ASSESSING THE SUSTAINABILITY OF BIOELECTRICITY SUPPLY CHAINS

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ABSTRACT: Large scale biomass power plants can make substantial contributions to the carbon savings needed to address the challenges of climate change. However, it is important to ensure that they also perform well across a broad range of sustainability issues. The rapidly evolving political and legislative agenda has resulted in a number of different sustainability reporting frameworks being developed for different bioenergy systems in different counties. Most of these give general consensus on the ecological principles applied, but there are some differences in approach and scope. Whilst many aspects of sustainability can be effectively managed using existing assessment methods and certification schemes, the differences in reporting frameworks can make it difficult for developers to objectively assess every sustainability aspect of all the links in their supply chains. This paper identifies the key challenges in assessing sustainability within that context. RES has carried out such an assessment of some theoretical but plausible supply chains, using the Cramer framework and this paper gives indications of some of the key considerations that arise from that assessment.

INTRODUCTION

Legislative context

The United Nations Framework Convention on Climate Change, established in 1992 aims to reduce global greenhouse gas emissions to 1990 levels by 2010 [1]. This legally binding treaty is the main global driver to increase sustainable energy and the UK is currently on course to meet its targets under that agreement; with the failure of the annual conference of parties in Copenhagen in 2009 meaning that there are presently no binding targets beyond 2012 [2, 3]. Despite this the European Union has proceeded with its own renewable energy targets, which were implemented via the EU Renewable Energy Directive (RED) which came into force in April 2009 [4]. This sets mandatory targets for the share of member states' energy supply from renewable sources by December 2010. The RED also includes provisions intended to promote the sustainability of biofuel supply. These are based on a range of principles related to biodiversity, preservation of soil carbon levels, minimum greenhouse gas savings, ecological impacts of agriculture etc. Socio-economic aspects are not specified in the RED, but a range of issues, such as biosafety, forced labour, soil, water and air protection are being monitored by the EC.

In late 2008 the EC commissioned work on the feasibility of extending this approach to cover sustainability assessment of solid biomass within the RED [5]. The report [ibid.] recommends that the EC should proceed with development of EU minimum biomass criteria for greenhouse gas savings, protection of biodiversity and protection of the local environment. However, this was ultimately not adopted solid biomass in the RED.

The UK's Renewable Transport Fuel Obligation (RTFO) was implemented by the UK government in response to the European Union Biofuels directive. It set an important precedent as it was the first legislation in the world to implement minimum sustainability requirements for energy supply systems. It incorporates declaration of biofuel origin and land-use change, calculation of greenhouse gas savings and reporting on environmental and social aspects. At present it is permissible for some of these categories to be reported as "unknown", but from April 2011 only feedstocks that meet appropriate sustainability standards will be rewarded [6].

However, these UK RTFO provisions apply only to liquid biofuels. The Renewables Obligation (RO) is the main legislative instrument applying to solid biomass conversion to electricity. In its original form this required no sustainability related provisions. In 2007 consultation by government on amendments to the RO resulted in some calls [7] for minimum regulated sustainability standards, but the government has proceeded initially by introducing a requirement to report on key sustainability issues, but no minimum standards [8]. Information must therefore be provided on material from which biomass is composed, its form, including whether a by-product, energy crop or waste, country of growth, whether it was certified under an environmental quality assurance scheme, and land-use change since 2005, although there is no actual power vested in the regulator (Ofgem) to rescind renewable obligation certificates (ROCs) on these bases.

Overall the UK government activities and statements seem to indicate that they would like to address wider sustainability assessment of solid biomass, including greenhouse gas balance reporting, but there is some reluctance to overburden the developing industry with reporting requirements and a recognition of a lack of understanding and data at present, which research work is attempting to address.

RES biomass developments

RES is an influential leader in the global sustainable energy market with a company vision that incorporates a commitment that "every project we undertake must build towards a sustainable future". As part of its portfolio of renewable energy projects RES is developing a number of biomass fired power projects in the UK, one of which is the large scale, CHP ready, North Blyth biomass power plant in the north east of England, with a nominal capacity of 100 MWe, which will be fuelled by approximately 450,000 odtpa of woody biomass from a number of geographic regions. RES wishes to comply with any existing or forthcoming legislation in relation to sustainability but also wants to ensure the long term sustainability of the fuel supply to the project, to maximize greenhouse gas savings and minimize any adverse impacts of the fuel supply through procurement activities. RES has accordingly commissioned an evaluation of the sustainability impacts of several different potential fuel supply chains for the North Blyth project, which are reported upon in this paper. At this stage they are only theoretical but plausible scenarios.

METHODOLOGY

Assessment frameworks

Assessing the sustainability of bioenergy systems requires an analysis of the ecological, economic and social impacts of the facility. This needs to include consideration of an adequately comprehensive set of potential impacts as well as being considered with appropriate specificity for the particular fuel supply chain. While bespoke assessment frameworks may be developed in the research community for particular purposes [9] care must be taken to ensure adequately comprehensive frameworks are used. Generally for commercial purposes it is most appropriate to utilize a recognized, established, appropriate, independent framework. The difficulty of doing this is that, while there has been significant interest in the sustainability of solid biomass supply, there are no applicable frameworks in place for UK power plants at present. A review of potential frameworks was carried out and it was decided to use the Dutch government's Cramer framework [10] on the grounds that it incorporates many of the principles found in the UK's RTFO (and therefore likely to be transposed into any future framework for solid biomass in the UK), that it is a recognized comprehensive and independent framework and that it has been specifically formulated with solid biomass feedstocks in mind.

The Cramer framework is focused on the following key sustainability themes:

- Greenhouse gas emissions
- Competition with food
- Biodiversity
- Environment: quality of soil, water and air
- Prosperity
- Social well-being (including working conditions, human rights, property rights/land-use, social circumstances, integrity)

These principles are developed into 26 indicators that can be used to gauge the sustainability of a fuel supply chain. Some indicators are formulated to mandate no ecological damage, others require minimum performance levels, compliance with standards or particular actions. It should be noted that RES does not yet have full fuel supply chains in place and this limits the extent to which some of these issues can be examined at this stage to just those of theoretical scenarios. However, it is possible to identify critera where there is a risk of a sustainability impact which in turn informs RES' procurement strategy.

Theoretical fuel supply chain scenarios

Three very distinct fuel supply chains were considered in this work; brief descriptions of which are given below:

Forest residues

Residues from a coniferous forest in the U.S.A. are harvested, aggregated, chipped and left to dry naturally in a pile at the forest landing site. They are then transported 100km by HGV to a port, from where they are transported a round trip distance of 16,800 km to a UK port.

Recycled wood

The wood supply is from a commercial recycling yard and comprises a mixture of clean wood waste, MDF and chipboard. The wood is shredded and transported 60 km by HGV to the power plant.

Eucalyptus energy crop

A new eucalyptus plantation is established on previously idle land in a tropical country such as Brazil. Pre- establishment ground preparation is via disking for weed control, manual and mechanical fertilizer dressings. The plantation is managed on a 7 year rotation basis, with tractor weeding, whole tree harvesting manually using chain saws, chipping, pelletising and transport by sea to the UK.

Greenhouse gas balances

A critically important part of evaluating the sustainability of the fuel supply chain is assessing its greenhouse gas balance. For the forest residues and recycled wood supply chains greenhouse gas balance calculations using the BEAT2 calculator, developed by Defra and the Environment Agency following the recommendations in the Biomass Task Force report [11]. BEAT2 sums the total amount of primary energy resources (direct energy associated with use of fuels, indirect energy associated with production of materials, equipment etc. and energy contained in any feedstocks) involved in the provision of electricity or heat from bioenergy and applies carbon co-efficients to these to calculate the life cycle burden of greenhouse gas emissions.

System boundaries within the BEAT2 calculation include "all process stages which are directly involved in the production of the final product from its principal natural resource" [12]. This includes:

- Land use reference systems – allowing credits for the GHG emissions that would have arisen from what was grown instead of the bioenergy crop
- Waste or residue reference systems – allows credits for the avoided emissions associated with landfilling with energy recovery from LFG
- Co-product allocation by substitution where the displaced product can be identified easily and unambiguously; otherwise allocation is economic, based on entered market values of product and co-product
- Credits for wood ash used to replace agricultural lime

It was not possible to model the greenhouse gas balance for the eucalyptus system using BEAT2 as the tool is not structured to facilitate 7 year energy crop cycles or pelletisation of energy crops. Therefore a bespoke spreadsheet was developed for this system which allowed a full greenhouse gas balance to be calculated but used system boundaries, constants and assumptions consistent with the BEAT2 calculations for the other 2 systems.

The greenhouse gas balance calculations do not take into account any loss of soil carbon as part of land conversion for the eucalyptus plantation, as this would have to be done on a site specific basis. Also RES has advised that the land would be idle; if it is poor quality land there may be a net carbon sequestration benefit from establishing the eucalyptus plantation. Full account is taken of soil emissions related to application of fertilizers. No account is taken of indirect impacts on greenhouse gas balances as there is no agreed methodology for quantifying these and the methodologies that are being developed are generally only suitable for application at a higher level than corporate activities [13]. However, where there is a recognizable potential for indirect effects to impact on the sustainability of a supply chain this has been identified for management purposes.

RESULTS AND DISCUSSION

Greenhouse gas balances

A summary of the greenhouse gas balances calculated for the three fuel supply systems is given in table 1. For reference purposes the UK grid average is 585.9 kg CO_2/MWh and a gas-fired CCGT station achieves 410.5 kg CO_2/MWh [14], so that all of the systems offer substantial savings of at least 74% compared to the UK grid average.

The largest potential savings are offered by the recycled wood system, which achieves significant negative emissions by virtue of the fact that it avoids landfilling of substantial quantities of waste material. This is recognized via reference system credits and is justifiable provided that the material was genuinely destined for landfill and would not otherwise have had an alternative use. Even if these credits are not included, the recycled wood stream still has a very low greenhouse gas emissions profile, largely because it is making use of an existing product, with no requirements for establishment, cultivation etc. It is noticeable that the largest component of greenhouse gas emission for the recycled wood system is due to electricity production. This is primarily due to conversion of nitrogen in chipboard or MDF to N_2O during the combustion process and is based on some assumptions in the BEAT2 tool for which there appears to be limited validation data.

Table 1: Total GHG emissions (CO_2, CH_4 and N_2O) as kg CO_2 eq per MWh electricity generated

	Forestry residue system	**Recycled wood system**	**Eucalyptus plantation system**
Electricity production (conversion of feedstock to electricity)	23.7	64.5	0.1
Ash disposal	0	0.1	0
Cultivation of feedstock	0	0	22.8
Processing of feedstock	180.8	38.1	12.0
Transport of feedstock	79.8	7.3	113.1
Total emissions incurred	**260.6**	**110**	**148**
Reference system credits	-225.9	-850.2	0
Net total	**58.3**	**-740.2**	**148**

The next lowest emission levels are achieved by the forest residue system, provided that the reference system credits are incorporated for alternative disposal of the residues. It should be noted that for the forestry residue system the largest contribution to the overall greenhouse gas balance is processing of the feedstock and over 96% of this can be attributed to disposal of waste wood chipping losses to landfill. In reality it is unlikely that this material would have been landfilled and this allowance is really a feature of how the BEAT2 tool operates: it balances this emissions penalty with the reference system credit. Therefore while application of a landfill credit may seem slightly strange in this context it does in fact make sense in the overall calculation.

After processing of the feedstock, the next most significant contributor to GHG emissions for the forestry residue system is transport emissions, a breakdown of which is given in figure 1. Clearly the single most significant impact is that of transoceanic transport. A reasonably efficient vessel has already been assumed (modified from the BEAT2 default) and the most effective way to reduce this impact would be for the vessel to return loaded with another cargo rather than empty. However, there are significant commercial and structural barriers to this.

The eucalyptus system has the highest net greenhouse gas emissions of the three systems considered. However, the availability of detailed published data relating to cultivation procedures was limited [15-17] and deviations from these could have significant impacts on the greenhouse gas balance. A breakdown of the emissions disaggregated by process step is given in figure 2. It can be seen that while shipping again dominates (for which the same comments apply as for the forest residue system) local transportation is fairly significant and fertilizer application has also become significant. A heavy ground dressing of NPK fertiliser was considered appropriate for this high-yielding crop since net nutrient removal is likely [15], but this might have to be adjusted in line with site-specific practices. Also, the figures for harvesting emissions are quite low, as this was assumed to be heavily manual using chainsaws as is practised elsewhere [ibid.]; using more mechanized harvesting would increase greenhouse gas emissions. However, it is also highly likely that establishment of perennial eucalyptus on previously idle land would result in an increase in underground soil carbon reserves. This would reduce net greenhouse gas emissions, but would require a site specific assessment and so has not been included in these figures.

Figure 1: Contribution of individual transport steps to greenhouse gas emissions associated with forest residue case

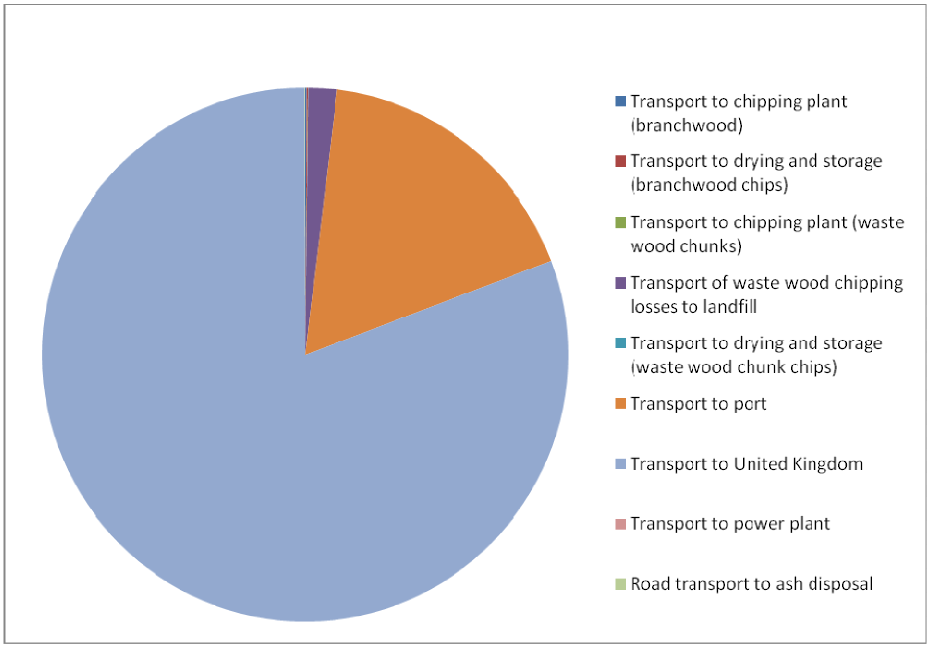
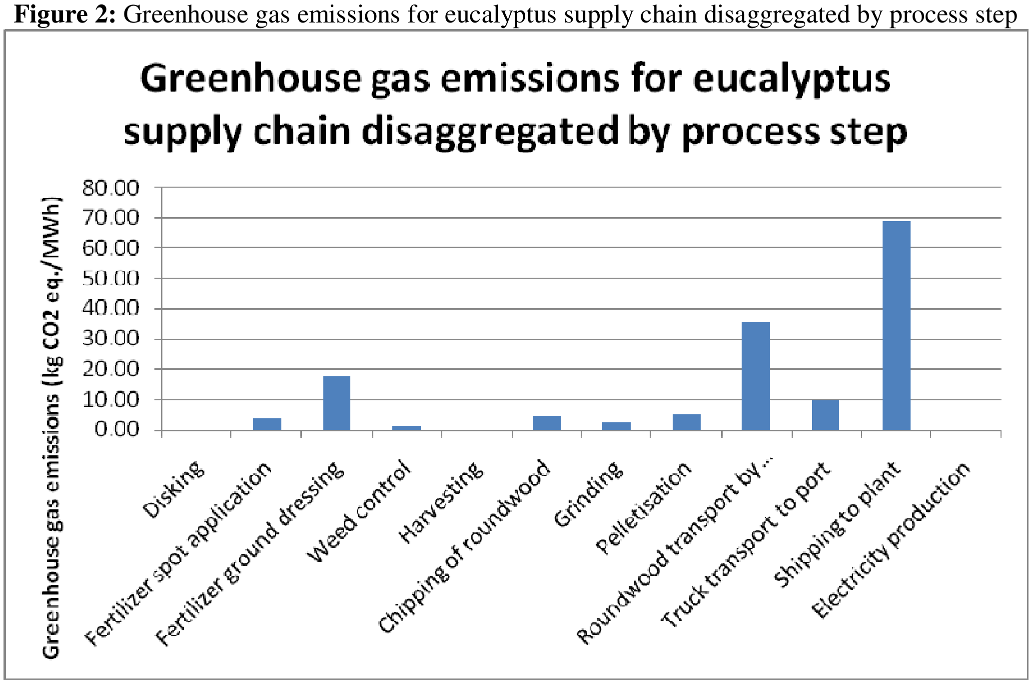


Figure 2: Greenhouse gas emissions for eucalyptus supply chain disaggregated by process step



Other significant sustainability impacts

A full assessment was carried out against each of the Cramer criteria for each of the feedstocks. Overall there is the potential for each of the RES supply chains to deliver substantial benefit in terms of not only greenhouse gas reductions, but also ecological impacts, employment and economic development. Particular issues have been identified that will need careful management during the fuel procurement process that in the absence of such could result in significant impact occurring. These issues are highlighted below. Issues which are particular to the actual company with whom RES eventually contract are impossible to properly assess at this stage and so are not discussed below. These include some of the socio-economic impacts e.g. related to the integrity of the company and consultation with local communities which are best dealt with by investigation, information gathering, vigilance and contractual negotiations with individual suppliers.

Sustainability risks of forest residue supply chain

Removal of forest residues may result in a decrease of the carbon pool within the litter on the forest floor [18]. This may affect the interaction between the litter pool and top layer of soil, which could manifest itself as a reduction in soil carbon in the long term. This could reduce soil fertility and impact on the greenhouse gas balance.

Eisenbies [19] presents evidence that residue removal can degrade soil, but with no consistent impacts on site productivity or soil C concentrations unless the forest floor is removed. He concludes that forest residue harvesting sites should be monitored, but expects no negative long-term effects on fertile sites as long as the forest floor remains intact.

However, others have shown that residue removal decreased tree volume by 10% and decreased soil carbon in the top 20cm soil layer by 9% after 18 years [20] and caused the forest floor carbon storage to decline by 30%+/-6% [21], with smaller losses in coniferous forests and no overall change in mineral soils.

Further investigation is clearly needed to clarify the extent and nature of this problem, which is being undertaken by IEA Bioenergy. In the interim the best approach to management appears to be site specific consideration and monitoring of soils and carbon pools as part of the forest management.

Another possible risk is on biodiversity in the forest system. Deadwood in a forest is an important substrate for insects and invertebrates and a refuge and nesting place for mammals and birds. There are concerns that demands for bioenergy will reduce the level of deadwood, which may again impact on carbon reservoirs and also on biological diversity [22]. However, the removal of residues can also have positive impacts in reducing pests [23, 24].

Intensive removal of forest residues may reduce the total capital and availability of nutrients [25], which may impair the long term balance of soil fertility. Removal of fresh residues with needles has been shown to have negative effects on growth increment in the short term (5-30 years) in areas where growth is limited by N (i.e. mineral soils when atmospheric deposition is low) [24], although this is significantly lessened by extracting dry branches without needles, which will have less of a nutrient balance impact. While the lost nutrients can be replaced by recycling of wood ash this can alter the soil pH, impacting on biodiversity [24].

In summary the risks associated with forest residue removal relate mainly to soil interactions that may impact on biodiversity, soil quality and overall greenhouse gas balances. There does not appear to currently be a robust scientific base from which to extrapolate general guidelines that would ensure sustainability. The issues associated with residue harvesting and deadwood retention are also not well covered in most certification schemes [25], making it particularly difficult for purchasers to ensure supply chain sustainability . None of the certification schemes examined during the course of this work currently deals specifically with the management of carbon (in its various forms and locations) within a forest, although one of the more recently edited standards mentions it within its objectives and management procedures [26]. As the bioenergy demand increases it is imperative that this is addressed in some depth with specific guidance to landowners to ensure meaningful greenhouse gas reductions continue to be obtained. In the meantime responsible fuel procurement will be reliant on substantial evidence gathering, site specific assessment and supplier negotiations.

Sustainability risks of recycled wood supply chain

In general the recycled wood supply chain performed very well against most of the sustainability criteria. However, it must be emphasized that it proved significant to establish that the wood being used was genuinely at the end of its life and would genuinely have otherwise been disposed of. The results for several sustainability indicators were dependent upon this. For fuel supply systems where that was the case the following additional issues were noted.

It is most sustainable to return wood ash to the soil from which biomass was extracted in order to close the nutrient cycle. However, if waste wood is contaminated the ash arising from combustion is less likely to be suitable for land-spreading. Care must therefore be taken with mixed feedstocks, where incorporating some waste wood would preclude sustainable land-spreading of ash from other fuel sources.

All facilities in the UK which combust waste wood operate within tight emission limits specified in the European Waste Incineration Directive and enforced by the Environment Agency via the plant's operating permit, which are sufficient to protect human health and the wider ecosystem. However, the fuel supplied to a particular facility can still affect the overall human toxicity, evaluated by considering exposure pathways via air, soil and water. Work by Skodras [27], demonstrated a reduction in human toxicity when switching from natural wood feedstock to MDF (despite an increase in several airborne pollutant species) but an increase when switching to waste power poles. This illustrates how the fuel supply chain may impact on toxicity levels and this may be different for different technologies and feedstocks, where the partitioning of components between flue gases and ash will be different.

Sustainability risks of eucalyptus fuel supply chain

Examination of the eucalyptus supply chain resulted in the largest number of potential impacts that would require avoidance, management or mitigation. This is partly because it is the theoretical fuel supply chain with most uncertainty attached to it at present and partly because it requires most interaction with the ecosystem in terms of crop growth and with society in terms of crop management and processing.

Possibly the largest risk associated with establishment of a new eucalyptus plantation is the impact of land-use change. For 500 years Brazil has suffered ecosystem damage and deforestation, amounting to 2.7 million km2 or 31.7% of its national territory [28]. Even as recently as between August 2003 and August 2004 26,130 km2 forests were lost, amounting to 18.6% of global deforestation that year (ibid.). However, there are also substantial efforts towards sustainable afforestation primarily to supply the pulpwood industry [17]. In principle establishment of new forest plantations should have a positive carbon sequestration impact provided that existing forest is not directly or indirectly displaced.

Smeets [29] argues that this is possible, demonstrating that up to half of agricultural land in use in Brazil in 1998 could be available for energy crop production in 2015 without endangering supply of food or further deforestation. However, his assumptions on efficiency improvements and mechanization go beyond current FAO projections.

There is doubtless some scope for sustainable expansion of forest plantations which would have global greenhouse gas benefits. However, the difficulty is in monitoring this expansion to ensure that it remains sustainable when considered alongside increasing population levels and increasing global food demands. Few countries actively manage land to the extent that would facilitate this and it is certainly not something that can be addressed at a corporate level. It may be possible to introduce elements into certification schemes that could address aspects of this but it is unlikely that they would be categorical.

The next most significant risk factor is related to hydrology. High rates of eucalyptus productivity are often related to high rates of water use, which may reduce yield from water-supply catchments [17, 28, 29]. It is important to be aware of water balance-vegetation interactions at the stand scale, which when extended over the landscape allow groundwater recharge to be estimated. This understanding can then be incorporated into operational estimates of groundwater recharge (important in years of reduced rainfall and anticipated water stress).

Environmentally sustainable land management can then be achieved by managing the trade-offs between economic viability and water resource security. Without this attention there is a significant risk that ground and surface water quality will not be retained or improved. Instead in full grown eucalyptus plantations water could become a growth limiting factor, particularly during the hotter parts of the year, when groundwater depletion could consequently occur [17].

While some certification schemes [30] do highlight the importance of protecting water resources generally (which could be interpreted as maintaining ground water resources), others focus only on bodies of water, such as streams and lakes [26]. There is a need to ensure that appropriate provisions are included in all certification schemes that apply to forest plantations. Water has been specifically identified by international bodies as an emerging issue of concern in bioenergy development and it is important that sustainability legislation/certification addresses this [31].

Indirect impacts

Searchinger [32] noted that conversion of land for biofuel production often resulted in its previous function being lost. If this function is replaced e.g. by conversion of other land then this could result in further greenhouse gas emissions which, it could be argued, should be attributed to the original activity that caused the displacement. The UK government reviewed this issue with respect to biofuels [33] and concluded that mechanisms did not exist to accurately measure or avoid the impacts of indirect land-use change. Since then some further work has been commissioned related to specific chains [13, 34, 35]. This work has shown that using materials that have existing non bioenergy uses could create additional indirect emissions not currently accounted for, but that these are broad market-level effects, not amenable to quantification at company level [13]. The insights offered by this work have been used to try to identify the key areas that may potentially give rise to indirect effects for the supply chains discussed in this paper. However, it must be cautioned that a full analysis would require thorough mapping of supply chains and alternative uses, which is beyond the scope of this work. It should also be noted that there is presently no clear guidance on how the boundaries of assessment should be constructed when indirect effects are considered.

In general the forest residues to be used are a waste material and so are not expected to have significant indirect impacts. However, it is noted that there have been some commercial concerns expressed about the potential for the increased demand related to significant numbers of large scale biomass combustion plants to increase the market price for raw material wood resources. This is particularly a potential issue for the pulp, paper and board industries. It has been argued that increasing demand for wood resources from biomass power plants could increase the price of raw materials to the extent that manufacturing industry may resort to other sources. If, for example, plastics were to emerge as a replacement for chipboard in some industrial sectors this could effectively increase net greenhouse gas emission through increased demand for plastics and possibly reduced requirements for forest timber, with its associated carbon sequestration benefits.

The recycled wood stream is possibly the supply chain with the most significant potential for indirect impacts. If there is another use for the fuel stream then using it in the power plant could have unintended additional emissions elsewhere. For example, if RES used clean wood waste which might otherwise have been used for animal bedding then some other product will likely be used to fill the demand for animal bedding instead. The additional greenhouse gas emissions associated with the production and supply of this material to its consumer are indirectly augmenting the greenhouse gas emissions of the RES power plant. It could also be argued that this material would then be landfilled after use as animal bedding and the use in the power plant should therefore entail credits for these avoided emissions. It is difficult to gauge the actual impacts on a single supply chain basis and to judge where the indirect impact chain of consideration should be terminated. Further work is needed at a national/international level to evaluate this.

For the eucalyptus fuel supply chain the main area where indirect impacts are likely to be experienced is in land-use change. Assessing this requires establishment of whether the previous land function has been displaced as a result of the plantation establishment and, if so, to where. Then the magnitude of any impact can be established. This can only be done on a site-specific basis, with historic knowledge of land use.

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CONCLUSIONS

The sustainability of 3 theoretical but plausible fuel supply chains for a dedicated biomass to electricity plant in the UK has been evaluated. Greenhouse gas balance calculations show savings of over 74% are offered by all supply chains, with the best performing showing substantial negative emissions achieved by credits for avoided landfill of waste material. The Cramer framework has been used to highlight key potential risks to wider sustainability. For the vast majority of the criteria it was possible to be confident that using the fuel supply would not result in unsustainable impacts. However, there were some areas where risks were identified that will require careful management.

For the forest residue supply chain the risks mostly focus on the carbon and nutrient balance implications of interactions with soil. The scientific understanding of the mechanisms involved and long term implications of these is limited and needs to be expanded in order to ensure long term sustainability. Then certification schemes need to be adapted to incorporate the most up-to-date knowledge. The recycled wood supply chain is primarily impacted by the extent to which the wood used is actually a waste material and there is no obvious mechanism by which this could be certified or clarified. The eucalyptus fuel supply chain raises two main potential areas of concern: the sustainability of the land-use change for the plantation including any indirect impacts and the potential impact of the plantation on hydrology and local ground water resources. The land-use issue has been well documented by various commentators and many are seeking a management method. The hydrology issue has potential to be a very significant one in the long term and is not adequately covered by all certification schemes at present. This should be addressed.

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