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Greenhouse gas and energy based life cycle analysis of products from the Irish wood processing industry

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Abstract

The timber industry in Ireland is an important producer of wood products for export and indigenous use, and supplies significant volumes of sawmill co-products as biomass for energy generation. This research expands existing knowledge on the environmental impacts of wood supply chains in Ireland by widening the analysis to incorporate the wood processing stage. The study determines and analyses energy and material inputs in the production of several timber products; sawnwood, wood chip, wood-based panel (WBP) boards and wood pellets, with an analysis of the resulting greenhouse gas emissions. Forestry operations and transportation make an important contribution to overall emissions. Electricity usage is responsible for the majority of emissions in sawmilling. Integration of combined heat and power (CHP) systems with sawmilling and pellet manufacture reduces greenhouse gas (GHG) emissions. The penetration of renewables in the Irish national grid mix is forecast to increase by 2020 in line with EU renewable energy targets. Analysis shows that the forecast fall in the carbon intensity of the grid will have a positive effect on the reduction of GHG emissions from the wood processing supply chains. Wood energy products compare favourably with other sources of biomass energy and with fossil fuels.

Keywords – wood processing, wood energy, wood chip, wood pellets, combined heat and power, life cycle assessment, LCA

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Nomenclature

CHP – combined heat and power

GHG - greenhouse gas

WBP - wood-based panel

RWE - roundwood equivalent

LCA - life cycle assessment

odt - oven-dried tonne

GJ - giga joule

MDF - medium density fibreboard

OSB – oriented strand board

GWP - global warming potential

CED - cumulative energy demand

SC – scenario

SRCW - short rotation coppice willow

1 Introduction

The timber industry in Ireland is an important aspect of the Irish economy, contributing 3 billion euro of export value in forest products, including sawn timber and wood-based panels, in 2012 (Irish Forestry and Forest Products Association, 2013). There are eight sawmills, three wood-based panel (WBP) mills, and one pellet manufacturer currently operating in the Republic of Ireland. The Irish sawmilling sector provides the primary outlet for indigenous roundwood, utilising 1.75 million m³ of roundwood to produce 900,000 m³ of sawn timber in 2012. Additionally, the wood-based panel sector utilised 1.28 million m³ of wood fibre in the production of 704,000 m³ of panel, and is a major user of pulpwood, sawmill residues (i.e. sawdust, wood chip and bark) and post-consumer recovered wood.

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In Ireland the timber industry supplies significant volumes of sawmill co-products (including bark, sawdust, shavings and wood chip) as biomass for energy generation. Between the years 2000 and 2012, renewable heat generation grew from 2.4% to 5.2% with this growth dominated by biomass (Howley and Holland, 2013). Traditionally, the majority (48%) of biomass-for-energy in Ireland has been consumed by sawmill and WBP industries as feedstock for kilns and process heat generation. However, with the introduction of the EU renewable energy target of 20% of energy from renewables by 2020 (European Commission, 2007), increasing volumes of wood biomass are being utilised by the energy, commercial and domestic heating sectors. For example, in 2012, 152,000 m³ of roundwood equivalent (RWE) were co-fired with peat at Edenderry power plant (Knaggs and O'Driscoll, 2013). In addition, the production and use of wood pellets and briquettes is gaining prominence, increasing from 82,000 m³ RWE in 2008 to 144,000 m³ RWE in 2012.

In order to meet the EU renewable energy targets, it is forecast that the demand for wood biomass on the island of Ireland will increase from 1.589 million m³ (overbark) to 3.084 million m³ (overbark) by 2020 (COFORD Roundwood Demand Group, 2011). This demand increase provides a new market for wood biomass which may be met by roundwood traditionally used in the wood processing sector or by the use of sawmill co-products in the form of chips or pellets. Consequently, competition between the energy and wood processing sectors for biomass will increase.

In addition to the 20% renewable energy target mentioned above, the EU has mandated a 20% reduction in greenhouse gas (GHG) emissions by 2020. Despite the fact that wood biomass contributing to this target is currently considered carbon neutral by the EU, the production and processing of this biomass utilises materials and fossil fuels which results in greenhouse gas emissions along the supply chain. It is important to analyse these wood energy supply chains in order to ensure actual GHG emissions reductions.

Opportunities exist in the wood processing sectors to improve environmental efficiency. In Ireland, the majority of sawmills burn by-products to fulfill their heating requirements, this is supplemented by fossil sources when required, and import electricity from the national grid. By integrating a combined heat and power (CHP) system with an existing sawmill, there is potential to increase energy efficiency and reduce electricity usage from the national grid. In addition, the location of a pellet mill with an existing sawmill allows optimal use of resources (Anderson and Toffolo, 2013).

Life cycle assessment (LCA) is a tool which can be used to assess the environmental impacts and energy requirements of wood processing systems and innovations in these systems from a holistic perspective. Please cite as: Murphy, et al., Greenhouse gas and energy based life cycle analysis of products from the Irish wood processing industry, Journal of Cleaner Production (2015), <http://dx.doi.org/10.1016/j.jclepro.2015.01.001>

perspective. LCA allows the evaluation of a product or system over its entire life cycle, from raw material production through processing, to consumption and disposal. The holistic nature of LCA allows the identification of points in the system of critical contributions to key environmental impacts (hotspots). A range of literature exists evaluating the environmental impacts of various wood processing systems. LCA studies have been carried out on the core sawmill products on national scales for Germany (Diederichs, 2014a), Norway (Tellnes et al., 2012) and Australia (Tucker et al., 2009). The production of sawnwood, one sawmill product, has been studied extensively from cradle-to-grave for several regions of the United States (Puettmann et al., 2013b, c, d, e). The functional unit for sawnwood production systems is generally reported as volume of sawnwood produced.

Life cycle assessment studies of medium density fibreboard (MDF) manufacture have been carried out for a number of regions including; the United States (Wilson, 2010), Germany (Diederichs, 2014b), Spain and Chile (Rivela et al., 2007), and Brazil (Silva et al., 2013). The functional unit is consistently reported as 'volume of product at the factory gate' in the reviewed studies with the majority including impacts from cradle-to-gate. Silva et al. (2013) identified the use of urea-formaldehyde resins as an environmental hotspot, with energy use also an important factor (Wilson, 2010). González-García et al. (2009) found that replacing formaldehyde resin in hardboard manufacture with a bio-adhesive (lacasse) results in environmental benefits and reduced energy demand compared to the conventional system.

Oriented strand board (OSB) manufacture has been studied from an LCA perspective in several regions, including the United States (Kline, 2005; Mason Earles et al., 2011; Puettmann et al., 2013a) and Luxembourg (Benetto et al., 2009). Similarly to studies on MDF, the functional unit is expressed on a volume basis and the majority consider upstream impacts from timber production and processing. Mason Earles et al. (2011) investigated co-production of OSB with ethanol and acetic acid with the aim of reducing environmental impacts. Results from the study show a reduction in emission of volatile organic carbon by this method but an overall increase of greenhouse gas emissions and energy requirements. A novel drying technique in OSB manufacture was assessed by Benetto et al. (2009) which lead to a reduction in environmental impacts compared to conventional manufacture.

The use of sawmill co-products for energy generation in power plants has been studied by Mälkki and Virtanen (2003), with the analysis extending from forestry operations to biomass combustion. A

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number of LCA studies have been carried out on the use of sawmill co-products for pellet production (Hagberg et al., 2009; Magelli et al., 2009; Mani et al., 2005; Pa et al., 2012; Petersen Raymer, 2006; Sikkema et al., 2013; Sjølie and Solberg, 2011). The functional unit used in LCA studies of wood pellet production is primarily 'mass of wood pellets produced', however a functional unit of 'energy contained wood pellets' has also been used to aid comparison with other energy sources. Emissions from wood pellet production are strongly dependent on the fuel used in drying, with emissions increasing when fossil fuels (oil or gas) are used rather than biomass (Hagberg et al., 2009; Magelli et al., 2009). In addition, as wood pellet production is an energy intensive process, the emission intensity of the electricity grid mix has a significant effect on environmental impacts (Hagberg et al., 2009).

In Ireland little research exists on the environmental impacts of the wood processing sector, with only wood production studied from an LCA perspective to date (Murphy et al., 2014b). The aim of this study is to add to the pre-existing LCA knowledge of forest operations in Ireland, by analysing the next step in the timber industry; the wood processing stage. The analysis considers each of the products from sawmilling, WBP manufacture and pellet manufacture from a life cycle point of view.

2 Materials and Methods

2.1 Goal and scope

This research endeavours to expand existing knowledge on the environmental impacts of biomass supply chains in Ireland by widening the analysis to incorporate the wood processing supply stage. The study determines and analyses energy and material inputs in the production of several timber products; sawnwood, WBP, wood chip and wood pellets, with an analysis of the resulting greenhouse gas emissions. The study represents a 'cradle-to-gate' LCA and as such the system boundary includes all processes from raw material production to the finished product at the factory gate. It is important to note that the analysis does not consider the embodied carbon in any of the wood products produced.

Functional unit

A number of products of the wood processing industry in Ireland are assessed. Different functional units are necessary when products of the system fulfill different functions. The functional unit for sawnwood and WBP production is '1 m³ of product at the factory gate'. The functional unit for wood chip and wood pellet production is '1 oven-dried tonne (odt) of product at the factory gate'. Please cite as: Murphy, et al., Greenhouse gas and energy based life cycle analysis of products from the Irish wood processing industry, Journal of Cleaner Production (2015), <http://dx.doi.org/10.1016/j.jclepro.2015.01.001>

However, to allow comparison with other energy sources, results are also expressed per giga joule (GJ) of energy contained in the biomass.

System description

This study examines a number of different scenarios in the wood processing industry. As CHP systems and pellet manufacturing are relatively new concepts in Ireland, this study explores a number of scenarios reflecting both traditional practices and new innovation for energy production. Fig. 1 outlines the system boundary of the study.

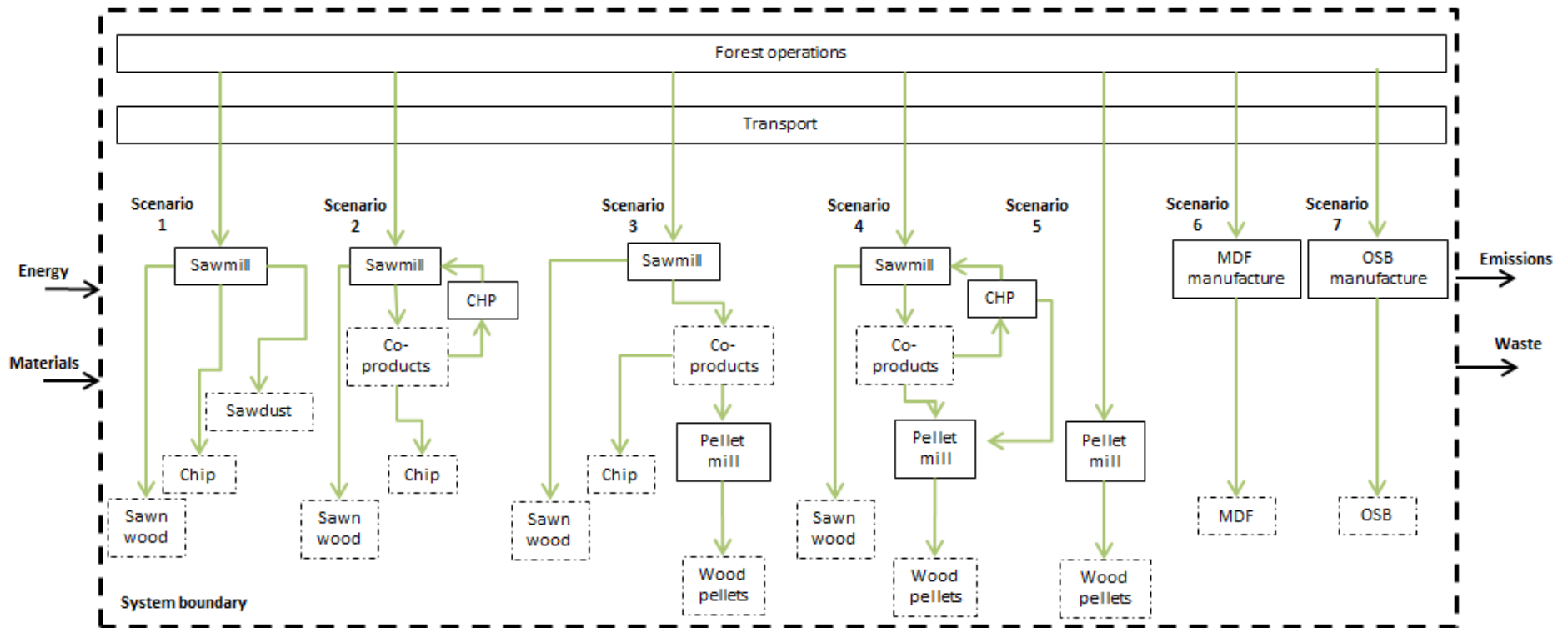


Figure 1 – System diagram

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Description of scenarios outlined in Figure 1.

- Scenario 1: Conventional sawmill. In the first step of the sawmill process, the logs are loaded onto the debarking line where they are debarked and graded. Debarked logs are sawn into planks and boards (producing co-products chips and sawdust). A proportion of the timber is treated with preservative such as Tanalith E. The co-products from sawmilling have a number of uses; bark is used to fuel biomass kilns for process heat or sold to the horticulture industry, chips are sold for energy generation or for WBP manufacture, and a proportion of sawdust is used to fuel biomass kilns for process heat with the remainder sold for energy generation or WBP or pellet production. The majority of bark and sawdust produced are combusted on-site to provide process heat for drying. The biomass heating is supplemented with heating from fossil energy sources if required.
- Scenario 2: Sawmill with integrated CHP. Conventional sawmill as described for Scenario 1 but with the integration of a CHP system to provide electricity and heat to meet the system requirements. The sawmill produces sawnwood, wood chip, and sawdust, bark and peelings. The CHP consumes the majority of the sawdust, bark and peelings produced in the sawmill, with additional biomass brought in to achieve the full biomass fuel requirement. Wood chip is sold to WBP manufacturers or exported. The capacity of the CHP plant is 2.1 MW_e and 3.6 MW_{th}. The CHP plant is backed up by a light fuel oil generator.
- Scenario 3: Sawmill integrated with pellet plant. Conventional sawmill integrated with a 25,000 ton per annum capacity pellet mill. The pellet mill utilises the sawdust and a proportion of wood chip produced in the sawmill with additional sawdust and chip sourced externally to fulfill the pellet mill biomass requirements. The remaining portion of wood chip is sold. The pelleting process involves; biomass drying, hammer milling, and pelleting in the pellet press. The finished wood pellets are cooled naturally in cooling tanks before storage. Process heat is provided by biomass kilns fuelled by sawmill co-products bark and a proportion of the clean wood chip. The biomass kilns are backed up by diesel generator.
- Scenario 4: Sawmill integrated with CHP and pellet manufacture. The sawmill and pellet operations are as described in Scenario 3, however an integrated CHP plant meets the electricity and heat requirements of both the sawmill and the pellet mill. The CHP plant is similar in specification to the CHP plant in Scenario 2, it provides sufficient electricity for both the sawmill and pellet operations. The CHP plant is fired by forest residues and is backed up by a light fuel oil generator.

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- Scenario 5: Pellet production from pulpwood. Pulpwood is chipped for subsequent pellet production. Bark from the incoming pulpwood logs is burned to provide heat for drying.
- Scenario 6: Medium density fibreboard production. MDF is a composite WBP product, comprised of wood fibres processed from clean wood chip and chips from pulpwood. The main steps in the production process include mechanical pulping of the wood biomass to fibres, drying, blending with additives, and hot pressing into a uniform, dense panel. The additives include; a synthetic resin binder, typically urea formaldehyde, added to provide strength properties, and paraffin wax in order to provide protection against water spillage. Process heat for drying is provided by biomass kilns, fired by forest residues, recovered wood, and sanderdust and fines from the process. Biomass heat is supplemented by propane and natural gas.
- Scenario 7: Oriented strand board production. OSB is a composite WBP product, composed of thin wafers of pulpwood pressed under heat and pressure with wax and synthetic resins. The main processes in OSB manufacture include; log debarking and flaking, drying, screening, blending with additives and pressing under high heat and pressure to form a dense mat. The drying process is heat intensive, with process heat provided by biomass kilns fired by processing co-products, bark and fines. The biomass kilns are backed up by a diesel generator.

2.2 Data Inventory

The LCA was conducted in Simapro7.3 (PRé Consultants, 2011). The data inventory compiled for this LCA study consists mainly of data specific to Irish conditions. Foreground data for each of the scenarios described was provided by company records for the year 2012 (Fahy, 2012; Lucey, 2012; McSwiney, 2012a, b; O'Meara, 2012; Roberts, 2012). Data on the operation and emissions from the CHP plant was obtained from DKM Economic Consultants & RPS Consulting Engineers (2012) and Nielsen et al. (2010). Data for scenario 5 related to the year 2011 and was provided by personal communication (Harrington, 2011).

Included from an earlier study are the environmental impacts of forestry operations in Ireland, including; seedling production, site establishment, harvesting, and haulage (Murphy et al., 2014b). Impacts from the supply of roundwood, pulpwood, and forest residues are taken from this study.

In this cradle-to-gate study it was also necessary to consider the impacts in each scenario arising from the use of fuels, electricity and materials such as wood preservative and resins etc. The

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secondary data for such processes was obtained from the ecoinvent database (Ecoinvent, 2007). Background data includes energy generation processes, such as diesel and natural gas production, chemicals production, and infrastructure.

Ecoinvent data for electricity production in Ireland contains data on the electrical grid fuel mix from 2007. This grid mix was updated to the 2012 fuel mix according to Howley & Holland (2013), see figure 2. Data on the forecasted national grid fuel mix for 2020 was obtained from Clancy & Scheer (2011), see figure 2.

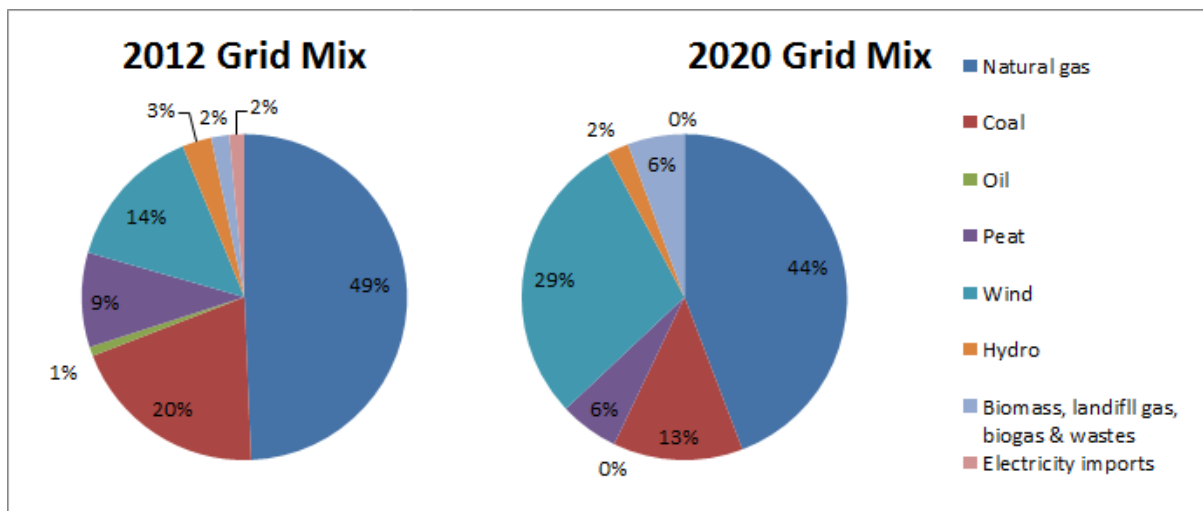


Figure 2 – Irish national grid mix 2012 and 2020 by fuel (%), figures derived from Howley & Holland (2013) and Clancy & Scheer (2011)

Allocation

Both forestry and wood processing systems are multi-output systems, as such allocation of the environmental impacts between these products is required. The impacts of the forestry and wood processing systems were allocated between products based on their contribution by mass to the overall output. Mass allocation is one of the methods recommended by the ISO 14044 standard on Life Cycle Assessment (ISO 14044, 2006). Economic allocation was not considered as the future economic value of wood energy products is uncertain, especially in the face of rising demand due to renewable energy targets.

2.3 Impact assessment

This study analyses two important categories in the evaluation of energy systems; global warming potential (GWP) and energy demand. GWP refers to the potential of the system to trap greenhouse gases in the atmosphere, leading to climate change. Gases which contribute to global warming Please cite as: Murphy., et al., Greenhouse gas and energy based life cycle analysis of products from the Irish wood processing industry, Journal of Cleaner Production (2015), <http://dx.doi.org/10.1016/j.jclepro.2015.01.001>

include carbon dioxide, methane and nitrous oxide. GWP is expressed in kg CO₂-equivalents (Guinée et al., 2002).

Cumulative energy demand (CED) of a product or system characterises both the direct and indirect energy use throughout the life cycle. Both renewable and fossil energy are included in CED, but it does not include embodied energy in the product. CED is expressed in joules (J) but for the purposes of this study the results are expressed in megajoules (MJ). It is particularly important to analyse the renewable energy use as the timber processing sector utilises a large amount of biomass in process heating. It is a particularly important evaluation of bioenergy systems in order to ensure that more energy is not consumed than produced.

A further way to assess the performance of renewable energy systems is to evaluate the pure energy ratio of the system. The term “energy ratio” is used to characterise relations between the energy input and output of the system. Energy ratio is a ratio between the energy output and energy input where the energy output is divided by the energy input (Klvac, 2011).

3 Results and discussion

Results are presented separately for each of the products produced in the wood processing industry in Ireland; sawnwood (table 1), wood-based panels (table 2), and energy products (table 3); wood chip and wood pellets (table 4).

3.1 Sawnwood production

Table 1 shows the greenhouse gas emissions and cumulative energy demand for the production of sawnwood in each of the relevant scenarios. The results show that forest operations and transportation of the raw material to the sawmill have an important impact on the overall results, contributing between 48 and 82% of GHG emissions and 61 and 87% of energy requirements. Greenhouse gas emissions in these phases mainly result from diesel combustion in forest machinery and transportation. The majority of emissions from wood processing in the sawmill result from electricity use. The emissions in scenario 3 are reduced in comparison with scenario 1 due to lower electricity consumption, and lower wood preservative usage being reported. The energy requirement for scenario 2 is higher than for the other scenarios due to the increased requirement for biomass energy in the CHP plant. The embodied energy in this scenario is higher than other scenarios as the combustion of wood fuel is less efficient, as such more wood fuel required to satisfy the same energy requirement (Wilson, 2010). However, the greenhouse gas emissions are lowest in

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scenario 2 as the combustion of wood fuel is assumed to be carbon neutral i.e. the carbon emitted by combustion has been absorbed by the biomass during forest growth. Renewable biomass for heat generation makes an important contribution to overall energy requirements, accounting for 15-45% of total energy from cradle-to-gate.

Table 1 – Results from the production of 1 m³ sawnwood

Impact category	Units	SC 1	SC 2	SC 3
		Sawnwood	Sawnwood	Sawnwood
Global warming potential	<i>kg CO₂-eq</i>	40.2	23.7	31.7
	% from forest operations and transportation	48	82	58
	% from processing	52	18	42
Cumulative energy demand	<i>MJ</i>	761	1460	914
	% from renewable biomass energy	15	36	45
	% from forest operations and transportation	42	23	34
	% from processing	58	77	66

The integration of a CHP plant alongside an existing sawmill to provide both heat and power greatly reduces greenhouse gas emissions from wood processing production by eliminating the usage of electricity from the national grid. A further analysis of the results for scenario 2 shows that overall greenhouse gas emissions from sawmill operation rise by 56% when electricity is provided by the grid rather than the CHP plant. The analysis also shows that by integrating a CHP plant with an existing sawmill (scenario 2), emissions can be reduced by approximately 41% compared to the conventional scenario (scenario 1) as electricity consumption from the national grid is eliminated. The results highlight the effectiveness of utilising biomass produced as a co-product of the wood processing industry in energy generation for the reduction of GHG emissions.

3.2 Wood-based panel board production

Wood-based panel board production is a resource and energy intensive process, requiring large quantities of raw materials, chemicals and energy in their production. The greenhouse gas emissions and energy requirements associated with WBP production in Ireland are presented in table 2.

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Assessing the contribution of each component in the processing system to GHG emissions and energy demand can be important in identifying the major contributors and thus methods to reduce impacts. In terms of GHG emissions, synthetic resin usage accounts for 62% of emissions from MDF production, electricity 19%, and biomass raw material 8%. Similarly, synthetic resin production requires 66% of overall energy demand, with electricity accounting for 15% and biomass for 6%. The synthetic resins used in WBP manufacture are produced from non-renewable and fossil intensive sources such as oil and gas. The GHG emissions from MDF production in this study are higher than reported by Wilson (2010) this may be explained due to significantly higher synthetic resin usage in this study.

OSB manufacture results in lower GHG emissions due to lower electricity requirements and resin usage than MDF production. In the case of OSB production, electricity usage accounts for approximately 34% of emissions, with resin usage accounting for 35%. OSB production in Ireland results in slightly lower greenhouse gas emissions when compared to the 290 kg CO₂-eq per m³ reported by Puettmann et al. (2013a) for the Southeastern United States. The study by Puettmann et al. (2013a) reports longer distances for raw material transportation than used in this analysis, and also includes packaging of the OSB which is not considered in this study.

Table 2 – Results from the production of 1 m³ WBP board

Impact category	Units	SC 6 MDF	SC 7 OSB
Global warming potential	<i>kg CO₂-eq</i>	896.7	235.6
	% from forest operations and transportation	5	4
	% from processing	95	97
Cumulative energy demand	<i>MJ</i>	17901	5569
	% from renewable biomass energy	7	13
	% from forest operations and transportation	4	3
	% from processing	96	97

With increasing demand for biomass energy forecast expected in the coming years, it is forecast that competition will increase for pulpwood between the energy and WBP sectors. It is difficult to compare the impacts of production of these sectors as the differing functions of the system result in Please cite as: Murphy., et al., Greenhouse gas and energy based life cycle analysis of products from the Irish wood processing industry, Journal of Cleaner Production (2015), <http://dx.doi.org/10.1016/j.jclepro.2015.01.001>

different functional units, namely energy content for the energy sector and volume for the WBP sector.

3.3 Energy products

3.3.1 Wood chip production

Table 3 outlines the impacts from production of 1 odt of wood chip as a sawmill co-product in each of the relevant scenarios. GHG emissions are lowest in scenario 2 where the sawmill is integrated with a CHP plant which utilises a portion of the sawmill by-products to meet the electricity and heating requirements of the process.

Table 3 – Results from the production of 1 odt wood chip

Impact category	Units	SC 1 wood chip	SC 2 wood chip	SC 3 wood chip
Global warming potential	<i>kg CO₂-eq</i>	86.7	51.2	68.6
	% from forest operations and transportation	48	83	58
	% from processing	52	17	42
Cumulative energy demand	<i>MJ</i>	1748	3150	1982
	% from renewable biomass	21	36	44
	% from forest operations and transportation	40	23	35
	% from processing	60	77	65

The production of wood chip as a sawmill co-product can be compared to other chip production methods used in Ireland; direct chip from pulpwood, and short rotation coppice willow (SRCW). On an energy basis, wood chip production as a sawmill co-product results in 2.7-4.5 kg CO₂-eq per GJ depending on the scenario, see figure 3. This is higher than direct chip production from pulpwood, with the production of wood chip in this method emitting 2.2–2.4 kg CO₂-eq per GJ (Murphy et al., 2014b). Direct chip production avoids the additional energy requirements in the sawmill process. Conversely, wood chip production in each scenario has a lower GHG impact than the production of SRCW chip which causes emissions of 5.84– 11.65 kg CO₂-eq per GJ depending on fertilisers applied, harvesting methods, and transportation distances (Murphy et al., 2014a).

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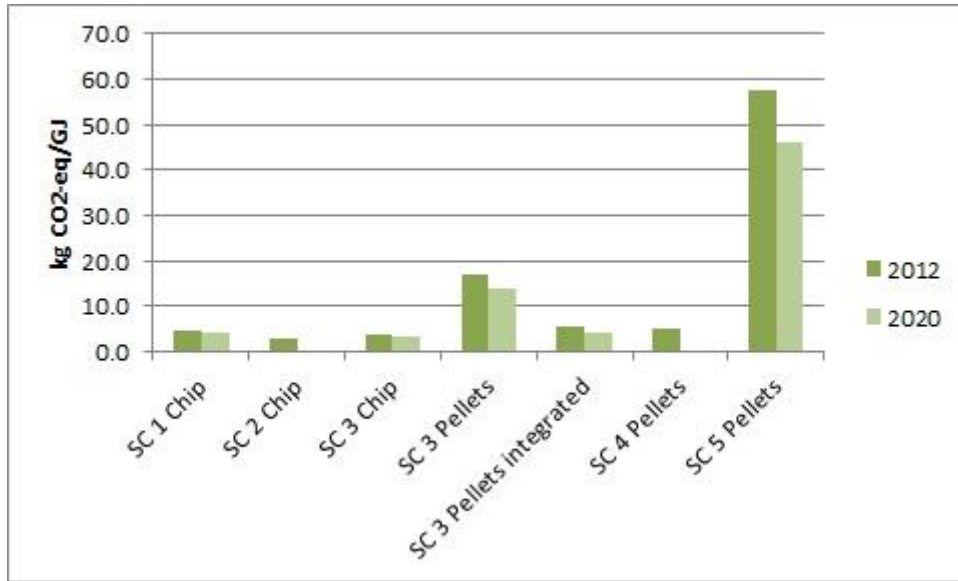


Figure 3 – Greenhouse gas emissions from energy product production per GJ of energy delivered, 2012 and 2020

3.3.2 Wood pellet production

Wood pellet production is an energy intensive process, requiring large quantities of delivered energy in the form of electricity. The majority of GHG emissions and energy requirements from the full wood pellet production chain occur during processing due to the high electricity demand. Wood pellet processing accounts for 40-96% of total greenhouse gas emissions from cradle-to-grave, depending on the scenario.

Renewable biomass for heat generation makes an important contribution to overall energy requirements, accounting for 7-17% of total energy from cradle-to-gate. This figure rises to 52% of overall energy requirements in scenario 4 where both the heat and electricity requirements are met by a biomass CHP plant.

Table 4 shows the impacts of wood pellet production from each relevant scenario.

Table 4 – Results from the production of 1 odt wood pellets

Impact category	Units	SC 3 wood			
		SC 3 wood pellets	pellets (integrated)	SC 4 wood pellets	SC 5 wood pellets
Global warming potential	<i>kg CO₂-eq</i>	327.8	103.8	100.1	1102.5
	% from forest operations and transportation	17	26	60	4
	% from processing	83	74	40	96
Cumulative energy demand	<i>MJ</i>	5431	1891	3338	19269
	% from renewable biomass energy	7	17	52	5
	% from forest operations and transportation	17	24	27	4
	% from processing	83	76	73	96

The base case for scenario 3 considers the pellet mill as separate to the sawmill but located on the same industrial site, and utilising the co-products of the sawmill. This study also considers an alternative to the base case in scenario 3 in which the pellet production is integrated with the sawmill and as such all burdens are allocated between each of the products based on their contribution to the total mass produced. The results in table 4 show the differences in allocation of impacts when pellet production is considered to be integrated with the sawmill process or if it is considered independent but on the same industrial site. If the pellet production is considered to be separate to the saw mill, but on the same site, all of the impacts from electricity usage in pelleting are allocation to wood pellets, as such the impacts of sawnwood production is lower but pellet production is higher. If pellet production is treated as part of the sawmill process, the impacts of both sawmill and pellet mill are allocated to each of the products produced, namely sawnwood, wood chip and wood pellets. As the pelleting process requires significantly higher electricity than the sawmill, production of pellets has higher associated impacts. As such, when considered to be integrated, the impacts from producing 1 odt of wood pellets is lowered as the high energy requirements of pelleting are shared between each of the products produced, see table 4. Consequently, the impacts in the production of sawnwood and wood chip in this scenario are increased.

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The results in table 4 show that wood pellet production from pulpwood (scenario 5) has significantly higher energy requirements and associated greenhouse gas emissions than pellet production from sawmill co-products (scenarios 3 and 4). While in conventional sawmilling the wood chips are produced as co-products and hence do not require any additional energy, pelleting from pulpwood requires chipping and processing of the logs. The biomass used in conventional pelleting is already in the form of sawdust or chip and as such does not require further processing. This represents an additional step in compared to conventional pelleting and has a high energy demand. An alternative use of pulpwood for the energy sector is direct chipping, as such it is interesting to compare the environmental impacts of pelleting versus direct chipping. Greenhouse gas emissions from the production of chip direct from pulpwood has been reported between 1.1 and 2.4 kg CO₂-eq per GJ contained in wood chip (Murphy et al., 2014b), significantly lower than the equivalent 57.42 kg CO₂-eq per GJ contained in wood pellets from pulpwood.

The benefits of integrating a CHP plant with a sawmill have been discussed previously. Scenario 4 represents the integration of a CHP plant with both an existing sawmill and pellet mill. This scenario represents a theoretical scenario based on data used in scenarios 2 and 3. The results in table 4 further highlight that scenario 4 represents the best case scenario for pellet production in terms of greenhouse gas and if implemented in Ireland would produce wood pellets with a lower global warming potential impact than pellets produced in the other scenarios. By utilising the electricity produced by the CHP plant, reliance on the national grid is eliminated, which, depending on the fossil fuel intensity of the fuel mix, can be a significant source of GHG emissions.

The production of wood pellets in Irish conditions can be compared to wood pellet production in Canada and Scandinavian countries as they are important suppliers of wood pellets in the European market. Sjølie and Solberg (2011) estimated GHG emissions of 149 kg CO₂ per tonne of wood pellets produced in Norway from wood shipped from Canada. Cargo boat transport accounts for 66% of this total, a process which does not occur for indigenous wood pellets produced in Ireland. Sjølie and Solberg (2011) also report lower emissions from electricity use than this study. The emission intensity of the Norwegian national grid mix is lower than the Irish grid mix as electricity is predominantly produced from renewable hydropower in Norway.

Wood pellet production in scenarios 3 and 4 emit 5.2 – 17.1 kg CO₂-eq per GJ, with scenario 5 producing 57.4 kg CO₂-eq per GJ, see figure 3. The lower end of the range of these emissions compares favourably with those estimated by Hagberg et al. (2009) for wood pellet production in

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Sweden at 3-4 g CO₂eq per MJ pellets. Similarly to Norway, the Swedish electricity mix is based mainly on hydropower and nuclear power, hence emissions from electricity use are lower than this study. In addition, transportation of the raw materials is approximately half of that specified in this study. Hagberg et al. (2009) found that switching to a more fossil intensive grid mix such as one reliant on coal power, increases emissions substantially to over 15 g CO₂-eq per MJ pellets.

Wood pellet production can be compared with pellet production from alternative raw materials in Ireland. The production of wood pellets in scenarios 3 and 4 compare favourably with miscanthus pellet production which emits 15.5-20.23 kg CO₂ eq per GJ (Murphy et al., 2013), while pellet production in scenario 5, from pulpwood, produces significantly greater GHG emissions.

3.3.3 Energy ratio

The energy ratios for the biomass energy products; wood chip and wood pellets, from each of the relevant scenarios were calculated using a gross calorific value of 19.2 GJ per odt for conifers (Kofman, 2010). The energy ratios are displayed in figure 4.

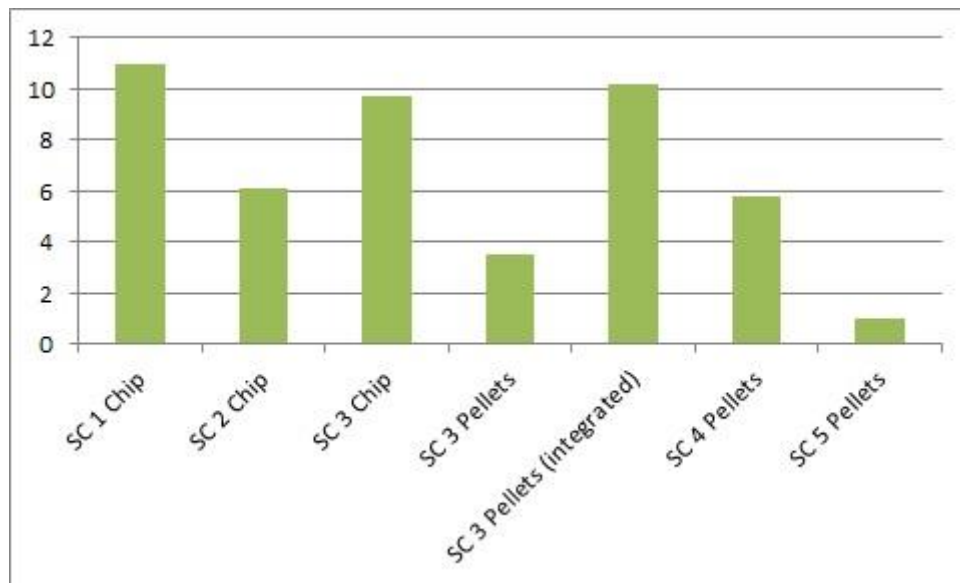


Figure 4 – Energy ratio of biomass energy products

Wood chip produced in scenario 1, conventional sawmilling, has the highest energy ratio, followed closely by scenario 3. The energy ratio for chip production from sawmilling with an integrated CHP plant is lowered by the additional energy requirement for biomass energy in the CHP. The energy ratios of wood chip production are in the range of SRCW chip production which ranges from 9.29 to 19.38 (depending on fertilisers applied, harvesting methods, and transportation distances) (Murphy et al., 2014a).

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The energy ratios for wood pellets in scenarios 3 and 5 production are lower than those reported for miscanthus pellet production (3.6 – 6.2) (Murphy et al., 2013). The energy ratio for pellet production in scenario 5 is less than one, the energy output is lower than the energy input, therefore it is not a viable process for the production of sustainable energy. Wood pellets from scenario 4 and scenario 3 (integrated) perform significantly better than miscanthus pellets in terms of energy ratio.

3.3.4 Comparison with fossil fuels

While comparisons with other biomass sources are important, it is necessary to compare wood energy products with the products they are likely to replace. In the case of Ireland, a major demand for wood energy products is in co-firing where they replace a proportion of coal and peat.

The production of wood energy products in all scenarios, with the exception of scenarios 3 and 5, compare favourably in terms of GHG emissions to coal production which emits approximately 12.28 kgCO₂ per GJ (Dones et al., 2007). The GHG emissions associated with peat provision are lower than the production of wood energy products, as the harvesting of peat is the only process considered. It is important to note that end-use emissions from combustion of these fuels or wood energy products are not considered in this analysis.

The energy ratios of all scenarios, again with the exception of scenarios 3 and 5, are higher than both coal and peat which have an energy ratio of 2 and 5, respectively (Dones et al., 2007), implying that more energy is required to produce these fuels.

3.4 Effect of national grid fuel mix development

The results of this study show that electricity usage in all aspects of wood processing has a significant impact on overall greenhouse gas emissions. As such, the fuels used in electricity generation have an important influence on the emissions from the wood processing sector. As previously discussed, Ireland has committed to EU Renewable Energy targets, and as such, renewable energy penetration in the national grid is expected to increase. The forecasted electrical grid fuel mix for Ireland in 2020, was used to examine the effect of improving the fuel mix of the national grid in line with EU renewable energy targets.

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Table 5 – Global warming potential of products 2012 versus 2020

		2012	2020
	Product	GWP (kg CO ₂ -eq)	
Scenario 1	Sawnwood (m ³)	40.2	36.3
	Chip (odt)	86.7	78.5
Scenario 2	Powered by CHP	-	-
Scenario 3	Sawnwood (m ³)	31.7	29.4
	Chip (odt)	68.6	63.6
	Wood pellets (odt)	327.8	266.1
Scenario 4	Powered by CHP	-	-
Scenario 5	Wood pellets (odt)	1102.5	881.5
Scenario 6	MDF (m ³)	896.7	856.8
Scenario 7	OSB (m ³)	235.6	217.4

The greenhouse gas emissions associated with the manufacture of wood products utilising the forecasted national grid mix for 2020 can be seen in table 5. By 2020 emissions from the production of 1 m³ of sawnwood will decrease by between 7 and 10% compared to 2012. In 2020, emissions from MDF manufacture will decrease by 4% and OSB manufacture by 8%. The emissions from production of 1 odt of wood chips and 1 odt of wood pellets are forecast to fall by 7 – 10%, and 19 – 20% respectively by 2020, see figure 3. These results emphasise the role of the national grid fuel mix in contributing to the impacts of the wood processing industry and highlight the influence of improving the national grid in reducing the GHG emissions in wood processing.

4 Conclusion

Forest operations and timber transportation make an important contribution to overall emissions in sawnwood and wood chip production chains. Electricity usage from the national grid is the major cause of GHG emissions in wood processing, including sawnwood, wood chip, wood pellet and OSB production. GHG emissions can be considerably reduced in sawmilling and wood pellet production by the integration of CHP plants with sawmills and pellet plants. Synthetic resin utilisation in wood-based panel board manufacture has a considerable GHG emissions impact, accounting for a large proportion of emissions in both MDF and OSB manufacture. Wood energy products compare favourably with other sources of biomass and with fossil fuels.

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