Costs	Support mechanisms	Premium price for biomass heat	0	£/ MWh heat			
Costs	Support mechanisms	Carbon trading	0	£/t CO2			
Costs	Support mechanisms	Establishment grant - SRC	£/ha				

Costs	Support mechanisms to…	CO_2 savings to be calculated in comparison	Oil fired boiler	
Costs	Discount rate	Discount Rate	3.5	%