Investigation of the potential impact of the Paris Agreement on national mitigation policies and the risk of carbon leakage; an analysis of the Irish bioenergy industry

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Abstract

A criticism of production-based reporting and accounting of greenhouse gas emissions, as implemented under the UNFCCC and Kyoto Protocol, is the risk of mitigation measures adoption in one country to reduce national emissions, leading consequentially to the displacement of the source activity to other jurisdictions, thus resulting in an increase in net global emissions referred to as "carbon leakage". An important outcome of the 21st Conference of the Parties (COP) to the 1992 UNFCCC may be "plugging" of carbon leakage. This study examined the bioenergy industry in Ireland to determine the extent of existing carbon leakage due to national energy policy and to establish if measures identified within the relevant intended nationally determined contributions will result in plugging of carbon leakage. The study focused on co-firing of biomass with peat, the major use of biomass for energy generation in Ireland. The results show that significant levels of carbon leakage occur due to reliance on imported biomass feedstocks to meet co-firing targets under Irish energy policy. In the post-COP21 scenario, one of the three Intended Nationally Determined Contributions analysed contains a measure which has the potential to reduce greenhouse gas emissions from imported biomass by 32%, highlighting the potential of the Paris Agreement to reduce carbon leakage.

Keywords:

Carbon leakage, greenhouse gas emissions, Paris Agreement, life cycle assessment, bioenergy, Ireland

Highlights:

- Carbon leakage occurs due to imported biomass use in the Irish bioenergy industry.
- The INDCs under the Paris Agreement have the potential to reduce carbon leakage.
- Imported biomass compares unfavourably with indigenous biomass for GHG emissions

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1 Introduction

1.1 International climate change agreements

A common criticism of production based reporting and accounting of greenhouse gas (GHG) emissions, as implemented under the United Nations Framework Convention on Climate Change (UNFCCC) and Kyoto Protocol, is the risk of mitigation measures adoption in one country to reduce national emissions, leading consequentially to the displacement of the source activity to other jurisdictions to meet an on-going market demand (Ostwald and Henders, 2014). Therefore, at best, there is no net reduction in global emissions. It is also often argued that the activity may be displaced to a less efficient economy, resulting in an increase in net global emissions, often referred to as 'carbon leakage'. Carbon leakage is defined as 'an increase in GHG emissions in third countries where industry would not be subject to comparable carbon constraints' according to Recital 24 of the Directive 2003/87/EC as amended in 2009 (European Commission, 2009b). This argument is especially compelling in the situation where there is no commitment across all economies to control emissions of GHGs.

The 21st yearly session of the Conference of the Parties (COP) to the 1992 UNFCCC took place in Paris in December 2015 with the aim of reaching a global agreement on the reduction of climate change (the Paris Agreement). Under this agreement, the COP agreed to hold 'the increase in the global average temperature to well below 2 °C above pre-industrial levels' and pursue 'efforts to limit the temperature increase to 1.5 °C above pre-industrial levels, recognizing that this would significantly reduce the risks and impacts of climate change' (United Nations Framework Convention on Climate Change, 2016). All parties were required to submit documentation on what actions they proposed to undertaken within their own economies to mitigate climate change. These are termed Intended Nationally Determined Contributions (INDCs). An important outcome from the engagement of all Parties under the Paris Agreement may be a 'plugging' of carbon leakage.

1.2 Irish greenhouse gas emissions and energy policy

The energy sector is the major contributor to GHG emissions in Ireland, accounting for 63% (37 Mt CO_2-eq) of total national GHG emissions in 2012 (Duffy et al., 2014). A key challenge facing the energy sector in Ireland is to moderate its GHG emissions. Ireland is committed, under the European Union (EU) Renewable Energy Directive (RED) 2009/28/EC, to reduce GHG emissions and to develop alternative energy sources to reduce dependence on finite fossil fuel resources (European Commission, 2009a). Ireland's specific requirements under the EU 2020 targets (European Commission, 2009a) are to achieve contributions of renewable energy of 40%, 12% and 10% to electricity (RES-E), heat (RES-H) and transport (RES-T) respectively by 2020 (Department of Communications Energy and Natural Resources, 2010). The majority of renewable energy in Ireland is currently generated by wind, accounting for 71% of the renewable electricity contribution in 2014, with biomass accounting for 8% (Howley et al., 2015). Most of the electricity from biomass is generated by co-firing with peat, to offset peat combustion. Peat combustion produces large volumes

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of CO_2 directly but also indirectly reduces the carbon budget of indigenous peatlands (Murphy et al., 2015a). Co-firing of biomass with peat is a key element of Ireland's renewable energy policy with the Government mandating each of the three peat-fired power plants to co-fire at a rate of 30% of the maximum rated capacity until 2017, 40% between 2017 and 2019, and 50% thereafter (Department of Communications Energy and Natural Resources, 2010). Under EU legislation (see section 1.3), biomass used in co-firing in the three power plants can be considered to be 'carbon neutral' for reporting purposes.

Edenderry power plant in County Offaly is the only one of the three peat-fired power plants currently co-firing at an appreciable rate, reaching a co-firing rate of approximately 32% in 2014. Figure 1 shows the breakdown of the different biomass types co-fired in 2014.

1.3 Indigenous biomass (woodchip, sawdust, and energy crops willow and miscanthus) accounted for approximately 45% of biomass co-fired on an energy basis, with the remaining 55% of biomass being imported (Edenderry Power Ltd., 2015).Biomass 'carbon neutrality'

Under current EU legislation, biomass used in the generation of electricity, heating or cooling is considered carbon neutral, based on the assumption that the carbon released when solid biomass is burned will be re-absorbed during tree growth (European Commission, 2009a). At present, there are no binding sustainability criteria for biomass at EU level, although some exist at national and industry level. As such, any biomass considered to be a waste (agricultural crop residues including straw, bagasse, husks, cobs and nut shells) used in energy generation are assumed to have a GHG emission balance of zero(up to the point of collection of those materials). This situation is likely to change as EU energy policy develops in the coming years. In February 2015, the European Commission launched an Energy Union package, which will propose a new Renewable Energy Directive for the period beyond 2020, aimed at reaching at least 27% of renewable energy in the EU energy mix by 2030 and setting out a new policy for sustainable biomass (European Commission, 2015). . It is likely that this new policy is will include sustainability criteria for solid biomass that must be satisfied for any electricity or heat generated from biomass to count towards a Member State's overall renewable energy output.

Significant concern exists over the carbon neutrality assumption and the environmental sustainability of large-scale bioenergy deployment compared to other energy options (Buytaert et al., 2011, McBride et al., 2011). The production of biomass for energy generation requires the use of fossil energy and raw material in several respects; in the extraction of raw materials (fuels, minerals), in production and transportation of system inputs (seedlings, fertilisers, pesticides), in field operations and transportation, and finally in processing. Large-scale increases in biomass cultivation and energy conversion may pose risks to natural ecosystems by impacting on soil and water resources, causing erosion, air pollution, and biodiversity loss (McBride et al., 2011). In addition, the carbon cycle and land use change are crucial aspects of bioenergy systems which require addressing when effectively and comprehensively estimating the environmental impacts of bioenergy systems. Several studies of biomass production systems neglect to consider the changes in soil organic carbon or biomass stock related with land use change or land management (Whittaker et al., 2011, Neupane et al., 2011, Berg and Lindholm, 2005, Eriksson, 2008). This approach underestimates the impacts of bioenergy systems

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by failing to consider the effects of land use change and changes in carbon stock in the emission of GHGs from biomass cultivation.

1.4 Carbon leakage induced by climate and energy policy

Several studies have explored the impact of climate change mitigation activities and policies on carbon leakage and indirect GHG emissions. Land-use-change and forestry mitigation have been suggested as mitigation options, however these options may cause shifts in economy-wide or global forest and agricultural activity resulting in carbon leakage if they affect a large proportion of global timber production and consequently prices (Fargione et al., 2008). For example, Sohngen and Brown (2004) reported that the creation of 20 hectares of forest set-asides in the US and Europe would consequentially lead to carbon leakage due to 1 hectare of inaccessible land elsewhere being converted to forestry. Several policies have been implemented worldwide aimed at mitigating impacts on climate change from the energy and transportation sectors by promoting GHG reductions based on estimates of the life cycle GHG emissions (Plevin et al., 2010). As mentioned previously, efforts in the EU have centred around the Renewable Energy Directive. These targets could potentially trigger direct and indirect effects both within and outside Europe via international trade (Frank et al., 2016), as the EU bioenergy demand will not be covered by domestic production alone (Don et al., 2012). For example, biofuel imports to the EU have grown substantially in the past few years to meet demand for biofuels in transportation; biodiesel is imported from Argentina (soy bean biodiesel) and Indonesia and Malaysia (palm oil biodiesel), with sugar can ethanol imported from Brazil and other Latin American countries (Di Lucia et al., 2012). In fact, palm oil imports from Malaysia and Indonesia increased by a factor of seven from 2005 to 2008, inducing carbon leakage globally as external land use change (Don et al., 2012).

1.5 Life cycle assessment for assessing impacts of bioenergy use

Life cycle assessment (LCA) is comprehensive sustainability assessment method which can be used to analyse the environmental impacts of biomass-to-energy systems over the entire life cycle; from biomass production, processing, and transportation, to combustion (Jungbluth et al., 2012). By including the impacts from each stage life cycle, LCA can provide the environmental impacts of a number of scenarios based on selection of different production or processing techniques. Environmental impacts are assessed based on a life cycle data inventory of relevant inputs, outputs and emissions over the life-time of the system. The holistic nature of LCA allows for the identification of hotspots in the system; points of critical contributions to key environmental impacts, and avoids the shifting of environmental burdens from one life cycle stage (or location) to another. By including the impacts throughout the product life cycle, LCA provides a complete view of the environmental aspects of the product or process and a picture of the environmental trade-offs in product and process selection (Scientific Applications International Corporation, 2006).

1.6 Study Aim

The aim of this study is to carry out an assessment of the bioenergy industry in Ireland to determine the extent of existing carbon leakage, to establish if measures can be identified within the relevant INDCs which will result in plugging of the carbon leakage, and finally to quantify the potential emissions reductions associated with implementation of such measures. The study focuses on

Edenderry power plant as the main user of biomass for energy generation in Ireland, and thus represents the bioenergy sector as a key sector related to Ireland's mitigation planning.

2 Materials and Methods

2.1 Edenderry Power Biomass Use

Edenderry power plant generated 844,198 MWh of electricity in 2014, and achieved a co-firing rate of approximately 32% (Molloy, 2015). Imported biomass accounted for 55% (on an energy basis) of all biomass co-fired in 2014. Palm kernel shells (PKS) and sunflower husk pellets accounted for 22% and 30% of total biomass co-fired and for 41% and 56% of all imported biomass co-fired respectively (see Figure 1). Approximately 39,866 tonnes of PKS and 42,434 tonnes of sunflower husk pellets were co-fired in 2014. Schmidt (2015) identified Malaysia and Indonesia as the marginal producers of palm oil, and Ukraine as the marginal producer of sunflower oil. Palm kernel shells are a co-product of palm oil production and sunflower husks are a co-product of sunflower oil production, as such this study focuses on these three countries as the suppliers of these biomass sources to Edenderry.

Under the EU Emissions Trading Scheme (ETS), Edenderry Power Ltd. is required to report the annual CO_2 emissions from the plant. However, CO_2 stemming from biomass use is excluded (Environmental Protection Agency, 2013). As such the emissions of 697,174 tonnes CO_2 reported to be emitted in 2014 (Molloy, 2015) does not include CO_2 emissions from biomass production and combustion.

2.2 Intended Nationally Determined Contributions

2.2.1 Malaysia

Malaysia intends to reduce the GHG emissions intensity of gross domestic product (GDP) by 45% by 2030 relative to the emissions intensity of GDP in 2005. Emissions from land use change account for 9% (288,663 Gg CO_2-eq) of emissions in the base year (2005) (Malaysian Government, 2015). The INDC itself makes no reference to specific actions aimed at reducing GHG emissions, however it states that the projected outcomes from the 11th Malaysian Development Plan and a number of policies (including the National Agro-food Policy) form the basis for the development of the INDC. The 11th Malaysia Plan envisages growth in the oil palm sector of 2.8% by 2020 with an increasing number of matured oil palm plantations (Economic Planning Unit, 2015).

2.2.2 Indonesia

Indonesia intends to reduce emissions to 29% of the business as usual scenario by 2030. The Indonesian INDC recognises the significant impact of land use change on GHG emissions, with land use change and peat and forest fires accounting for 63% of emissions in 2005 (Indonesian Government, 2015). Indonesia instituted a moratorium on the clearing of primary forests and prohibited conversion of peat lands for oil palm cultivation from 2010 to 2016. The INDC does not mention specifically extending these actions, however it is stated that they will reduce deforestation and practice sustainable forest management.

2.2.3 Ukraine

Ukraine intends to decrease GHG emissions to 60% of 1990 GHG emissions by 2030. No specific actions are laid out, however, it is stated that 'Ukraine's INDC will be revised after the restoration of its territorial integrity and state sovereignty as well as after the approval of post-2020 socio-economic development strategies with account of investment mobilisation' (Ukranian Government, 2015). In addition to this, a land-use strategy will be developed as soon as technical opportunities emerge, but no later than 2020.

2.3 Life cycle assessment

The LCA was conducted in Simapro 8.0.1 (PRé Consultants, 2011). This study assesses the global warming potential (GWP) of imported biomass production. GWP refers to the potential of the system to trap GHGs in the atmosphere, leading to climate change. Gases which contribute to global warming include carbon dioxide, methane and nitrous oxide. GWP is expressed in kg CO_2-equivalents (kg CO_2eq) (Guinée et al., 2002).

2.3.1 System description and life cycle inventory

This study focuses on determining the GHG emissions from the production and transportation of imported biomass to Edenderry Power Station in Co. Offaly (53° 17′ 26.5″ N and 7° 5′ 12.9″ W). The processes included are; biomass cultivation (including land use change), biomass processing, and transportation to the power plant. Emissions from combustion are not included as per the reporting requirements for the EU-ETS scheme (Environmental Protection Agency, 2013). As palm kernel shells and sunflower husk pellets account for the majority of biomass imported to Edenderry, this study focuses on these two feedstocks.

The study considers two scenarios; the reference scenario which is the current business as usual scenario, and the post-COP21 scenario which includes the measures identified in the INDCs.

The functional unit is defined as 1 gigajoule (GJ) of energy contained in the imported biomass; as the focus of this paper is on the production of biomass for the generation of electricity, it is useful to express the results in terms of energy content of the final delivered product.

The system diagram is outlined in Figure 2. Note that only products for allocation are included as outputs in figure 2.

2.3.2 Palm kernel shell production

Life cycle inventory data used in this study for PKS production are based mainly on Schmidt (2015) and Schmidt (2007).

2.3.2.1 Land use change

As the oil palm plantations considered in this study are based in two different countries; Malaysia and Indonesia, a weighted average is applied according to Schmidt (2015). The weighted average is based on area cultivated with oil palm in Malaysia (40%) and Indonesia (60%). A large proportion of oil palm plantations are cultivated on drained peatlands. According to Agus et al. (2013), approximately 2.4 Mha of oil palm plantations were on peat soils, accounting for 18% of all plantations in Malaysia and Indonesia. Of the total oil palm plantations on peatlands, 70% occur in Indonesia. Drainage of peatlands for agricultural use can result in significant CO_2 emissions when compared to peatlands in their undisturbed state (Murphy et al., 2015a). CO_2 emissions from oil palm cultivation on peatlands are estimated as 43 t CO_2 per ha per year (for average drainage depth) by Agus et al. (2013b). N_2O emissions from peat oxidation were obtained from Schmidt (2015).

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2.3.2.2 Production data

The production of palm oil is divided into four stages; agricultural stage, oil mill stage, refinery stage and transport stage (Schmidt, 2007). The oil palm fruits (from which palm oil is extracted) are attached to fresh fruit bunches. Each fresh fruit bunch weighs approximately 25 kg and contains 1,500-2,000 single fruits. The processed fresh fruit bunch produces 20% oil, 25% nuts (5% kernels, 13% fibre and 7% shell) and 23% empty fruit bunches, with the remainder yielding palm oil mill effluent (POME) which is sent for treatment (Schmidt, 2007). The fresh fruit bunches are harvested and delivered to the oil mill where the fruitlets are removed, leaving empty fruit bunches which are typically sent back to the palm oil plantations for use in mulching and as a fertiliser subsitute (Subramaniam et al., 2010). The crude palm oil is extracted during the oil mill stage, along with palm kernels which are further refined in the palm kernel mill (this step is outside the boundary of this study as we are interested in palm kernel shells which are produced in the palm oil mill).

The main co-products from the oil milling process are the empty fruit bunches (mentioned above), pressed mesocarp fibre and palm kernel shells, and POME (Subramaniam et al., 2010). In this analysis, empty fruit bunches and POME are not considered as a co-product for allocation as both are considered as inputs to nutrient balances in the agricultural stage of oil palm according to Schmidt (2007). As such, treament of the POME is considered to be within the boundary of the study. In conventional palm oil production the POME is treated in an anerobic pond, after which it is land spread on the palm oil plantation. An alternative POME treatment method involves treatment in a digester tank to produce biogas and subsequent utilisation of the biogas for electricity production in a gas turbine (Schmidt, 2007). Schmidt (2015) assume that 95% of POME produced is treated in the conventional manner, while 5% is used for biogas production and susbsequent land application.

The oil mill has its own power and steam supply which is fuelled with some of the fibre and shell from the processing (Schmidt, 2007). Schmidt (2007) describes a scenario in which the required steam input for the oil palm mill is provided by combustion of 100% of the fibre and 50% of the shell produced as co-products of the oil mill process. The remaining shell (35 kg per t fresh fruit bunch) can then be sold as an energy product.

The PKS are transported 200 km in a 28 t lorry to a port. From there they are transported in an oceanic tanker 8,117 nautical miles corresponding to 15,033 km (Schmidt, 2007). The distance is represented by the distance from Port Kelang in Malaysia to the port in Amsterdam, the Netherlands. From there they are transported 656 nautical miles from Amsterdam Port to Dublin port (1,215 km) (sea-distances.org, 2016), and then subsequently transported 78.4 km by road to Edenderry power plant.

The inputs to and outputs from the agricultural and oil mill processes include land use, diesel for vehicles, lubricating oil, fertilisers, steam and electricity from the power central, etc. All inputs and outputs of the system are outlined in Table 1.

2.3.2.3 Post-COP21 Changes

As outlined in section 2.2.1, the Malaysian INDC outlines no specific actions aimed at reducing GHG emissions in the palm oil sector. As such in the post-COP21 scenario, emissions from PKS production in Malaysia were left as in the reference scenario. The Indonesian INDC on the other hand mentions the moratorium on the clearing of primary forests and prohibited conversion of peat lands from 2010-2016. While the INDC does not mention specifically extending these actions, it is stated that they will reduce deforestation and practice sustainable forest management. As such the post-COP21 scenario assumes that future palm oil production does not occur on peatlands, as such the emissions from peatland cultivation in Indonesia are removed. As outlined in section 2.3.2.1, approximately 70% of palm oil plantations cultivated on peatlands occur in Indonesia (Agus et al., 2013). Therefore, we assume that land use change emissions are reduced by 70% in the post-COP21 scenario.

2.3.3 Sunflower Husk Pellets Production

Life cycle inventory data used in the this study for sunflower husk pellet production are based on Schmidt (2015), Carre (2009) and Valin et al. (2015).

2.3.3.1 Land use change

The expansion of sunflower crop production in Ukraine and the rest of Europe is resulting in the conversion of natural vegetation to cropland (Valin et al., 2015). It is estimated that land use emissions from the conversion of natural vegetation to sunflower cropping results in soil carbon emissions of approximately 53 Mt CO_2 (Valin et al., 2015). This equates to emission of 556 kg CO_2 per hectare of natural vegetation converted to sunflower cropping.

2.3.3.2 Production data

The production of sunflower oil is similar to that of palm oil in that it is divided into four stages; agricultural stage, oil mill stage, refinery stage and transport stage (Schmidt, 2015). The percentage of kernels (from which sunflower oil is extracted) and husk in sunflowers vary according to the cultivar, the size of the sunflower seeds and their oil percentage, with husk percentage typically ranging from 22 to 28% (Carre, 2009). Crude sunflower oil is produced in the oil mill. Sunflower seeds are de-husked in the mill prior to oil extraction as husks have deleterious effects on oil presses and reduce the quality of both oil and meal (Kartika, 2005). Schmidt (2015) assumed that 34% of husks (85 kg husk per t of sunflower processed) are removed and the remainder are kept in the meal. Schmidt (2015) assumed that all of the removed sunflower husks were used for energy purposes in the oil mill, covering all of the mills heat requirement, as such only electricity was purchsed by the mill. However, according to Carre (2009), heat consumption in the oil mill is 300 kWh which is met by combusting approximately 60 kg of husks with a calorific value of 5.1 kWh per kg. Therefore in this analysis it is assumed that 60 kg of husks are combusted for heat production, with the remainder (25 kg) used for pellet production and used for energy production elsewhere (Edenderry power plant in this case).

Data on resource requirments and emissions associated with sunflower husk pellet production is obtained from Giuntoli et al. (2015), see Table 2. The typical moisture content of sunflower husk is approximately is 9% (Carre, 2009), therefore no drying is required prior to pelleting

The sunflower husk pellets are transported 200 km in a 28 t lorry to a port. From there they are transported in an oceanic tanker 3,338 nautical miles corresponding to 6,182 km (sea-distances.org, 2016). The distance is represented by the distance from Odessa in Ukraine to the port in Dublin, Ireland. From there they are transported 78.4 km by road to Edenderry power plant.

The inputs to and outputs from the agricultural and oil mill processes include land use, diesel for vehicles, lubricating oil, fertilisers, heat from light fuel oil, and electricity from the Ukranian national grid, etc. All inputs and outputs of the system are outlined in Table 2.

2.3.3.3 Post-COP21 Changes

As outlined in section 2.2.3, Ukraine intends to decrease GHG emissions to 60% of 1990 GHG emissions by 2030, however, the Ukrainian INDC outlines no specific actions aimed at reducing GHG emissions in the sunflower oil sector. As such in the post-COP21 scenario, emissions from sunflower husk pellet production in Ukraine were left as in the reference scenario.

2.3.4 Allocation

According to the European Commission (2010), the allocation of emissions between products and co-products of a process should include emissions that take place up to and including the process step at which a co-product is produced. In this study both palm kernel shells and sunflower husks are produced in the first oil mill processes for palm oil and sunflowers respectively. As such, emissions produced up to this point are allocated between the products produced at this point; crude palm oil, palm kernel meal, and PKS in the case of palm oil production, and crude sunflower oil, sunflower meal, and sunflower husks in the case of sunflower oil production.

Furthermore, according to the EU Renewable Energy Directive, the allocation of emissions to the co-products should to be carried out on the lower heating value (LHV) of the products (European Commission, 2009a), thus this approach is followed in this study. The LHV, mass produced and subsequent allocation factor for each of the products produced are outlined in Table 3.

3 Results and Discussion

Table 4 presents the GHG emissions associated with the production, processing and transportation of imported biomass (sunflower husk pellets and PKS) in both the reference and post-COP21 scenarios. The impacts are expressed per gigajoule (GJ) of energy contained in the imported biomass; as the focus of this paper is on the production of biomass for the generation of electricity, it is useful to express the results in terms of energy content of the final delivered product.

3.1 Reference scenario

Sunflower husk pellet production results in 61 kg CO_2-eq per GJ, palm kernel shells produce 256 kg CO_2-eq per GJ in the reference scenario, reducing to 173 kg CO_2-eq per GJ in the post-COP21 scenario.

Table 4 outlines the contribution of each stage in the life cycle to the total GHG emissions from the production of PKS and sunflower husk pellets. It is clear from the results that land use change has a significant impact on total GHG emissions for both PKS production (118 kg CO_2-eq per GJ, 46% of total emissions in reference scenario) and sunflower husk pellet production (16 kg CO_2-eq per GJ, 27% of

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total emissions). In the case of PKS, the cultivation of oil palm on peat soils causes significant GHG emissions due to peat soil decay. If we consider that cultivation on peatlands is reduced by 70% in the post-COP21 scenario, land use change emissions reduce to 30% with total life cycle emissions reducing to 120 kg CO_2-eq per GJ. In the case of sunflower husk pellet production, expansion of crop cultivation into natural vegetation causes significant loss in soil carbon, and hence emission of GHGs.

The cultivation stage of fresh fruit bunches and sunflowers also contributes significantly to total GHG emissions, 52% in the case of sunflower husk pellets, and 27-14% in the case of PKS (depending on reference or post-COP21 scenario). The majority of emissions in cultivation arise from the use of synthetic fertilisers, which require significant quantities of energy and resources in production.

The oil mill (processing) stage of PKS production also contributes significantly to total GHG emissions. The treatment of POME is included in the processing stage with the emission of methane from POME treatment making a significant contribution to global warming.

The pelleting process causes 4.51 kg CO_2-eq per GJ of sunflower husk pellets produced, this is an energy intensive process requiring large quantities of delivered energy in the form of electricity.

Shipping of sunflower husk pellets and PKS from the country of origin to Ireland results in the emission of 4.9 and 9.9 kg CO_2-eq per GJ respectively. Transportation of the biomass to Edenderry power plant results in 0.5 kg CO_2-eq per GJ.

The reported emissions from Edenderry power plant in 2014 amounted to 697,174 t CO_2, as outlined in section 2.1 this figure does not include emissions from biomass production and combustion. As can be seen in Figure 3, PKS and sunflower husk pellet production and transportation to Edenderry resulted in GHG emissions of 166,220 t CO_2-eq and 42,609 t CO_2-eq respectively in the reference scenario. If we add these emissions to the reported emissions, total emissions increase to 906,003 t CO_2-eq, 30% higher than the reported emissions.

3.2 Post-COP21 Scenario

As shown by the results, land use change has a significant impact on total GHG emissions from PKS production. Based on analysis of the INDCs, it was assumed that land use change emissions in PKS production are reduced by 70% in the post-COP21 scenario (as outlined in section 2.3.2.3). An analysis of the results shows that emissions from land use change reduce from 118 kg CO_2-eq per GJ in the reference scenario to 35 kg CO_2-eq in the post-COP21 scenario. This results in a total emission reduction of 83 kg CO_2-eq per GJ (or 32%) compared to the reference scenario.

In the post-COP21 scenario GHG emissions from PKS production and importation to Edenderry in 2014 reduce to 112,588tonnes CO_2-eq, which reduces total emissions to 852,371t CO_2-eq, still 22% higher than the reported emissions.

The analysis shows that measures mentioned in the Indonesian INDC have the potential to reduce GHG emissions from PKS production by approximately 32%. However, it is important to note here that this study assumes that Indonesia will retain the moratorium on the clearing of primary forests and prohibited conversion of peat lands. The Indonesian INDC however does not specifically claim that this

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will be done. Analysis of the Malaysian and Ukrainian INDCs found that there was no mention of measures which would affect the production of PKS or sunflowers respectively.

3.3 Comparison with indigenous biomass

Imported biomass can be compared with indigenous biomass which is currently being co-fired in Edenderry including; short rotation coppice willow (SRCW) chip, miscanthus, wood chip, and wood pellets. Recent research has assessed the GHG emissions from the production of this range of indigenous biomass over the full life cycle (Murphy et al., 2013, 2014a, b; Murphy et al., 2015b).

SRCW is a purpose grown energy crop currently cultivated on over 900 hectares of land in Ireland[1]. The production of SRCW chip results in GHG emissions of 5.84-11.65 kg CO_2-eq per GJ depending on fertilisers applied, harvesting methods, and transportation distances (50 or 100 km) (Murphy et al., 2014a). Similarly, miscanthus is currently grown on over 2,000 hectares, and production of miscanthus chip results in emission of 5.6-6.5 kg CO_2 per GJ, again depending on fertilisers applied, harvesting methods, and transportation distances (50 or 100 km) (Murphy et al., 2013). Purpose grown indigenous energy crops have a significantly lower GHG emissions footprint compared to the imported feedstocks examined in this study.

Furthermore, indigenous wood chip produced as a sawmill co-product has a lower footprint again at 2.7-4.5 kg CO_2-eq per GJ produced (Murphy et al., 2015b). It should be noted here that the lower value is obtained when the sawmill is powered by a biomass combined heat and power (CHP) plant, while the higher value is obtained when the sawmill is powered by grid electricity. Both values are higher than direct chip production from pulpwood, with the production of wood chip by this method emitting 2.2-2.4 kg CO_2-eq per GJ (Murphy et al., 2014b). Direct wood chip production avoids the additional energy requirements in the sawmill process, however the board manufacturing industry is a competitor for pulpwood so affects the availability of this resources for energy generation.

Despite the high energy requirement of wood pellet production, GHG emissions from indigenous wood pellet production are again significantly lower than imported feedstocks, ranging from 6 to 17.1 kg CO_2-eq per GJ (Murphy et al., 2015b). Again, it should be noted here that the lower value is obtained when the pellet mill is powered by a biomass CHP plant, while the higher value is obtained when the pellet mill is powered by grid electricity.

Recent research has examined the co-firing of indigenous biomass (energy crops SRCW and miscanthus, wood chip and wood pellets, and forestry residues) with peat with the aim of maximising GHG emissions reductions over the full life cycle (peat harvesting and biomass cultivation to combustion). The results show that co-firing at rates of 31% and 50% in the 3 peat-fired power plants in Ireland reduces emissions by 27% and 46% respectively compared to peat only combustion (Murphy et al., 2016). The study finds that more efficient energy generation systems such as CHP systems cause lower environmental impacts when compared to co-firing systems when considering the system in

[1] Dáil Éireann Debate, Vol. 884 No. 1, Written Answer No. 149 'Alternative Farm Enterprises' (24 June 2015)

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isolation, displacing carbon intensive peat combustion achieves superior GHG emissions reductions overall.

Despite the benefits of utilising indigenous biomass for energy generation, limits on the availability of this material may affect the decision to import biomass. It is predicted that demand for wood for energy will reach 3.08 million m^3 by 2028, with available supply projected to only reach 1.75 million m^3 in that year, leading to a shortfall of 1.33 million m^3 (Phillips, 2011). It appears unlikely that indigenous energy crops will broach this gap as energy crop cultivation is forecast to expand to only 6,000 hectares by 2020 (less than 1 percent of total forested area) (Clancy et al., 2012). In the likely situation that the indigenous biomass resource is insufficient, imported biomass may be inevitable for the bioenergy industry in Ireland.

3.4 Comparison with peat-only combustion

One of the justifications for increased bioenergy utilisation is the perceived reduction in GHG emissions achieved when compared to fossil fuel systems (Santos Oliveira et al., 2001; Smeets et al., 2009; Wang et al., 2012). However, the results of this study show that the 'carbon neutrality' assumption dramatically underestimates the total GHG emissions from the power plant by failing to consider emissions from biomass production. The inclusion of GHG emissions from biomass imports to Edenderry increase emissions by 30% compared to the reported emissions, without considering the indigenous biomass that is also co-fired. The majority of these emissions are occurring outside of Ireland; 99% in the case of sunflower husk pellets, and 99.7-99.8% for PKS. This raises significant concern regarding the sustainability of the co-firing targets.

Approximately 175,321 tonnes (1,349,969 GJ) of peat would need to be burnt to meet the energy input of the imported PKS and sunflower husk pellets. A previous study has shown that the harvesting and combustion of 1 GJ of peat results in the emission of 120 kg CO_2-eq per GJ (Murphy et al., 2015a). Combustion of the same quantity of peat as the imported biomass co-fired would result in GHG emissions of 161,996 t CO_2-eq, significantly lower than the emissions from imported biomass in the reference scenario (208,829 t CO_2-eq) and the Post-COP21 scenario (155,197 t CO_2-eq). This comparison confirms that the use of imported biomass increases GHG emissions relative to the use of the quantity of peat required to replace the energy input from the imported biomass.

4 Conclusion and Policy Implications

This study finds that significant levels of carbon leakage are occurring due to the Irish Governments co-firing policy requiring 30% co-firing of biomass with peat until 2017, 40% between 2017 and 2019, and 50% thereafter. Palm kernel shells and sunflower husk pellets accounted for 22% and 30% of biomass co-fired (on an energy basis) in 2014. However, under the EU Emissions Trading Scheme (ETS), Edenderry power is not required to report the annual CO_2 emissions arising from biomass production and combustion, in essence biomass is considered to be 'carbon neutral'.

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In conclusion, this study has shown that significant levels of carbon leakage are occurring due to the reliance on imported biomass feedstocks to meet the co-firing target for Edenderry power plant. When compared to indigenous sources of biomass, imported biomass sources have significantly larger GHG emissions profiles. When looking at the post-COP21 scenario, one of the three INDCs analysed in this study (the Indonesian INDC) mentions a measure which has the potential to reduce GHG emissions from imported biomass by 24%. This highlights the potential of the Paris Agreement to reduce existing carbon leakage. The study highlights the previously unforeseen carbon leakage associated with the current policy relating to the bioenergy industry in Ireland. This finding may have implications for other sectors in which there may also be significant levels of carbon leakage, e.g. the agricultural and food sector, indicating that further research in this area is required.

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