Research Paper

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Woody Biomass for Power and Heat
Impacts on the Global Climate

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Contents

Executive Summary

The use of wood for electricity generation and heat in modern (non-traditional) technologies has grown rapidly in recent years. For its supporters, it represents a relatively cheap and flexible way of supplying renewable energy, with benefits to the global climate and to forest industries. To its critics, it can release more greenhouse gas emissions into the atmosphere than the fossil fuels it replaces, and threatens the maintenance of natural forests and the biodiversity that depends on them. Like the debate around transport biofuels a few years ago, this has become a highly contested subject with very few areas of consensus. This paper provides an overview of the debate around the impact of wood energy on the global climate, and aims to reach conclusions for policymakers on the appropriate way forward.

Although there are alternatives to the use of wood for biomass power and heat, including organic waste, agricultural residues and energy crops, they tend to be less energy-dense, more expensive and more difficult to collect and transport. Wood – and particularly wood pellets, now the dominant solid biomass commodity on world markets – is therefore likely to remain the biomass fuel of choice for some time.

Biomass is classified as a source of renewable energy in national policy frameworks, benefiting from financial and regulatory support on the grounds that, like other renewables, it is a carbon-neutral energy source. It is not carbon-neutral at the point of combustion, however; if biomass is burnt in the presence of oxygen, it produces carbon dioxide. The argument is increasingly made that its use can have negative impacts on the global climate. This classification as carbon-neutral derives from either or both of two assumptions. First, that biomass emissions are part of a natural cycle in which forest growth absorbs the carbon emitted by burning wood for energy. Second, that biomass emissions are accounted for in the land-use sector, and not in the energy sector, under international rules for greenhouse gas emissions.

Is biomass carbon-neutral?

The first assumption is that woody biomass emissions are part of a natural cycle in which, over time, forest growth balances the carbon emitted by burning wood for energy. In fact, since in general woody biomass is less energy dense than fossil fuels, and contains higher quantities of moisture and less hydrogen, at the point of combustion burning wood for energy usually emits more greenhouse gases per unit of energy produced than fossil fuels. The volume of emissions per unit of energy actually delivered in real-world situations will also depend on the efficiency of the technology in which the fuel is burnt; dedicated biomass plants tend to have lower efficiencies than fossil fuel plants depending on the age and size of the unit. The impact on the climate will also depend on the supply-chain emissions from harvesting, collecting, processing and transport. Estimates of these factors vary widely but they can be very significant, particularly where methane emissions from wood storage are taken into account. Overall, while some instances of biomass energy use may result in lower life-cycle emissions than fossil fuels, in most circumstances, comparing technologies of similar ages, the use of woody biomass for energy will release higher levels of emissions than coal and considerably higher levels than gas.

The impacts on the climate will also vary, however, with the type of woody biomass used, with what would have happened to it if it had not been burnt for energy and with what happens to the forest from which it was sourced.

Biomass energy feedstocks

The harvesting of whole trees for energy will in almost all circumstances increase net carbon emissions very substantially compared to using fossil fuels. This is because of the loss of future carbon sequestration from the growing trees – particularly from mature trees in old-growth forests, whose rate of carbon absorption can be very high – and of the loss of soil carbon consequent upon the disturbance.

The use of sawmill residues for energy has lower impacts because it involves no additional harvesting; it is waste from other operations of the wood industry. The impact will be most positive for the climate if they are burnt on-site for energy without any associated transport or processing emissions. However, mill residues can also be used for wood products such as particleboard; if diverted instead to energy, this will raise carbon concentrations in the atmosphere. The current high levels of use of mill residues mean that this source is unlikely to provide much additional feedstock for the biomass energy industry in the future (or, if it does, it will be at the expense of other wood-based industries). Black liquor, a waste from the pulp and paper industry, can also be burnt on-site for energy and has no other use; it is in many ways the ideal feedstock for biomass energy.

The use of forest residues for energy should also imply no additional harvesting, so its impacts on net carbon emissions can be low (though whole trees can sometimes be misclassified as residues). This depends mainly on the rate at which the residues would decay and release carbon if left in the forest, which can vary substantially. If slow-decaying residues are burnt, the impact would be an increase in net carbon emissions potentially for decades. In addition, removing residues from the forest can adversely affect soil carbon and nutrient levels as well as tree growth rates.

Many of the models used to predict the impacts of biomass use assume that mill and forest residues are the main feedstock used for energy, and biomass pellet and energy companies tend to claim the same, though they often group 'low-grade wood' with 'forest residues', although their impact on the climate is not the same. Evidence suggests, however, that various types of roundwood are generally the main source of feedstock for large industrial pellet facilities. Forest residues are often unsuitable for use because of their high ash, dirt and alkali salt content.

Biomass and the forest carbon cycle

It is often argued that biomass emissions should be considered to be zero at the point of combustion because carbon has been absorbed during the growth of the trees, either because the timber is harvested from a sustainably managed forest, or because forest area as a whole is increasing (at least in Europe and North America). The methodology specified in the 2009 EU Renewable Energy Directive and many national policy frameworks for calculating emissions from biomass only considers supply-chain emissions, counting combustion emissions as zero.

These arguments are not credible. They ignore what happens to the wood after it is harvested (emissions will be different if the wood is burnt or made into products) and the carbon sequestration forgone from harvesting the trees that if left unharvested would have continued to grow and absorb carbon. The evidence suggests that this is true even for mature trees, which absorb carbon at a faster rate than young trees. Furthermore, even if the forest is replanted, soil carbon losses during harvesting may delay a forest's return to its status as a carbon sink for 10–20 years.

Another argument for a positive impact of burning woody biomass is if the forest area expands as a direct result of harvesting wood for energy, and if the additional growth exceeds the emissions from combustion of biomass. Various models have predicted that this could be the case, but it is not yet clear that this phenomenon is actually being observed. For example, the timberland area in the southeast of the US (where most US wood pellet mills supplying the EU are found) does not appear to be increasing significantly. In any case, the models that predict this often assume that old-growth forests are replaced by fast-growing plantations, which in itself leads to higher carbon emissions and negative impacts on biodiversity.

The carbon payback approach argues that, while they are higher than when using fossil fuels, carbon emissions from burning woody biomass can be absorbed by forest regrowth. The time this takes – the carbon payback period before which carbon emissions return to the level they would have been at if fossil fuels had been used – is of crucial importance. There are problems with this approach, but it highlights the range of factors that affect the impact of biomass and focuses attention on the very long payback periods of some feedstocks, particularly whole trees.

The many attempts that have been made to estimate carbon payback periods suggest that these vary substantially, from less than 20 years to many decades and in some cases even centuries. As would be expected, the most positive outcomes for the climate, with very low payback periods, derive from the use of mill residues (unless they are diverted from use for wood products). If forest residues that would otherwise have been left to rot in the forest are used, the impact is complex, as their removal may cause significant negative impacts on levels of soil carbon and on rates of tree growth. The most negative impacts involve increasing harvest volumes or frequencies in already managed forests, converting natural forests into plantations or displacing wood from other uses.

Some have argued that the length of the carbon payback period does not matter as long as all emissions are eventually absorbed. This ignores the potential impact in the short term on climate tipping points (a concept for which there is some evidence) and on the world's ability to meet the target set in the 2015 Paris Agreement to limit temperature increase to 1.5°C above pre-industrial levels, which requires greenhouse gas emissions to peak in the near term. This suggests that only biomass energy with the shortest carbon payback periods should be eligible for financial and regulatory support.

BECCS

There is growing interest in the combination of bioenergy with carbon capture and storage (BECCS) with the aim of providing energy supply with net negative emissions. The latest assessment report of the Intergovernmental Panel on Climate Change (IPCC) relies heavily on bioenergy for heat and power, and specifically on BECCS, in most of its scenarios of future mitigation options. However, all of the studies that the IPCC surveyed assumed that the biomass was zero-carbon at the point of combustion, which, as discussed above, is not a valid assumption. In addition, the slow rate of deployment of carbon capture and storage technology, and the extremely large areas of land that would be required to supply the woody biomass feedstock needed in the BECCS scenarios render its future development at scale highly unlikely. The reliance on BECCS of so many of the climate mitigation scenarios reviewed by the IPCC is of major concern, potentially distracting attention from other mitigation options and encouraging decision makers to lock themselves into high-carbon options in the short term on the assumption that the emissions thus generated can be compensated for in the long term.

Recommendations

- In assessing the climate impact of the use of woody biomass for energy, changes in the forest carbon stock must be fully accounted for. It is not valid to claim that because trees absorb carbon as they grow, the emissions from burning them can be ignored.
- Along with changes in forest carbon stock, a full analysis of the impact on the climate of using woody biomass for energy needs to take into account the emissions from combustion (which are generally higher than those for fossil fuels) and the supply-chain emissions from harvesting, collection, processing and transport. There is still some uncertainty over some of these factors and further research would be helpful.
- The provision of financial or regulatory support to biomass energy on the grounds of its contribution to mitigating climate change should be limited only to those feedstocks that reduce carbon emissions over the short term.
- In practice, this means that support should be restricted to sawmill residues, together with post-consumer waste. Burning slower-decaying forest residues or whole trees means that carbon emissions stay higher for decades than if fossil fuels had been used.

Accounting for biomass carbon emissions

The second assumption that leads to the perception that biomass energy is zero-carbon at the point of combustion derives from the international greenhouse gas reporting and accounting frameworks established under the UN Framework Convention on Climate Change (UNFCCC) and the Kyoto Protocol. In order to avoid double-counting emissions from biomass energy within the energy sector (when the biomass is burned) and the land-use sector (when the biomass is harvested), the rules provide that emissions should be reported within the land-use sector only.

While this approach makes sense for *reporting*, it has resulted in significant gaps in the context of *accounting* – measuring emissions levels against countries' targets under the Kyoto Protocol (or, potentially, the Paris Agreement), largely deriving from the different forest-management reference levels that parties have been permitted to adopt. The problem of 'missing', or unaccounted-for, emissions arises when a country using biomass for energy:

- Imports it from a country outside the accounting framework – such as the US, Canada or Russia, all significant exporters of woody biomass that do not account for greenhouse gas emissions under the second commitment period of the Kyoto Protocol;
- Accounts for its biomass emissions using a historical forest-management reference level that includes higher levels of biomass-related emissions than in the present; or
- Accounts for its biomass-related emissions using a business-as-usual forest-management reference level that includes, explicitly or implicitly, anticipated emissions from biomass energy (since the associated emissions built in to the projection will not count against its national target).

This risks creating perverse policy outcomes. Where a tonne of emissions from burning biomass for energy does not count against a country's emissions target but a tonne of emissions from fossil fuel sources does, there will be an incentive to use biomass energy rather than fossil fuels in order to reduce the country's greenhouse gas emissions – even where this reduction is not 'real' in the sense that it is not accounted for by either the user or the source country.

The quantity of emissions missing from the international greenhouse gas accounting framework is impossible to calculate precisely. Forest-management reference level submissions do not contain sufficient information on the quantity of woody biomass projected to be used, the origins of that biomass (additional domestic forest harvests, increased use of domestic forestry residues or higher imports) and the resulting emissions. Nevertheless, the quantity of emissions is likely to be significant, as demonstrated in several country case studies.

In 2014, countries listed in Annex I to the UNFCCC in aggregate emitted 985 million tonnes of carbon dioxide ($MtCO_2$) from biomass combustion, including an estimated 781 $MtCO_2$ from solid biomass. The latter figure is equivalent to 5.6 per cent of aggregate, economy-wide carbon dioxide emissions from Annex I countries in 2014, and 6 per cent of their total energy emissions. The US accounts for almost 28 per cent of total Annex I solid biomass carbon emissions, while Germany, Japan and France account for a further 26 per cent. Neither the US nor Japan account for emissions from their land-use sectors under the Kyoto Protocol, while Germany accounts against a business-as-usual projection that does not explicitly include bioenergy policies, and France uses a business-as-usual projection that includes bioenergy demand from policies up to, but not including, the EU Renewable Energy Directive. Woody biomass emissions from all these countries, therefore, have the potential to go unaccounted for.

Recommendations

Four steps could be taken within the existing framework to reduce the potential for missing emissions:

- All parties to the Kyoto Protocol and the Paris Agreement should include the land-use sector in their national accounting.
- Forest-management reference levels should contain detailed information on projected emissions from using biomass for energy, the origins of that biomass (additional domestic forest harvests or increased use of domestic forestry residues) and the resulting emissions.
- Countries that import biomass for energy should be required to report on whether and how the country of origin accounts for biomass-based emissions. Emissions associated with biomass imported from a country that does not account for such emissions, or from one that has built biomass energy demand into its accounting baseline, should be fully accounted for by the importing country.
- Countries using domestic biomass for energy should reconcile their energy and land-use sector accounting approaches in order to put emissions from each sector on a par with each other, if possible through using the same benchmarks – either a historical reference year/period or a business-as-usual scenario – to avoid emissions leakage between the sectors. This should be uniform across all countries.

If the land-use accounting rules are not reformed as suggested above, a more radical option would be to account for carbon dioxide emissions from biomass burned for energy within the energy sector, with additional rules to avoid double-counting in the land-use sector.

Sustainability criteria

One means of avoiding, or at least ameliorating, the impacts on the climate of the use of woody biomass for energy is to apply preconditions that biomass installations are required to meet before they are eligible for the regulatory and financial support afforded to renewable energy sources. The European Commission published proposals for sustainability criteria for solid biomass in late 2016. Many EU member states already apply some criteria; the most detailed have been developed in Belgium, Denmark, the Netherlands and the UK.

In general these have two components: requirements for minimum levels of greenhouse gas savings compared to fossil fuels, and requirements (often called 'land criteria') relating to the legality and sustainability of forest management, usually taken from national timber procurement policies. Sometimes other criteria, such as restrictions on types of feedstock or on minimum plant energy efficiency levels, are also included. However, none of these systems includes changes in levels of forest carbon stock in their calculation of greenhouse gas savings (apart from direct land-use change), though the Dutch criteria contain a requirement that the forest is managed with the aim of retaining or increasing carbon stocks in the medium or long term, and the EU proposed criteria include a requirement for the country from which the forest biomass is sourced to be a party to the Paris Agreement, which accounts for changes in carbon stock associated with biomass harvests.

Several voluntary certification schemes have developed with the aim of including climate impacts alongside other criteria, such as sustainable forest management. The main one is the Sustainable Biomass Partnership (SBP), established in 2013 by seven major European utility companies. Its standard includes the need to define the supply base of the biomass, to ensure feedstock can be traced back to its source area, and a requirement that 'regional carbon stocks are maintained or increased over the medium to long term'. The standard includes a calculation of the energy and carbon balance of the biomass used for energy, but this does not include changes in forest carbon stock. Verification involves a regional approach that uses a desk-based assessment against the criteria leading to a risk rating for each indicator. Where risks are identified, appropriate mitigation measures must be defined, implemented and monitored.

These schemes' failures to account, comprehensively or at all, for changes in forest carbon stock mean they cannot be considered as satisfactory. Effectively, their criteria permit the provision of financial and regulatory support to policy options that could increase carbon emissions in the short and medium term, and possibly in the long term too. The references to forest carbon stock in the Dutch and SBP's criteria are too vague. Forest carbon stock levels may stay the same or increase for reasons entirely unconnected with use for energy. The important issue is what levels they would have reached in the absence of biomass energy use. Similarly, the requirement in the proposed EU criteria for land-use sector accounting in the country of origin to take account of changes in forest carbon stock is a step in the right direction. It is still subject to the flaws identified earlier, however, and cannot take account of the full climate impact of the use of forest residues, which may be significantly underestimated in current models, given the potential effects on soil carbon levels and tree growth rates.

To date, no national biomass sustainability standards have been developed outside the EU, though the US state of Massachusetts restricts eligibility for subsidies based on net carbon accounting over a 20-year timeframe, and includes sustainability provisions such as the requirement that harvests leave sufficient woody material on the forest floor to replenish soil nutrients and protect wildlife. In addition, biomass plants must demonstrate emissions reductions over time on the basis of life-cycle emissions analyses, including a carbon-debt emissions factor, and must satisfy a minimum efficiency level.

Recommendations

- Robust sustainability criteria must deal with the impact on greenhouse gas emissions and the legality and sustainability of forest management.
- One option would be for the greenhouse gas element to be underpinned by a comprehensive life-cycle analysis for each type of feedstock, including changes in the forest carbon stock alongside supply-chain emissions. However, this is a complex calculation depending partly on the counterfactual (what would have happened to the wood, and the forest from which it was sourced, if it had not been used for energy?) and difficult to implement in real life.
- A more practical approach is to restrict eligibility for support to those feedstocks that are most likely to reduce net carbon emissions (or have low carbon payback periods): primarily mill residues, together with post-consumer waste. An additional element could be a requirement for a minimum level of efficiency of the unit in which the biomass is burnt.
- Policies should also ensure that subsidies do not encourage the biomass industry to divert raw material (such as mill residues) away from alternative uses (such as fibreboard), which have far lower impacts on carbon emissions.
- Alongside these emissions criteria, land criteria for legal and sustainable sourcing should be used to protect the way in which the forests are managed. Risk-based assessments of areas lacking coverage of forest certification schemes should supplement desk-based assessments with on-the-ground inspections.

Introduction

The use of wood for electricity generation and heat in modern (non-traditional) technologies has grown rapidly in recent years. For its supporters, it represents a relatively cheap and flexible way of supplying renewable energy, with benefits to the global climate and to forest industries. To its critics, it can release more greenhouse gas emissions into the atmosphere than the fossil fuels it replaces, and threatens the maintenance of natural forests and the biodiversity that depends on them. Just like the debate around transport biofuels a few years ago, this has become a highly contested subject with very few areas of consensus.

This paper aims to provide an overview of the debate around the impact of wood energy on the global climate, and to reach conclusions for policymakers on the appropriate way forward.

Global demand and supply

In energy policy terms, wood is one form of solid biomass, with other forms being agricultural crops and residues, herbaceous and energy crops, and organic wastes such as food waste or manure. Biomass-based energy is the oldest source of consumer energy known to humans, and is still the largest source of renewable energy worldwide, accounting for an estimated 8.9 per cent of world total primary energy supply in 2014.[1] Most of this is consumed in rural areas of non-industrialized or less industrialized parts of the world for cooking and heating, usually on open fires or in simple cookstoves. Together with the use of wood charcoal, these are categorized as 'traditional' uses and are not covered in this paper or its companion papers.

The focus here is on the combustion of woody biomass to produce electricity or heat, or both, through modern, non-traditional technologies: power stations, combined heat and power facilities, industrial processes such as pulp and paper mills, modern biomass burners, and so on. Biomass can also be co-fired with coal; coal plants do not need to be modified up to a mix of about 5 per cent biomass, making this the cheapest way of using biomass for power.

Taken together with bioliquids (which are mainly used for transport fuel) and biogas, these forms of biomass are the largest source of modern renewable energy used worldwide, accounting for an estimated 5.1 per cent of total final energy consumption in 2014. Heating for industry and buildings accounts for the bulk of this, while combustion for electricity is comparatively small, though it has grown rapidly in recent years (see Figure 1).

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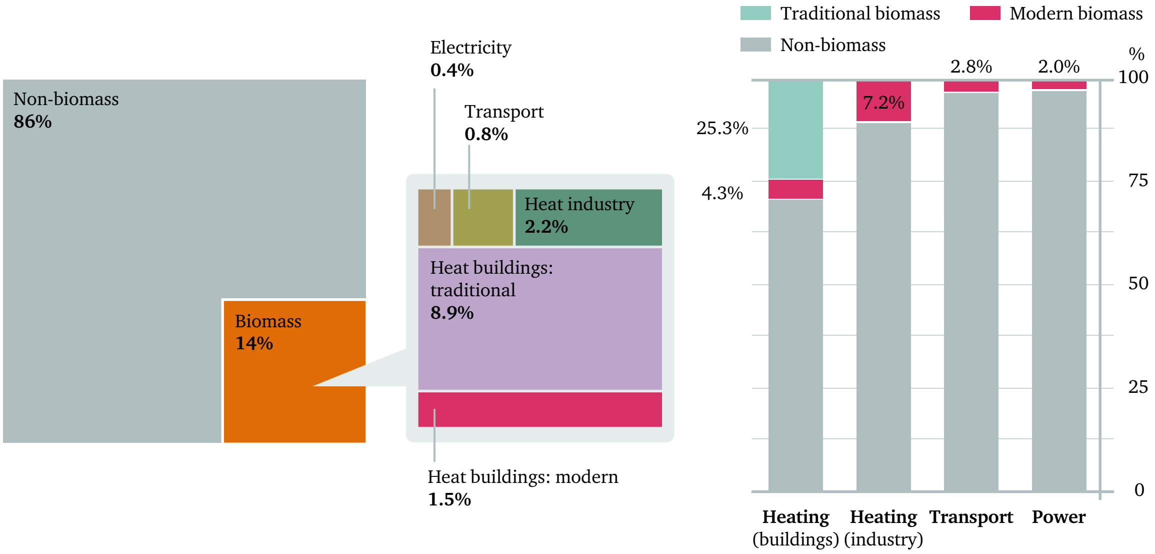
[1] United Nations Environment Programme (2016), *Renewables 2016: Global Status Report*, Nairobi: United Nations Environment Programme, p. 28.

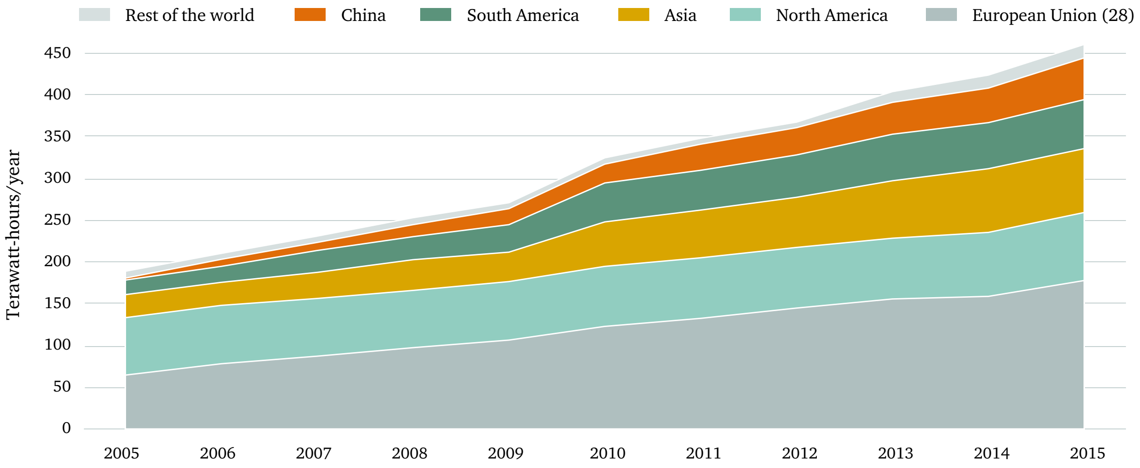
Figure 1: Shares of traditional and modern biomass (solid, liquid and gaseous) in total final energy consumption and in final energy consumption by end-use sector, 2014



Source: United Nations Environment Programme (2016), *Renewables 2016: Global Status Report*, Nairobi: United Nations Environment Programme, p. 43.

The growth of biomass energy has the potential to continue as countries increasingly adopt support policies for these uses of biomass, primarily in response to climate and energy security concerns. In the EU – the largest global consumer of modern biomass energy – a major driver has been the 2020 targets set for member states under the 2009 Renewable Energy Directive. In 2012, of the over \$7 billion invested in biomass-based power worldwide, Europe was the leader, accounting for about one-third.[2] While the EU has the largest share of biomass-fired electricity generation, the US, China, Japan, India and Brazil are all also significant consumers (see Figure 2).

Figure 2: Bio-power global generation, by country/region, 2005–15



Source: United Nations Environment Programme (2016), *Renewables 2016: Global Status Report*, Nairobi: United Nations Environment Programme, p. 45.

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[2] Roberts, D. G. (2013), 'International Wood Fibre Markets (and Emerging Shocks)', presentation at Megaflorestais conference, Bali, October 2013.

Most analyses assuming expansion in renewable energy envisage significant growth in the use of biomass, at least to 2030 and often beyond. In 2012, for example, the International Energy Agency (IEA) estimated that, as long as appropriate policies were in place by 2050, bioenergy (wood and other forms of biomass) could provide 3,100 terawatt hours (TWh) of electricity (7.5 per cent of total world electricity generation, an eight-fold increase from 2011), 22 exajoules (EJ) of final heat consumption in industry (15 per cent of the total, a tripling of the total) and 24 EJ in the buildings sector (20 per cent of the total, though this represented a fall from 35 EJ in 2009 as inefficient traditional forms of heating were gradually replaced).[3]

These estimates may be revised downwards, however, particularly for electricity generation, as the cost of other forms of renewable energy – mainly solar photovoltaic (PV) and wind – have fallen significantly in recent years and seem likely to reach grid parity with fossil fuel-sourced electricity very soon without subsidy. However, biomass energy has the advantage over solar and wind of being ‘dispatchable’; i.e. the electricity it generates can be dispatched at the request of power grid operators or of the plant owner. Biomass plants can be turned on or off, or can adjust their power output according to need, whereas solar, wind and hydroelectric power are present or not depending on the conditions (apart from pumped-storage hydroelectricity).[4]

In addition, there is growing interest in the combination of bioenergy and carbon capture and storage technology (BECCS) with the aim of providing energy supply with net negative emissions. The latest assessment report of the Intergovernmental Panel on Climate Change (IPCC) relies heavily on bioenergy for heat and power, and specifically on BECCS, in most of its scenarios of future mitigation options (see Chapter 1).[5] Despite the falling price and growing share of other forms of renewable energy, biomass accordingly retains some potential for future growth.

Wood for power and heat

There are alternatives to the use of wood in biomass power and heat, including organic wastes, agricultural residues such as sugarcane bagasse or palm kernels, and energy crops such as miscanthus (elephant grass) or switchgrass. Agricultural wastes and residues are, or are planned to be, important sources of biomass energy in China, India and Brazil, and energy crops may become more significant in the EU, though there is considerable uncertainty over the likely availability of land for their cultivation, among other factors.[6] However, all these forms of biomass tend to be less energy dense and more expensive to grow, collect and transport than wood. Wood is therefore likely to remain overwhelmingly the biomass fuel of choice for electricity generation and heat, at least in the short and medium term, as it is now in Europe, North America and Japan.

Wood in various forms can be used for electricity generation and heat. Primary end-products that are used for this purpose include:

- **Fuelwood (or firewood):** Simple logs, branches, twigs and so on, produced from logging, or thinnings and coppicings from managed forests. This is the simplest form of wood for fuel and

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[3] International Energy Agency (IEA) (2012), *Technology Roadmap: Bioenergy for Heat and Power*, Paris: IEA, http://www.iea.org/publications/freepublications/publication/2012_Bioenergy_Roadmap_2nd_Edition_WEB.pdf (accessed 28 Dec. 2016).
[4] These issues will be discussed at more length in the companion paper, *Woody Biomass for Power and Heat: Global Patterns of Demand and Supply.*
[5] Intergovernmental Panel on Climate Change IPCC (2014), *Climate Change 2014: Mitigation of Climate Change,* Cambridge: Cambridge University Press, http://www.ipcc.ch/pdf/assessment-report/ar5/wg3/ipcc_wg3_ar5_full.pdf (accessed 28 Dec. 2016).
[6] See, for example, Allen, B. et al. (2014), *Space for energy crops – assessing the potential contribution to Europe’s energy future,* London: Institute for European Environmental Policy, http://www.birdlife.org/sites/default/files/attachments/IEEP_2014_Space_for_Energy_Crops_0.pdf (accessed 30 Dec. 2016).

requires no processing, but it is bulky and contains high levels of moisture. It can therefore be relatively difficult and costly to collect and transport.

- **Wood chips:** Medium-sized solid material (typically 30–60 mm in size) made by cutting, or chipping, larger pieces of wood. Wood chips are easier than fuelwood to transport and store but can contain just as much moisture. Globally, most high-quality chips are used for composite-board products such as oriented strandboard or the production of pulp and paper; lower-quality wood chips may be used for energy, particularly where the transport distances to the installation are relatively low.
- **Wood pellets:** These are produced by compressing wood material and extruding it through a die into cylinders (normally 6–12 mm in diameter and 10–30 mm in length). This process, together with the necessary drying of the wood, requires energy input. Compared to wood chips, pellets are more dense and have a lower moisture content, and are therefore better suited to transport and storage. They are now the favoured form of wood for biomass power generation, particularly where transport distances are great. Pellets can be made from any organic material, including agricultural wastes, sawdust or other wastes from sawmilling and wood product manufacturing, but many power stations, particularly those co-firing wood pellets with coal, can only use clean wood mainly sourced from whole trees (see Chapter 1).
- **Wastes and residues:** Bark, shavings, sawdust, trim ends, offcuts and so on can be burned for energy on-site in sawmills where they are produced or made into pellets. Residues from forest operations – stumps, tops, small branches and pieces too short or defective to be used for other purposes – can also be made into chips or pellets, but, as noted earlier, their quality is sometimes too low to be used in power stations.
- **Black liquor:** A waste product from pulp and paper mills, this is generally burnt in recovery boilers on-site to generate energy for the mill and often also for export to the local electricity grid. Although it is a liquid, black liquor is generally classified as solid biomass, and forms a substantial share of the wood-based fuel consumed in some EU member states and the US (see Chapter 1).

Several new technologies for using wood for energy are under development. So-called ‘torrefied pellets’, ‘black pellets’ or ‘biocoal’ are normal (‘white’) pellets heated in the absence of oxygen to further reduce moisture and sugar content. Compared to white pellets, they have a higher energy density (though also require more energy to produce) and are water-resistant and more robust in handling, and they can be more easily burned in coal stations.[7] Wood (and other organic material) can also be gasified and the gas produced then used directly for electricity generation or fed into gas networks for heating or adapted for transport; though this technology has not been extensively commercialized so far.

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[7] Several slightly different processes can be used to produce torrefied or black pellets, including thermal roasting and steam explosion. While technically these are not the same, the end products are similar and the terms ‘black pellet’ or, less commonly, ‘biocoal’, are often used to describe them all.

About this paper

In national policy frameworks, biomass is always classified as a source of renewable energy, alongside other technologies such as solar PV, wind or tidal power. It benefits from the same kind of financial and regulatory support as those technologies on the grounds that, like other renewables, it is a carbon-neutral energy source. However, at the point of combustion, biomass is not carbon-neutral – if wood or other organic material is burnt in the presence of oxygen, it produces carbon dioxide – and the argument is increasingly being made that its use can have negative impacts on the global climate.

This classification of biomass as carbon-neutral derives from either one of two assumptions. The first is that biomass emissions are part of a natural cycle in which, over time, forest growth balances the carbon emitted by burning wood for energy. Chapter 1 examines this assumption.

The second assumption derives from IPCC reporting rules intended to avoid the double-counting of carbon emissions, which determine that emissions from wood energy are accounted for in the land-use sector and not in the energy sector. In effect, emissions are assumed to occur at the point of harvest, not at the point of burning, and thus biomass energy is carbon-neutral from the energy-sector perspective. Chapter 2 examines the framework for reporting and accounting of biomass emissions.

Governments, particularly those in the EU, have not been immune to the growing concerns over the impacts of the use of biomass for power and heat explored in this paper, and some have introduced or are planning to introduce sustainability criteria designed to minimize the environmental impact of biomass: biomass feedstocks must meet these requirements if they are to receive financial and regulatory support. Some private schemes are also being developed. Chapter 3 examines this development and considers the likely impact of the criteria currently in use or development.

This is the first of four papers to be published by Chatham House on this topic. Two more – *Woody Biomass for Power and Heat: Global Patterns of Demand and Supply* and *Woody Biomass for Power and Heat: Demand and Supply in Selected EU Member States* will review the recent and anticipated growth of demand for wood for electricity generation and heat in modern technologies on a global scale and in specific countries, and assess the likely sources of supply, in recent years and in the future. The fourth paper, *Woody Biomass for Power and Heat: Impacts on the Local Environment and Forest Users*, will consider the impacts of the use of woody biomass for energy on forest ecosystems and on other forest users.

1. Is Biomass Carbon-neutral?

This chapter reviews the argument that biomass emissions are part of a natural cycle in which forest growth balances the carbon emitted by burning wood for energy. The following issues are discussed:

- The level of greenhouse gases emitted by woody biomass when burnt, compared to those of the fossil fuels it potentially replaces.
- The types of woody biomass used for energy and their potential impact on carbon emissions.
- The relationship between the emissions from burning woody biomass and forest growth or regrowth, and the time forest growth may take to absorb the emissions from burning woody biomass (the ‘carbon payback period’).
- The debate around bioenergy with carbon capture and storage.

Most of the studies carried out on these topics relate to the sourcing of woody biomass from the US, generally for export and use in the EU. This is a relatively small proportion of total global use of woody biomass for energy, even in modern technologies. Across the UN Economic Commission for Europe region (Europe, North America, and north, west and central Asia), forest-based industries form the largest end-use sector, consuming over 40 per cent of wood energy.[8] However, the use of woody biomass for heat and power is growing more quickly, particularly in the EU, and imports from outside the EU, chiefly from the US and Canada, have risen sharply in recent years. This is likely to continue. It is estimated that, if it is to achieve its aim of providing 27 per cent of its energy consumption from renewable sources by 2030, the amount of biomass the EU will need is the equivalent to the total EU wood harvest for all purposes in 2015.[9] While studies based on the US may not always be applicable to the sourcing of woody biomass in other regions, they focus attention on the country that has experienced most rapid recent changes in this respect and many of the conclusions they reach are applicable more broadly.

Greenhouse gas emissions from burning woody biomass

Since in general woody biomass is less energy dense than fossil fuels, and contains higher quantities of moisture and less hydrogen, at the point of combustion burning wood for energy usually emits more greenhouse gases per unit of energy produced than is the case with fossil fuels.[10] Table 1 presents the emission factors agreed by the IPCC in 2006 and widely used, for example, in emissions calculations under the EU Emissions Trading Scheme and for some national inventory reports under the UN Framework Convention on Climate Change.

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[8] Griffiths, J. (2016), *Scoping Dialogue on Sustainable Woody Biomass for Energy*, p. 8, New Haven, CT: The Forests Dialogue, http://theforestsdialogue.org/sites/default/files/files/TFD%20Bankground%20Paper%20Scoping%20dialogue%20Sustainable%20Woody%20Biomass%20DRAFT%2020%2022%20June%202016(1).pdf (accessed 30 Dec. 2016).

[9] Strange Olesen, A. et al. (2015), *Environmental Implications of Increased Reliance of the EU on Biomass from the South East US,* p. 8, Brussels: European Commission, http://www.aebiom.org/wp-content/uploads/2016/08/DG-ENVI-study-imports-from-US-Final-report-July-2016.pdf (accessed 30 Dec. 2016).

[10] As noted in, for example, Agostini, A., Giuntoli, J. and Boulamanti, A. (2013), *Carbon accounting of forest bioenergy: Conclusions and recommendations from a critical literature review,* p.16, European Commission Joint Research Centre, http://publications.jrc.ec.europa.eu/repository/bitstream/JRC70663/eur25354en_online.pdf (accessed 30 Dec. 2016); and IEA Bioenergy Task 38 on Climate Change Effects of Biomass and Bioenergy Systems (2013), ‘Description of IEA Task 38’, http://www.task38.org/publications/task38_description_2013.pdf (accessed 30 Dec. 2016).

Table 1: Greenhouse gas emissions of wood, coal and natural gas, net calorific basis

	Emissions (kg CO_2/TJ) (1 TJ = 278 MWh)				
Source	Wood	Anthracite	Bituminous	Lignite	Natural gas
Carbon dioxide	112,000 (95,000–132,000)	98,300 (94,600–101,000)	94,600 (89,500–99,700)	101,000 (90,900–115,000)	56,100 (54,300–58,300)
Methane	30 (10–100)	1 (0.3–3)	1 (0.3–3)	1 (0.3–3)	1 (0.3–3)
Nitrous oxide	4 (1.5–15)	1.5 (0.5–5)	1.5 (0.5–5)	1.5 (0.5–5)	0.1 (0.03–0.3)

Source: Intergovernmental Panel on Climate Change (2006), *Guidelines for National Greenhouse Gas Inventories*, Vol. 2 (Energy), Table 2.2, pp. 2.16–2.17.

The emission levels from wood are compared with emissions from natural gas and three different types of coal (anthracite, bituminous coal and lignite). The table includes ranges of factors together with the central default values agreed by the IPCC. As can be seen, wood has a wider range of carbon dioxide emissions than all of the fossil fuels. Nevertheless, while some types of wood may have lower levels of carbon emissions than some types of coal, in general wood is more carbon intensive than coal and significantly more so than natural gas, as well as having higher levels of emissions of methane and nitrous oxide.

These figures are calorific values, i.e. the energy released from complete combustion of the fuel in the presence of oxygen. The energy actually delivered in real-world situations will differ from this depending primarily on the efficiency of conversion to 'useful' energy – i.e. thermal energy and electricity. Efficiency values vary substantially depending on the plant's size, design, age and type of fuel used. The European Commission's Joint Research Centre has reported average net thermal efficiencies of coal-burning plants of 40–45 per cent and average electric efficiencies of dedicated biomass plants of 20–30 per cent.[11] More recent figures for biomass plants in the EU indicate electric efficiencies of 24–32 per cent.[12] Very large modern plants such as the Drax power station in the UK, which has converted three of its six coal-fired units to biomass, may achieve electric efficiencies of around 38 per cent, though this depends on burning wood pellets rather than green chips.

Nevertheless, even in the case of Drax, carbon emissions per unit of energy are higher for woody biomass than for coal. Table 2 shows the figures for fuel use, electricity generation and carbon dioxide emissions reported by Drax for 2013. As can be seen, the carbon dioxide intensities of the fuels are 856 kg CO_2/MWh (coal) and 965 kg CO_2/MWh (biomass), i.e. a level of emissions from biomass about 13 per cent higher than from coal.

Table 2: Fuel used, electricity generated and carbon dioxide emissions, Drax, 2013

	Weight burnt (tonnes)	Electricity generated (TWh)	CO_2 emissions (tonnes)	CO_2 intensity (kg/MWh)
Coal and petcoke	9,301,000	23.4	20,089,607	856
Biomass	1,596,000	2.9	2,799,391	965

Source: Drax, *Annual review of Environmental Performance 2013*, pp. 3, 4, 8.

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[11] European Commission Joint Research Centre (2006), *Integrated Pollution Prevention and Control Reference Document on Best Available Techniques for Large Combustion Plants*, http://eippcb.jrc.ec.europa.eu/reference/BREF/lcp_bref_0706.pdf (accessed 30 Dec. 2016).

[12] Biomass Availability and Sustainability Information System (BASIS) (2015), *Report on conversion efficiency of biomass,* Version 2. http://www.basisbioenergy.eu/fileadmin/BASIS/D3.5_Report_on_conversion_efficiency_of_biomass.pdf (accessed 30 Dec. 2016).

Similarly, data provided by the US Environmental Protection Agency show that power plants burning wood tend to have higher emissions per megawatt-hour than plants burning gas or coal. To take a particular example, the Schiller power station in New Hampshire has coal boilers and a wood boiler; emissions from the wood boiler are 1,444 kg CO_2/MWh, compared to 1,243 kg CO_2/MWh for the coal boilers.[13] These solid fuel boilers are old and inefficient; new combined cycle gas boilers in the database have emission rates that are less than one third the emissions of the Schiller biomass boiler.

For biomass and fossil fuels, efficiency levels for combined heat and power (CHP), or cogeneration, plants, can be much higher – 80 per cent or more – as a much higher proportion of the heat produced during combustion is trapped and used. For example, DONG Energy's Avedøre CHP plant near Copenhagen, which is converting from coal and gas to biomass (wood pellets and straw), is claimed to be one of the most efficient in the world, achieving fuel efficiencies up to 89 per cent.[14]

In addition to the emissions produced at the point of combustion, the production and processing of the biomass gives rise to additional greenhouse gas emissions, from the energy consumed in harvesting the forest or collecting the wood, to processing it (e.g. into pellets), and transporting it. Calculations of these supply-chain emissions vary substantially.[15] A 2014 study estimated the emissions from supplying wood pellets from the southeastern US to power plants in the Netherlands, from truck, train and oceanic transport and from the process of pelletizing, as equivalent to 322 kg CO_2 per tonne of pellets. Assuming 499 kg of pellets is burnt to generate 1 MWh of electricity, this gives additional emissions of 162 kg CO_2/MWh – equivalent to about one-sixth of the emissions released during combustion (using the Drax figures above).[16]

In contrast, a 2016 study used the figure of 34.4 kg CO_2 per tonne of pellets burnt, one-tenth of that of the 2014 study.[17] The figures will vary with the particular scenario – e.g. with the distance between the forest and pellet plant, and between the plant and the power station, as well as with the amount and type of energy used in the plant – but this degree of variation seems excessive. A 2015 article calculated base-case figures of 132–140 kg carbon dioxide equivalent (CO_2-eq)/MWh but then also considered the impact of methane emissions from wood chips and sawdust during storage, either at the pellet mill or the power station. It found this raised the associated emissions to 317 kg CO_2- eq/MWh after storage for one month and 862 kg CO_2-eq/MWh after four months – higher by itself (even ignoring emissions from combustion) than emissions from coal (estimated in this study as 752 kg CO_2-eq/MWh).[18]

Given the considerable uncertainties associated with all these figures, further research would be valuable. This is particularly true for the contribution of methane emissions, which is a factor not usually included in calculations but which can have a major impact. The studies reviewed in the 2015

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[13] Partnership for Policy Integrity (2012), uploaded data: 'EPA's non-cogen egrid data for 2012', http://www.pfpi.net/epas-non-cogen-egrid-data-for-2012 (accessed 20 Feb. 2017).

[14] DONG Energy (undated), 'Avedøre Power Station', http://www.dongenergy.com/en/our-business/bioenergy-thermal-power/where-we-operate (accessed 30 Dec. 2016).

[15] As noted in Wang, W. et al. (2015), 'Carbon savings with transatlantic trade in pellets: accounting for market-driven effects', pp. 4–5, *Environmental Research Letters,* 10, doi:10.1088/1748-9326/10/11/114019 (accessed 30 Dec. 2016).

[16] Jonker J. G. G., Junginger, M. and Faaij, A. (2014), 'Carbon payback period and carbon offset parity point of wood pellet production in the South-eastern United States', p. 375, *GCB Bioenergy,* 6:4, DOI: 10.1111/gcbb.12056 (accessed 30 Dec. 2016).

[17] Galik, C. S. and Abt, R. C. (2016), 'Sustainability guidelines and forest market response: an assessment of European Union pellet demand in the southeastern United States', *GCB Bioenergy*, p. 6, 8:3, DOI: 10.1111/gcbb.12273 (accessed 30 Dec. 2016).

[18] Röder, M., Whittaker, C. and Thornley, P. (2015), 'How certain are greenhouse gas reductions from bioenergy? Life cycle assessment and uncertainty analysis of wood pellet-to-electricity supply chains from forest residues', *Biomass and Bioenergy,* 79, http://dx.doi.org/10.1016/j.biombioe.2015.03.030 (accessed 30 Dec. 2016). The study considered the impact of a wide range of factors, including different fuels used for drying.

article mentioned above, together with other estimates,[19] show considerable variability in methane emissions from stored sawdust, chips and pellets, and this can also vary depending on the storage conditions, whether the pile is covered, the ambient temperature and so on.

Similar supply-chain emissions are associated with fossil fuel extraction, from mining or drilling, processing and transport, and these should be taken into account in comparing alternative fuel scenarios. Again estimates vary, but studies suggest that an additional 5–10 per cent greenhouse gas emissions should be added to the combustion emissions from coal and about 30–35 per cent to those from gas (the figure is higher for gas because of the methane released during production).[20]

These variations in the technology in which the fuel is used, and in the life-cycle assessments, explain much of the difference in the greenhouse gas emission levels cited in various studies. Converting an old coal station to a modern biomass station or a remote rural community transiting from diesel-fired electricity generators to a biomass CHP plant using locally sourced feedstock might reduce carbon emissions over the entire life cycle of the system (depending on factors such as the type of feedstock and its impact on the forest). But these are limited examples; in most circumstances, comparing technologies of similar ages, it can be assumed that the use of woody biomass for energy releases higher levels of emissions than coal, and considerably higher levels than gas, as shown by the emission levels from Drax and Schiller quoted above.

This is only part of the picture, however, of the climate impact of woody biomass. The impacts will also vary with the type of woody biomass used, with what would have happened to it if it had not been burnt for energy and with what happens to the forest from which it was sourced. These questions are explored in the sections below.

Biomass energy feedstocks

Several different types of wood are commonly burnt for energy. The impact of their use on net carbon emissions, and therefore on the climate, depends partly on what would otherwise have been done with them if they had not been burnt for energy.

Mill residues

Mill residues are sides, bark, shavings, sawdust, trim ends, offcuts and so on produced as waste in sawmills; they typically amount to 45–55 per cent of the volume of timber entering the mill. Many years ago these were often burnt as waste, or sometimes disposed of in landfill, but now they are generally in demand for fibre products such as particleboard (e.g. MDF) or for use in pulp mills or for energy, either on-site in the sawmill or in biomass energy facilities elsewhere.

If the mill residues would otherwise have been burnt as waste or landfilled, or left to decay, it makes sense to use them for energy as the carbon content of the residues would be released into the atmosphere anyway as carbon dioxide and methane. If they would otherwise have been used for

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[19] See, for example, Svedberg, U., Samuelsson, J. and Melin, S. (2008), 'Hazardous Off-Gassing of Carbon Monoxide and Oxygen Depletion during Ocean Transportation of Wood Pellets', *Annals of Occupational Hygiene,* pp. 259–66 (which showed methane concentrations in the holds of ships transporting pellets varying between 216 and 956 parts per million (ppm), 52:4, DOI: 10.1093/annhyg/men013 (accessed 30 Dec. 2016); and Zilkha Biomass Energy (2013), 'Cofiring Zilkha Black® Pellets', presentation at 3rd IEA CCC Cofiring Biomass with Coal Workshop, June 2013, which included figures of 275 ppm for white pellets (compared to about 50 ppm for black pellets) after 20 days' storage in laboratory jars.

[20] See, for example, Spath, P. L., Mann, M. K. and Kerr, D. R. (1999), *Life Cycle Assessment of Coal-fired Power Production,* Golden, CO: US National Renewable Energy Laboratory, DOI: 10.2172/12100 (accessed 30 Dec. 2016); Fulton, M. et al. (2011), *Comparing Life-Cycle Greenhouse Gas Emissions from Natural Gas and Coal,* Deutsche Bank, https://www.db.com/cr/en/docs/Natural_Gas_LCA_Update_082511.pdf (accessed 27 Dec. 2016).

wood products, however, using them for energy will result in increased carbon emissions equal to the difference between the emissions from combustion and the supply chain (collection, transport and processing such as pelletizing) and combustion and supply-chain emissions from the fossil fuels replaced (plus any impacts from the manufacturers using alternative sources of wood). A full life-cycle analysis would be needed to calculate the precise impact in any given scenario. Using mill residues locally for energy in the sawmill would have the lowest impact, as supply-chain emissions are minimized.

Forest residues

Forest residues (or 'slash') are the parts of harvested trees that are left in the forest after log products have been removed, including stumps, tops and small branches, and pieces too short or defective to be used. These can amount to as much as 40–60 per cent of the total tree volume. Sometimes forest residues may be burnt as waste, but more frequently they are left to rot in the forest or at the roadside. They can be used for energy and can be made into pellets, but this can cause problems in biomass plants (particularly when co-fired with coal) because of their high ash, dirt and alkali salt content, which accelerates corrosion of the boilers.

The impact on overall carbon emissions from using forest residues for energy depends partly on the rate at which they would have decayed and released carbon dioxide and methane into the atmosphere, which varies with factors such as the local climate, the type of soil and the amount of water present. All else being equal, decay rates tend to be faster in wet conditions. In the US, the majority of logging residue decay half-lives are 50 years or less. While under warm conditions (such as in much of the southeastern US) decay half-lives are generally less than 20 years, under cooler conditions half-lives of 100 years or longer have been reported.[21] A study of forest-residue decay in Finland found significant differences between types of residue (branches decayed far more quickly than stumps, for example) and between the southern and northern (and much colder) parts of the country.[22] The European Commission Joint Research Centre has reported decay rates varying between 40 per cent per year for needles and twigs, 11.5 per cent a year for branches in temperate climates and 2 per cent a year for coarse deadwood.[23]

> Many studies have shown that the removal of forest residues reduces both soil carbon storage and nutrient availability, which in turn leads to a fall in site fertility and tree growth, thereby reducing carbon storage in tree biomass in the long term.

The slower the decay rate the larger will be the net increase in carbon emissions from the use of residues for energy in the short and medium term, as the carbon is released immediately on combustion rather than being trapped in the residue. The net impact gradually falls over time as the residues would have rotted and released carbon.

These decay rates by themselves understate the impact of using forest residues for energy, however, as their removal may also have significant impacts on levels of soil carbon and on rates of tree growth.

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[21] Miner, R. A. et al. (2014), 'Forest Carbon Accounting Considerations in US Bioenergy Policy', *Journal of Forestry,* 112:6, p. 9, https://doi.org/10.5849/jof.14-009 (accessed 27 Dec. 2016).

[22] Repo, A. (2015), *Climate impacts of bioenergy from forest harvest residues,* Aalto University. https://aaltodoc.aalto.fi/bitstream/handle/123456789/15923/isbn9789526061887.pdf? (accessed 27 Dec. 2016).

[23] Marelli, L. and Giuntoli, J. (2016), 'Assessing climate change mitigation potential of bioenergy technologies', presentation to European Commission bioenergy stakeholder conference, Brussels, 12 May 2016.

Many studies have shown that the removal of forest residues reduces both soil carbon storage and nutrient availability, which in turn leads to a fall in site fertility and tree growth, thereby reducing carbon storage in tree biomass in the long term.[24] The reduction in soil nutrients may also necessitate the use of fertilizers, with additional impacts on greenhouse gas emissions.[25] If these impacts are taken into account, the use of forest residues for energy may result in much larger increases in net carbon emissions, though this will depend partly on the proportion of residues removed. It should also be noted that the dynamics of soil carbon, including the amount of carbon from residues sequestered in the soil over time, and how much may be released due to harvesting, are not yet fully understood, and further research would be helpful.[26]

Roundwood

Compared to residues, the burning of roundwood (i.e. wood in its natural state as felled, including stemwood – the wood above ground – and stumps, which are sometimes classified as residues) for energy, represents the removal of growing forest carbon stock. Some of this roundwood may derive from other harvesting operations, or from additional fellings specifically for use as energy (through, for example, an increase in the area harvested annually or an increase in the intensification of felling, including clear-cutting) or from the diversion of harvested wood from other uses.

As with other types of wood, the impact on carbon emissions depends on what would have happened to the roundwood in the absence of use for energy – whether it would have been left growing, or harvested for some other use, or burnt or left to rot as otherwise unmerchantable, i.e. not fit for sale, parts of a harvest. In general, however, the net increase in carbon emissions will be much higher than from the use of mill or forest residues, as it includes not only the higher volume of emissions from burning biomass compared to burning fossil fuels but also the carbon emissions that would otherwise have been sequestered by the growing tree. (See below in this chapter for a discussion of carbon absorption by mature trees.)

Thinnings – the removal of selected trees or rows to allow stronger growth of the remaining trees, or to reduce the risk of fire – is one source of roundwood, though in the southeastern US the volume of thinnings has fallen in the last 20 years as plantation management has tended towards planting at lower densities.[27] However, studies suggest that the use of thinnings even from fire-prone forests do not reduce net greenhouse gas emissions for decades.[28] One study found that the use of thinnings for energy reduced carbon stocks in the forest, compared to leaving the forest alone, over 50 years.[29]

The increase in carbon emissions will also be high if roundwood is diverted from use in wood products such as panels or furniture or construction timber, as the carbon is emitted immediately rather than being fixed for years or decades. The competition for the raw material may also tend to

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[24] See, for example, Buchholz, T. et al. (2014), 'Mineral soil carbon fluxes in forests and implications for carbon balance assessments', *GCB Bioenergy,* 6:4, DOI: 10.1111/gcbb.12044 (accessed 27 Dec. 2016); Achat, D. L. et al. (2015), 'Quantifying consequences of removing harvesting residues on forest soils and tree growth – A meta-analysis', *Forest Ecology and Management,* 348, http://dx.doi.org/10.1016/j.foreco.2015.03.042 (accessed 27 Dec. 2016); Achat, D. L. et al. (2015), 'Forest soil carbon is threatened by intensive biomass harvesting', *Nature Scientific Reports*, 5, DOI:10.1038/srep15991 (accessed 27 Dec. 2016).

[25] Schulze, E.-D. et al. (2012), 'Large-scale bioenergy from additional harvest of forest biomass is neither sustainable nor greenhouse gas neutral', *GCB Bioenergy*, 4:6, DOI: 10.1111/j.1757-1707.2012.01169.x (accessed 27 Dec. 2016).

[26] See, for example, Lamers, P. and Junginger, M. (2013), 'The "debt" is in the detail: A synthesis of recent temporal forest carbon analyses on woody biomass for energy', *Biofuels Bioproducts and Biorefining*, 7:4, DOI: 10.1002/bbb.1407 (accessed 27 Dec. 2016); 'Re: Burning wood from Southern US forests to generate electricity in Europe' Letter from US academics to European Commissioner for Energy Günther Oettinger, 30 August 2013, https://www.nrdc.org/sites/default/files/ene_13090603a.pdf (accessed 27 Dec. 2016).

[27] Strange Olesen, A. et al. (2015), *Environmental Implications of Increased Reliance of the EU on Biomass from the South East US*, p. 40.

[28] See, for example, Hudiburg, T. et al. (2011), 'Regional carbon dioxide implications of forest bioenergy production', *Nature Climate Change,* 1, DOI:10.1038/nclimate1264 (accessed 27 Dec. 2016).

[29] Clark, J. et al. (2011), *Impacts of thinnings on carbon stores in the PNW: A plot level analysis*, Corvallis, OR: Oregon State University, https://www.nrdc.org/sites/default/files/ene_13041704a.pdf (accessed 27 Dec. 2016).

increase prices, which may lead to increased rates of harvesting, higher imports of wood products, substitution to non-wood products, and an increase in the rate of planting new forests. This depends, though, on the relative levels of demand; for example, there may be little competition in practice if the output of the competing industry is declining.

In 2015 a comprehensive review of the supply of woody biomass from the southeastern US to the EU found little evidence of any such diversion in practice, apart possibly for some sawmill residues.[30] Similarly, in 2016 a European Commission state aid investigation into the UK government's financial support for the conversion of the third unit at Drax from coal to biomass, triggered in part because of its potential impact on competition for wood, concluded that the increased demand from wood pellets 'could be fulfilled by the market without undue negative side-effects'.[31] Nevertheless, a number of wood-products industries have expressed concern over the distorting effect of subsidies for biomass energy on the market for the raw material on which they depend.[32]

Black liquor

Although black liquor is an important source of biomass energy in many countries, its climate impacts have received relatively little attention compared to those of other feedstocks. A waste product from the kraft pulping process, which digests pulpwood into paper pulp, black liquor comprises a solution of lignin residues, hemicellulose and the inorganic chemicals used in the process. Originally simply discharged into local watercourses (with major local environmental impacts), virtually all pulp and paper mills now burn black liquor in recovery boilers for energy, generating steam and recovering some of the chemicals used. Modern mills should be self-sufficient for energy; indeed, many produce a surplus of electricity for export to the local or national grid. New waste-to-energy methods involving gasification have the potential to achieve higher efficiencies than the conventional recovery boiler while also generating an energy-rich syngas, which can be used to generate electricity or be converted into methanol and other transport fuels.

Black liquor is very different from most other uses of biomass. It is in its entirety waste produced as a by-product of a wood-based industry, with no impact on forest carbon stock (separate from the impact of the pulp and paper industry). It is generated and used on-site, with no transport costs. If it was not burnt for energy, the pulp mills would face the task of disposing of a highly polluting substance. In general the use of black liquor should be economic without the need for subsidy, though in the US a tax loophole aimed at promoting alternative fuels has allowed paper companies to claim very substantial tax refunds for its use.[33] One study of the life-cycle impact of black liquor recovery on climate change concluded that greenhouse gas emissions were approximately 90 per cent lower than those for a comparable fossil fuel-based system.[34] From the point of view of analysis, it is highly regrettable that black liquor is often included alongside other types of solid biomass in reported statistics since its climate impact is clearly very different.

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[30] Strange Olesen, A. et al. (2015), *Environmental Implications of Increased Reliance of the EU on Biomass from the South East US*, pp. 141–44.

[31] European Commission (2016), 'State aid: Commission authorises UK support to convert unit of Drax power plant from coal to biomass', 19 December 2016, http://europa.eu/rapid/press-release_IP-16-4462_en.htm (accessed 27 Dec. 2016).

[32] See, for example, American Forest and Paper Association (undated), 'Biomass and Renewable Energy Mandates', http://www.afandpa.org/issues/issues-group/biomass-and-renewable-energy-mandates (accessed 27 Dec. 2016); and RISI (2015), *An Analysis of UK Biomass Power Policy, US South Pellet Production and Impacts on Wood Fiber Markets*, Bedford, MA: RISI, http://docplayer.net/25281897-An-analysis-of-uk-biomass-power-policy-us-south-pellet-production-and-impacts-on-wood-fiber-markets-prepared-for-the-american-forest-paper.html (accessed 27 Dec. 2016).

[33] Hoffman, W. (2014), 'Black Liquor: The Loophole That Won't Quit', Tax Analysts, 9 April 2014 http://www.taxanalysts.org/content/black-liquor-loophole-wont-quit (accessed 27 Dec. 2016).

[34] Gaudreault, C. et al. (2012), 'Life cycle greenhouse gases and non-renewable energy benefits of kraft black liquor recovery', *Biomass and Bioenergy*, 46, http://dx.doi.org/10.1016/j.biombioe.2012.06.027 (accessed 27 Dec. 2016).

Feedstocks in use

The discussion earlier highlights the critical influence of the type of wood product used as feedstock. In general the use of residues and wastes is likely to result in a much smaller net increase in carbon emissions, or in some circumstances a reduction, compared to the use of roundwood.

Many of the models contained in studies of the impacts of using wood for energy (discussed further below) assume that residues are the main feedstock. In the model used in a 2012 paper, residues supplied 65 per cent of the woody biomass projected to be used for energy in 2015, and remained important beyond that unless constrained by policy.[35] Similarly, scenarios modelled in one 2015 study, which looked ahead to 2032, assumed that mill residues comprised 67 per cent of feedstock in a situation of low demand; additional harvesting (of pulpwood – debarked sections of stems 5–23 cm in diameter) provided 19 per cent.[36] In a situation of high demand, however, that study assumed that the supply of mill residues would not be sufficient and would only provide 36 per cent of feedstock; the proportion provided by additional harvesting was estimated as 36 per cent. Two other papers in 2013 and 2015 argued for using residues more intensively.[37] The second of these claimed a much greater potential for using forest residues in Sweden than the 20 per cent currently used for bioenergy.[38] As discussed above, however, greater use of forest residues seems likely to release more soil carbon and to reduce forest growth, thus increasing net carbon emissions.

Information provided by the biomass energy industry, including wood pellet companies, tends to emphasize the use of residues. For example, in its supply report for 2014 Drax reported that its feedstock mix included 37 per cent sawdust and sawmill residues, 29 per cent forest residues (which it defined as including low-grade wood) and 24 per cent thinnings.[39] For 2015–16 it reported 47 per cent sawmill residues, 26 per cent low-grade roundwood and forest residues, and 24 per cent thinnings.[40] Enviva, the largest US pellet producer, stresses its use of low-grade wood fibre (wood that would otherwise have been rejected from lumber mills), tops and limbs, chips made by suppliers in the forest out of low-grade wood and waste materials and commercial thinnings, alongside mill waste and residues.[41] Both companies tend to group 'low-grade wood' along with 'forest residues', though the impact on carbon emissions is not the same.

In contrast, however, in April 2015, in the prospectus accompanying its initial public offering, Enviva stated that:

> Our primary source of wood fiber is traditional pulpwood, which has historically exhibited less pricing volatility than other sources of wood fiber…we also procure industrial residuals (sawdust and shavings) and forest residuals (wood chips and slash), which have been more volatile historically in terms of price and supply but occasionally represent lower cost alternative inputs.[42]

NGOs in the US have identified cases where biomass energy companies have stated either that they regard waste and forest residues as unsuitable feedstocks in terms of quantity or quality, or both, or

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[35] Daigneault, A., Sohngen, B. and Sedjo, R. (2012), 'Economic approach to assess the forest carbon implications of biomass energy', *Environmental Science and Technology*, p. 5668, 46:11, DOI: 10.1021/es2030142 (accessed 27 Dec. 2016).

[36] Wang, W. et al. (2015), 'Carbon savings with transatlantic trade in pellets', pp. 5–6.

[37] Lamers, P. and Junginger, M. (2013), 'The "debt" is in the detail', p. 382; Gustavsson, L. et al. (2015), 'Climate effects of bioenergy from forest residues in comparison with fossil energy', *Applied Energy,* 138.

[38] Gustavsson, L. et al. (2015), 'Climate effects of bioenergy from forest residues in comparison with fossil energy'.

[39] Drax (2015), *Biomass Supply 2014*, p. 6, DOI: 10.1016/j.apenergy.2014.10.013 (accessed 27 Dec. 2016).

[40] Drax (undated), 'Drax feedstock mix by fibre type for compliance year 2015–16', http://www.drax.com/sustainability/sustainability-reporting (accessed 27 Dec. 2016).

[41] Enviva (undated), 'Wood Fiber Resources', http://www.envivabiomass.com/wp-content/uploads/Enviva-Wood-Fiber-Resources.pdf (accessed 27 Dec. 2016).

[42] Enviva (2015), 'Prospectus', 28 April 2015, p. 131, http://www.sec.gov/Archives/edgar/data/1592057/000119312515155449/d808391d424b4.htm (accessed 27 Dec. 2016).

classify whole trees or whole-tree chips as 'waste'.[43] The Vyborgskaya pellet plant in Russia sources only logs, according to a corporate presentation in 2013 that did not mention either mill or forest residues.[44]

The European Commission's 2015 review of the supply of woody biomass from the southeastern US to the EU concluded that, while sawmill residues were in many ways the ideal source material for pellets, US mill residues were already almost entirely utilized by the biomass energy or other industries, and there was very limited room for expansion.[45] As noted earlier, the use of forest residues can cause problems in biomass plants because of their high ash, dirt and alkali salt content. Partly for this reason, the European Commission concluded that residues such as tops, limbs and other unmerchantable materials 'currently do not play a significant role' in the woody biomass supply chain. Various types of roundwood, mainly pulpwood but also larger sizes, were therefore the main source – typically about three-quarters – of the feedstock volume of large industrial pellet facilities.[46]

These findings are supported by other studies. One 2015 study suggested that 76 per cent of feedstock used to produce pellets in the southern US was pulpwood while mill residues and forest residues accounted for 12 per cent each.[47] A survey of forest resources in the US found that in 2011 less than 1 per cent of mill residues was not already used; 43 per cent was used for commercial fuel, 40 per cent for fibre products and the rest for other products.[48]

The question of the types of wood used for biomass energy has become one of the most bitterly contested issues in the debate over its impacts. NGOs have published reports claiming that pellet plants use whole trees extensively, including sourcing from harvesting specifically for energy use.[49] Where these are hardwoods – which provide up to 100 per cent of the feedstock for some of Enviva's pellet plants, according to information provided by the company in 2015 – this increases net carbon emissions over time, as hardwoods take much longer to grow back than softwoods.[50] The pellet and biomass energy companies counter that where whole trees are used they tend only to be dead or diseased or otherwise unmerchantable trees that would have no other use – though trees that would not qualify as high-quality sawtimber could nevertheless be used for pulp, panels or laminated products.

This is important because of the significant difference these categories can make to the impact on net carbon emissions. As discussed above, the impacts from using mill or forest residues are much lower than those for material from growing trees harvested specifically for energy use, since in the latter case carbon absorption from growing trees is foregone (along with the higher carbon emissions from using biomass instead of fossil fuels). In 2015 an analysis of the feedstock sources from the southern US reported by Drax for 2014 (which differentiated between 'forest residues' and 'low-grade wood' – as noted, the two are combined in Drax's figures) used the UK government's BEaC scenarios

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[43] See, for example, Booth, M. and Bitov, K. (2013), *Analysis of Risks and Corporate Disclosures Regarding Environmental and Climate Considerations in the Biomass Power Sector,* Partnership for Policy Integrity, http://www.pfpi.net/wp-content/uploads/2013/11/PFPI-report-to-SEC-on-bioenergy-Nov-20-2013.pdf (accessed 27 Dec. 2016); Partnership for Policy Integrity and Dogwood Alliance (2016), *Carbon Emissions and Climate Change Disclosure by the Wood Pellet Industry – A Report to the SEC on Enviva Partners LP*, https://www.dogwoodalliance.org/wp-content/uploads/1999/11/Report-to-SEC-on-Enviva-March-14-2016.pdf (accessed 27 Dec. 2016).

[44] Dale, A. (2013), 'Wood Pellets from Russia', presentation to Wood Pellet Association of Canada, 18–20 November 2013, http://www.pellet.org/images/21_-_Arnold_Dale_-_From_Russia_with_Love_2013.pdf (accessed 27 Dec. 2016).

[45] Strange Olesen, A. et al. (2015), *Environmental Implications of Increased Reliance of the EU on Biomass from the South East US,* pp. 95–96.

[46] Ibid.

[47] RISI (2015), *An Analysis of UK Biomass Power Policy, US South Pellet Production and Impacts on Wood Fiber Markets*, p. 20.

[48] Oswalt, S. N. et al. (2014), *Forest Resources of the United States, 2012: a technical document supporting the Forest Service 2015 update of the RPA Assessment,* p. 21, Washington, DC: US Department of Agriculture, Forest Service, https://www.srs.fs.usda.gov/pubs/gtr/gtr_wo091.pdf (accessed 27 Dec. 2016).

[49] See, for example, reports produced by Dogwood Alliance, https://www.dogwoodalliance.org/campaigns/bioenergy/bioenergy-reports/), the Natural Resources Defense Council, https://www.nrdc.org/issues/support-renewable-energy-protects-wild, and the Southern Environmental Law Center, https://www.southernenvironment.org/cases-and-projects/biomass-energy-in-the-south.

[50] Partnership for Policy Integrity and Dogwood Alliance (2016), *Carbon Emissions and Climate Change Disclosure by the Wood Pellet Industry*, p. 29.

(see below) to calculate net carbon emissions.[51] This concluded that Drax's emissions were at least 2,677 kg CO_2-eq/MWh for a scenario in which 80 per cent of feedstock derived from additional biomass harvests in southeastern US hardwoods, with the remainder coming from sawmill or forest residues; or at least 1,227 kg CO_2-eq/MWh for a scenario assuming 48 per cent of the feedstock derived from forest residues that would otherwise have decayed, with the remainder sourced from sawmill residues (17 per cent) and additional biomass harvests (35 per cent). In each case these emissions levels are significantly higher than those from coal. A Drax spokesperson commented that the study was based 'on a mountain of assumptions… based on an outlandish scenario' and insisted that the hardwood sourced by Enviva for its pellets was a residue of normal commercial operations.[52]

Part of the problem is the lack of clear definitions of the term 'forest residues'. The EU Renewable Energy Directive, for example, does not define it. In the UK, the energy regulator, Ofgem, defines forestry residues as material 'derived from "virgin wood"', including:

> all raw materials collected directly from the forest, whether or not as a result of thinning or logging activities. This may include (but is not limited to) materials such as tree tops, branches, brash, clippings, trimmings, leaves, bark, shavings, woodchips and saw dust from felling.[53]

'Virgin wood' is defined as:

> timber from whole trees and the woody parts of trees including branches and bark derived from forestry works, woodland management, tree surgery and other similar operations. It does not include clippings or trimmings that consist primarily of foliage (though these may be forestry residues).[54]

These definitions are confusing and potentially overlapping: whole trees, or logs, could fall under the definition of forest residues or of virgin wood despite their very different impacts on emissions. Similarly, the definitions of logging residues by the US Forest Service and US Department of Energy can include whole trees. In one 2016 report the latter defined logging residues as 'trees not meeting merchantable timber specifications and tree components, such as limbs, tops, and cull logs'.[55] These imprecise definitions are not helpful in resolving the debate over climate impacts.

Biomass and the forest carbon cycle

It is not disputed that burning woody biomass for energy produces emissions of carbon dioxide and other greenhouse gases. But the argument is often made that since these carbon emissions are absorbed as part of the natural forest cycle of growth and regrowth, they should therefore be counted as zero at the point of combustion (in other words, that the discussion above about the climate impact of different types of feedstocks is irrelevant). Many studies of the benefits of biomass energy, including the ones cited above, assume just that. Similarly, national sustainability criteria for woody biomass that set minimum levels of greenhouse gas savings compared to the fossil fuels they replace ignore the emissions produced during combustion and consider only supply-chain emissions from harvest, processing and transport (see Chapter 3). This is what lies behind claims such as one about biomass

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[51] Buchholz, T. and Gunn, J. (2015), *Carbon Emission Estimates for Drax biomass powerplants in the UK sourcing from Enviva Pellet Mills in U.S. Southeastern Hardwoods using the BEAC model,* Pleasanton, CA: Spatial Informatics Group.

[52] ENDS Waste and Bioenergy (2015), 'Drax rejects carbon criticism', 3 June 2015, http://www.endswasteandbioenergy.com/article/1349937/drax-rejects-carbon-criticism (accessed 27 Dec. 2016).

[53] Ofgem (2016), *Renewables Obligation: Sustainability Criteria Guidance,* Table 11, pp. 83–84, https://www.ofgem.gov.uk/system/files/docs/2016/03/ofgem_ro_sustainability_criteria_guidance_march_16.pdf (accessed 27 Dec. 2016).

[54] Ibid, Table 10, pp. 81–82.

[55] US Department of Energy (2016), *2016 Billion-Ton Report: Advancing Domestic Resources for a Thriving Bioeconomy, Volume 1: Economic Availability of Feedstocks*, Washington, DC: US Department of Energy, p. 127 https://energy.gov/sites/prod/files/2016/12/f34/2016_billion_ton_report_12.2.16_0.pdf (accessed 27 Dec. 2016).

representing an 80 per cent emissions saving compared to coal.[56] The argument may also be used that, if waste (including residues) is used as the feedstock, emissions can be considered to be zero, since no additional harvesting is involved.

This argument takes various forms. The most extreme version is that woody biomass emissions should count as zero because carbon has already been absorbed during the growth of the trees that are logged and burnt. As one study argued in 2011, 'Those trees have been gathering carbon (some of which is from the combustion of fossil fuels) for… 30 years… We have accrued a dividend. We can then derive a benefit from that dividend by using those trees for energy.'[57] This argument implies that, once they have grown, what happens to trees later – whether they are left to grow further, or harvested and made into wood products, or harvested and burnt for energy – somehow makes no difference to carbon concentrations in the atmosphere. This is obviously not the case.

A similar argument is that, as long as the trees are harvested from a forest that is sustainably managed, their carbon emissions should be considered to be zero: effectively, forest growth, replacing the logged trees, cancels out the emissions released when burnt. The description of the IEA's Bioenergy Task 38 on Climate Change Effects of Biomass and Bioenergy Systems, for example, includes the statement that:

> Biomass fuels can have higher carbon emission rates (amount of carbon emitted per unit of energy) than fossil fuels (e.g. oil, or natural gas) due to generally lower energy density of biomass. This fact is only relevant, when biomass fuels are derived from unsustainable land-use practices (the carbon emissions from combustion of sustainable biomass are excluded from calculations because they are counterbalanced by the uptake of CO_2 as the feedstock is grown i.e. the photosynthetic and combustion stages of the life cycle are carbon neutral).[58]

As mentioned earlier, this argument must assume that whatever happens to the trees after they are harvested (assuming sustainable management, i.e. that forest growth replaces the forest carbon lost when logged) makes no difference to carbon concentrations in the atmosphere: burning them for energy is the same as fixing the carbon in wood products. Again, as above, this is clearly wrong. Furthermore, this argument ignores the carbon sequestration forgone from harvesting the trees: they would have continued to grow and absorb carbon if left un-harvested, and the uptake of carbon therefore falls when they are logged, whether or not the forest is sustainably managed. This is not true only if the forest grows *more slowly* in the absence of logging for energy, or if harvesting promotes *additional growth* fast enough to replace the carbon emitted when burnt; both issues are discussed below.

The third version of the argument discounts any link between the trees, or parts of trees, burnt for energy and the forest stand, or the forest, from which they derive, and asserts that as long as the forest as a whole or forests in general are expanding, emissions from combustion can be ignored. Although globally deforestation is continuing, this is not the case in Europe or North America, which are currently the main sources of wood for energy in modern technologies and are seeing an increase in forest cover. This fact is sometimes cited as evidence that the use of wood from these areas for energy is sustainable: if total forest cover is increasing, more carbon is being absorbed, which offsets the additional carbon emitted to the atmosphere when wood from those areas is burnt.[59]

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[56] For example, according to a Drax spokesperson, 'Using the latest biomass technology has resulted in an over 80 per cent carbon saving compared to coal. This independently verified data factors in the full carbon costs from across the whole supply chain – including harvesting, processing and transportation.' Timperley, J. (2016), 'Is biomass really more polluting than coal?', Business Green, 17 October 2016, http://www.businessgreen.com/bg/analysis/2474217/is-biomass-really-more-polluting-than-coal (accessed 27 Dec. 2016).

[57] Strauss, W. (2011), 'How Manomet Got It Backwards: Challenging the 'Debt-Then-Dividend' Axiom', Biomass Magazine, 22 June 2011, http://biomassmagazine.com/articles/5621/how-manomet-got-it-backwards-challenging-the-undefineddebt-then-dividendundefined-axiom (accessed 27 Dec. 2016).

[58] IEA Bioenergy Task 38 (2013), 'Description of IEA Task 38'.

[59] Evans, S. (2015), 'Investigation: Does the UK's biomass burning help solve climate change?', Carbon Brief, 11 May 2015, https://www.carbonbrief.org/investigation-does-the-uks-biomass-burning-help-solve-climate-change (accessed 27 Dec. 2016).

Again, this ignores the carbon absorption forgone when the trees are harvested and burnt as well as the counterfactual regarding what would have happened if the trees had not been harvested and burnt for energy. There is no automatic link between the increase in forest growth and burning wood for biomass – particularly when the argument depends on expansion in forests entirely unconnected to those from which the wood for energy is harvested – and there is no reason to assume that, globally, forests would grow more slowly in the absence of the biomass industry.

Carbon absorption, forest growth and forest age

The main argument for a positive impact of burning woody biomass is if the forest area expands as a direct result of harvesting wood for energy, and if the additional growth exceeds the emissions from combustion of biomass. Various models have predicted that this could be the case: that the additional income from selling wood for energy (even if this is only part of the harvest) may encourage forest owners to invest more in their forests and plant a greater area.[60] These are models, however, rather than real-world observations, and it is not clear that this phenomenon is actually being observed. As can be seen in Table 3, the area of commercial timberland (i.e. forest land available for the production of forest products) in the five southeastern US states where most US wood pellet mills are found did not change significantly between 2011 and 2014, a period during which the wood pellet and biomass industries were both expanding.

Table 3: Timberland area of southeastern US states, 2011 and 2014

	Area of timberland (000 ha)		
State	2011	2014	Change 2011–14
Alabama	9,279	9,320	+0.44%
Georgia	9,874	9,776	–0.99%
North Carolina	7,316	7,331	+0.21%
South Carolina	5,237	5,180	–1.10%
Virginia	6,198	6,228	+0.48%

Source: US Forest Service (undated), 'Forest Inventory and Analysis – Southern Research Station', http://srsfia2.fs.fed.us/states/state_information.shtml.

If anything, the evidence suggests the opposite. In 2014, for example, the US Forest Service reported that while forest hardwood inventories were expected to continue increasing to 2020, even as bioenergy demand increased, the rate of growth of forest carbon stocks would be lower as a result of demand for biomass for energy. It concluded: 'Even assuming full utilisation of mill residues and increased utilisation of logging residues, harvest of pine and hardwood non-sawtimber feedstock increases… hardwood inventories continue to increase although these end at lower levels' than without new bioenergy demand.[61]

In addition, the models always assume that younger trees grow faster and therefore absorb more carbon than older, more mature trees; as one study stated, 'the CO_2 uptake in old forests is low, and

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[60] See, for example, Daigneault, A., Sohngen, B. and Sedjo, R. (2012), 'Economic approach to assess the forest carbon implications of biomass energy'; Miner, R. A. et al. (2014), 'Forest Carbon Accounting Considerations in US Bioenergy Policy'; Wang, W. et al. (2015), 'Carbon savings with transatlantic trade in pellets'; Hektor, B., Backéus, S. and Andersson, K. (2016), 'Carbon balance for wood production from sustainably managed forests', *Biomass and Bioenergy*, 93, DOI: 10.1016/j.biombioe.2016.05.025 (accessed 27 Dec. 2016).

[61] Abt, K. L., et al. (2014), *Effect of Policies on Pellet Production and Forests in the U.S. South: A Technical Document Supporting the Forest Service Update of the 2010 RPA Assessment,* Washington, DC: US Department of Agriculture, https://www.srs.fs.usda.gov/pubs/gtr/gtr_srs202.pdf (accessed 27 Dec. 2016).

in very old stands the CO_2 is even negative' (because of the greater likelihood of carbon losses due to fire, storms or insects).[62] Thus it is argued that harvesting mature trees and replanting will increase the rate of carbon uptake. Studies suggest, however, that this is not true, particularly in old-growth forests, though it may be in plantations (possibly because of lower soil nutrient availability in plantations compared to natural forests).

Many studies, particularly some conducted recently, have shown that mature trees absorb more carbon than younger trees, mainly because of their much higher number of leaves, which enable greater absorption of carbon dioxide from the atmosphere.[63] As a 2014 study concluded:

> for most species mass growth rate increases continuously with tree size. Thus, large, old trees do not act simply as senescent carbon reservoirs but actively fix large amounts of carbon compared to smaller trees; at the extreme, a single big tree can add the same amount of carbon to the forest within a year as is contained in an entire mid-sized tree.[64]

According to one 2008 study:

> [the] commonly accepted and long-standing view that old-growth forests are carbon neutral… was originally based on ten years' worth of data from a single site. It is supported by the observed decline of stand-level net primary production with age in plantations, but is not apparent in some ecoregions.[65]

Although the rate of carbon uptake does tend to decline with the age of the tree, it found that 'in forests between 15 and 800 years of age, net ecosystem productivity (the net carbon balance of the forest including soils) is usually positive.'[66] Several studies suggest that the rate of carbon uptake has accelerated in recent years with the increasing concentration of carbon dioxide in the atmosphere. Since trees are prone to disease and pests, the high rate of carbon uptake of older trees is somewhat offset by their higher mortality rates, but only partially, and it should be possible to reduce this by management for conservation (e.g. removing diseased or dead trees).

This conclusion is supported by other studies suggesting that, far from accelerating carbon uptake, harvesting may in fact bring it to a temporary halt. One reviewing the impacts of forest disturbances (including harvesting, fires, storms and insect infestation) throughout the US concluded that in most cases the forest did not return to its status as a carbon sink for at least 10, and sometimes as much as 20, years, partly due to the large soil carbon losses associated with the event.[67] Similarly, a model-based study of forest carbon storage in the northeastern US compared different types of forest management and concluded that the highest rate of carbon uptake and storage was achieved simply by leaving the forest alone:

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[62] Hektor, B., Backéus, S. and Andersson, K. (2016), 'Carbon balance for wood production from sustainably managed forests', p. 3.

[63] See, for example, Luyssaert, S. et al. (2008), 'Old-growth forests as global carbon sinks', *Nature,* 455, DOI:10.1038/nature07276 (accessed 27 Dec. 2016); Lewis, S. et al. (2009), 'Increasing carbon storage in intact African tropical forests', *Nature,* 457, 19 February 2009, DOI:10.1038/nature07771 (accessed 27 Dec. 2016); Bellassen, V. and Luyssaert, S. (2014), 'Carbon sequestration: Managing forests in uncertain times', *Nature,* 506, 12 February 2014, DOI: 10.1038/506153a (accessed 27 Dec. 2016); Stephenson, N. L. et al. (2014), 'Rate of tree carbon accumulation increases continuously with tree size', *Nature* 507, DOI:10.1038/nature12914 (accessed 27 Dec. 2016); Craggs, G. (2016), *The Role of Old-Growth Forests in Carbon Sequestration,* Dalkeith: Future Directions International, http://www.futuredirections.org.au/publication/role-old-growth-forests-carbon-sequestration (accessed 27 Dec. 2016). Over 60 studies showing the same phenomenon are summarized in CO_2 Science (2014), 'Forests (Growth Rates of Old vs. Young Trees) – Summary', http://www.co2science.org/subject/f/summaries/forestold.php (accessed 27 Dec. 2016).

[64] Stephenson, N. L. et al. (2014), 'Rate of tree carbon accumulation increases continuously with tree size'.

[65] Luyssaert, S. et al. (2008), 'Old-growth forests as global carbon sinks', p. 213.

[66] Ibid.

[67] Amiro, B. D. et al. (2010), 'Ecosystem carbon dioxide fluxes after disturbance in forests of North America', *Journal of Geophysical Research*, 115:G4, DOI: 10.1029/2010JG001390 (accessed 27 Dec. 2016).

> The results supported both our first hypothesis that passive management sequesters more carbon than active management, as well as our second hypothesis that management practices favoring lower harvesting frequencies and higher structural retention sequester more carbon than intensive forest management.[68]

Most of the models assuming that the production of wood for energy accelerates carbon uptake also assume that much of the rapid growth is achieved by replacing old-growth forests with plantations, most commonly of relatively fast-growing pine species.[69] As well as causing higher carbon emissions from the loss of mature trees, at the point of harvest and in terms of foregone future carbon sequestration, this is also highly likely to have negative impacts on biodiversity and habitats.[70] This reinforces the need to protect old-growth forests, not only for their value for biodiversity and amenity but also for their role as a significant carbon sink.

The temporal dimension: the carbon payback period

A different way of looking at the climate impacts of biomass energy is to consider the temporal dimension of the issue. It can be argued that the carbon dioxide emitted by burning woody biomass for energy is indeed absorbed from the atmosphere by forest growth, but this takes place only over time, a factor ignored by the arguments discussed earlier.

Following this argument, the carbon dioxide (and other greenhouse gases) released by the burning of woody biomass for energy, along with their associated life-cycle emissions, create what is termed a ‘carbon debt’ – i.e. the additional emissions caused by burning biomass instead of the fossil fuels it replaces, plus the emissions absorption foregone from the harvesting of the forests.[71] Over time, regrowth of the harvested forest removes this carbon from the atmosphere, reducing the carbon debt. The period until carbon parity is achieved (i.e. the point at which the net cumulative emissions from biomass use are equivalent to those from a fossil fuel plant generating the same amount of energy) is usually termed the ‘carbon payback period’. After this point, as regrowth continues biomass may begin to yield ‘carbon dividends’ in the form of atmospheric greenhouse gas levels lower than would have occurred if fossil fuels had been used. Eventually carbon levels in the forest return to the level at which they would have been if they had been left unharvested. (Some of the literature employs the term ‘carbon payback period’ to describe this longer period, but it is more commonly used to mean the time to parity with fossil fuels; this meaning is used in this paper.)

The factors affecting the length of the carbon payback period are the same as those discussed above: the level of emissions produced during harvesting, collecting, processing, transporting and burning the biomass compared to the fossil fuels that it replaces, together with the counterfactual about what would have happened to the wood if it had not been used for energy and to the forest from which it was sourced.[72]

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[68] Nunery, J.S., and Keeton, W.S. (2010), ‘Forest carbon storage in the northeastern United States: Net effects of harvesting frequency, post-harvest retention, and wood products’, *Forest Ecology and Management*, 259:8, http://dx.doi.org/10.1016/j.foreco.2009.12.029 (accessed 27 Dec. 2016).

[69] Including Hektor, B., Backéus, S. and Andersson, K. (2016), ‘Carbon balance for wood production from sustainably managed forests’; Jonker J. G. G., Junginger, M. and Faaij, A. (2014), ‘Carbon payback period and carbon offset parity point of wood pellet production in the South-eastern United States’.

[70] See, for example, Strange Olesen, A. et al. (2015), *Environmental Implications of Increased Reliance of the EU on Biomass from the South East US*, pp. 127–31.

[71] ‘Carbon debt’ is not a precise term. It is sometimes used instead to refer to the period it takes for growing trees to recapture the emissions released from an equivalent amount of carbon. The meaning used here is taken from Mitchell, S. R., Harmon, M. E. and O’Connell, K. E. B. (2012), ‘Carbon debt and carbon sequestration parity in forest bioenergy production’, *GCB Bioenergy,* 4:6, DOI: 10.1111/j.1757-1707.2012.01173.x (accessed 27 Dec. 2016).

[72] For an overview of many of these factors, see Agostini, A., Giuntoli, J. and Boulamanti, A. (2013), *Carbon accounting of forest bioenergy.*

Following the discussion earlier, the carbon payback period for mill residues can be assumed to be very low as no additional felling is involved. If the residues would otherwise have been burnt as waste the payback period may be zero. The carbon payback period for forest residues is more complex, depending on the rate at which they would decay if left to rot in the forest, and on the impacts on forest growth of the removal of residues; but again no additional felling is involved. In neither case is there any additional regrowth of forests; the carbon debt is repaid over time from the lower emissions from the residues not being burnt as waste or decaying.

Since the burning of roundwood in general represents the removal of growing forest carbon stock, the carbon payback period will be longer as it includes the foregone future absorption of carbon emissions. This is particularly the case in forest systems with relatively slow growth rates – such as hardwoods, common in the southeastern US – and will also vary depending on the age of the trees, whether they are natural growth or plantations and the extent to which the forest has been managed before the harvest.[73] As discussed above, harvesting may also release significant volumes of soil carbon.[74]

If wood is diverted from alternative uses, such as construction or wood panels or paper, the carbon payback period may be very high as carbon can be fixed in some of these products for decades – though, as discussed above, there is little evidence of this taking place so far.

Many attempts have been made to estimate average payback periods.[75] Eight different studies carried out between 2009 and 2012 in Europe and North America, summarized in a 2012 report, produced estimated payback periods between zero (for the use of fellings residues to replace coal for electricity) to 459 years (for the use of wood from old-growth forests to produce ethanol for transport fuel).[76] The scenarios using residues, branches, thinnings or stumps all showed payback periods between zero and 74 years, with most less than 25 years. Where old-growth or second-growth trees were assumed to be used, the payback period was much longer.

Similarly, a 2013 survey of studies of the replacement of fossil fuel-generated electricity reported payback periods between zero and 400 years.[77] The use of residues and slash saw payback periods between zero and 44 years, with the lowest periods for the replacement of coal and the highest for natural gas. The lowest payback periods for the use of roundwood was between zero and 105 years in the case of additional fellings in previously unmanaged forests, or 12–46 years for the use of thinnings and additional fellings from existing plantations with a 20–25 year rotation, in each case replacing coal. A 2014 study found some greenhouse gas benefits from the use of forest residues with payback periods up to 25 years, while the use of whole trees, whether from thinnings, reduced-impact logging or short-rotation forestry, saw little or no savings over 50 years.[78]

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[73] Gunn, J. S., Ganz, D. V. and Keeton, W S. (2012), 'Biogenic vs. geologic carbon emissions and forest biomass energy production', *GCB Bioenergy,* 4:3, DOI: 10.1111/j.1757-1707.2011.01127.x (accessed 27 Dec. 2016).

[74] Buchholz T. et al. (2014), 'Mineral soil carbon fluxes in forests and implications for carbon balance assessments'.

[75] See, for example, Walker, T. et al. (2010), *Biomass Sustainability and Carbon Policy Study,* Brunswick, ME: Manomet Center for Conservation Sciences, http://www.mass.gov/eea/docs/doer/renewables/biomass/manomet-biomass-report-full-hirez.pdf (accessed 27 Dec. 2016); Searchinger, T. (2012), 'Global Consequences of the Bioenergy Greenhouse Gas Accounting Error', in Inderwildi, O. and King, D. (eds) (2012), *Energy, Transport and the Environment,* London: Springer-Verlag; and Bowyer, C. et al. (2012), *The GHG Emissions Intensity of Bioenergy: Does bioenergy have a role to play in reducing Europe's GHG emissions?,* London: Institute for European Environmental Policy, http://www.ieep.eu/assets/1008/IEEP_-_The_GHG_Emissions_Intensity_of_Bioenergy_-_October_2012.pdf (accessed 27 Dec. 2016).

[76] See Agostini, A., Giuntoli, J. and Boulamanti, A. (2013), *Carbon accounting of forest bioenergy*, pp. 43–44.

[77] Lamers, P. and Junginger, M. (2013), 'The "debt" is in the detail'.

[78] Baral, A. and Malins, C. (2014), *Comprehensive Carbon Accounting for Identification of Sustainable Biomass Feedstocks,* Washington, DC: International Council on Clean Transportation, http://www.theicct.org/sites/default/files/publications/ICCT_carbonaccounting-biomass_20140123.pdf (accessed 27 Dec. 2016).

In 2014 the UK Department of Energy and Climate Change published a comprehensive assessment of the climate impacts of imports of biomass from the US (the main source of woody biomass for UK consumption) – the Bioenergy Emissions and Counterfactuals (BEaC) calculator.[79] Of the 29 scenarios analysed, those that involved utilizing residues that would otherwise have been burnt as waste, or newly established tree plantations on low-carbon land resulted in low net carbon emissions and short payback periods. In contrast, scenarios that involved harvesting additional roundwood from naturally growing forests or converting forests into plantations resulted in high or very high emissions (depending on the rotation length and hence carbon stocks of the forests and plantations). Of the 29 scenarios, 11 resulted in net emissions higher than using natural gas, and five of those had net emissions higher than using coal. For some types of biomass, such as additional fellings in already managed forests, the carbon payback period was many decades, perhaps even centuries.

The BEaC report was criticized by industry. For example, a spokesperson for Drax claimed that the model was 'not a very accurate way of estimating carbon changes in forests and its scenarios were "hypothetical"'.[80] In 2015 the Department of Energy and Climate Change commissioned a further study, including an assessment of the likelihood of the high-emission scenarios, an analysis of the factors determining harvest rates as well as consideration of whether harvest rotation lengths had changed in response to the demand for biomass, whether UK demand for biomass could divert pulpwood, thinnings or sawmill residues from other users, and whether whole trees were used in pellet manufacture and if so, the carbon stock impacts.[81] At the time of publication the report is still awaited.

> The evidence suggests that mature trees continue to absorb carbon (at least in old-growth forests) and that harvesting not only removes mature trees, thus substantially reducing total carbon uptake, but in the short term also increases carbon losses from soil disturbance.

The concepts of carbon debt and carbon payback have proved helpful in focusing attention on the range of factors that influence their magnitudes, and therefore the impact of different types of biomass feedstock on the climate. The approach is not, however, without its problems. It depends partly on the hypothesis that the higher levels of carbon emitted from burning woody biomass are compensated over time by faster growth of the forest from which it is sourced. This implictly accepts the argument that mature forests do not absorb carbon, and that harvesting and replacing old (carbon-neutral) trees with young (carbon-absorbing) trees increases the rate of carbon uptake in the forest, thereby offsetting the biomass-related emissions.

This is an essential part of the approach: if carbon absorption carries on at the same (or a lower) rate after harvesting as before, the carbon debt cannot be repaid. As discussed above, however, the evidence suggests that mature trees continue to absorb carbon (at least in old-growth forests) and that harvesting not only removes mature trees, thus substantially reducing total carbon uptake, but in the short term also increases carbon losses from soil disturbance. If this is correct, harvesting biomass for energy permanently reduces the rate of carbon uptake: the carbon debt can never be paid back

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[79] Stephenson, A. and Mackay, D. (2014), *Life Cycle Impacts of Biomass Electricity in 2020: Scenarios for Assessing the Greenhouse Gas Impacts and Energy Input Requirements of Using North American Woody Biomass for Electricity Generation in the UK*, London: Department of Energy and Climate Change, https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/349024/BEAC_Report_290814.pdf (accessed 27 Dec. 2016).
[80] Quoted in Evans, S. (2015), 'Investigation: Does the UK's biomass burning help solve climate change?'.
[81] Ibid.

and the carbon payback period is infinite. At the very least, if forest carbon uptake eventually stops (after perhaps 800 years, according to one of the studies cited above), the carbon payback period is extremely long. This may not be the case in plantations, where carbon absorption does appear to plateau, but the disturbance caused by harvesting, plus the fact the young trees absorb far less carbon than older trees, suggest long payback periods even there.

The carbon payback period and climate targets

Despite these reservations, the carbon payback approach has gained relatively wide acceptance (including in the impact assessment published by the European Commission to accompany the new draft Renewable Energy Directive in November 2016 – see further in Chapter 3). So how much does the length of the carbon payback period matter? Payback periods in the hundreds of years will counteract efforts to limit climate change over any reasonable timeframe, but what is a suitable time horizon over which to measure the impact?

Opinions on this question vary. One study considers 2050 to be an appropriate reference point, since energy systems (fossil and bioenergy) have lifetimes of typically 20 to 30 years. Of the scenarios it surveyed, only the use of residues that would otherwise have been burnt as waste or left to decay, replacing coal or oil-fired electricity (not gas), had payback period ranges falling wholly before 2050. Some of the roundwood scenarios would fall before 2050 only at the bottom end of their estimated payback ranges.

Some analysts prefer longer time horizons. A 2016 study looking at Swedish forests chose a 100-year time horizon, mirroring the Swedish Forests Agency's 100-year forest impact assessments.[82]

Other studies prefer not to specify any particular timeframe. A 2014 one drew attention to the IPCC's conclusion that it is cumulative greenhouse gas emissions that matter, not the timeframe within which these emissions are released: 'The concept of cumulative carbon also implies that higher initial emissions can be compensated by a faster decline in emissions later or by negative emissions.'[83] For carbon dioxide, the longest-lived of the greenhouse gases, it was cumulative emissions over the entire century that 'to a first approximation determine the CO_2 concentration at the end of the century, and therefore no individual year's emissions are critical'.[84] The study concluded that it is more important, therefore, to avoid lock-in of high-carbon technologies and infrastructure – such as coal – than to worry about short-term or even medium-term increases in carbon emissions, particularly if there could later be a carbon dividend from the use of biomass energy.

There are two main reasons, however, for thinking that short-term increases in carbon emissions matter. First, there is increasing concern over the possible existence of 'climate tipping points', when global temperature rise triggers a possibly irreversible change in the global climate from one stable state to another at a higher temperature. Examples include boreal forest dieback, Amazon rainforest dieback, the loss of Arctic and Antarctic sea ice and the melting of the Greenland and Antarctic ice sheets, disruption to the Indian and West African monsoon, and the loss of permafrost leading to potential Arctic methane release.[85] Although in 2013 the IPCC concluded that there was as yet

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[82] Gustavsson, L. et al. (2017), 'Climate change effects of forestry and substitution of carbon-intensive materials and fossil fuels', *Renewable & Sustainable Energy Reviews*, 67, http://dx.doi.org/10.1016/j.rser.2016.09.056 (accessed 27 Dec. 2016).
[83] Miner, R. A. et al. (2014), 'Forest Carbon Accounting Considerations in US Bioenergy Policy'.
[84] Ibid.
[85] See, for example, Lenton, T. M. et al. (2008), 'Tipping Points in the Earth's Climate System', *Proceedings of the National Academy of Science*, 105:6, DOI: 10.1073/pnas.0705414105 (accessed 27 Dec. 2016).

no evidence for global-scale tipping points (though there was possibly evidence for regional-scale tipping points, particularly in the Arctic),[86] more recent studies have contested this, concluding that the probability is much higher than previously thought.[87] If this is true, the risks of increasing carbon emissions in the short or medium term are accordingly higher than considered by the IPCC in 2013.

The second reason is the global climate targets adopted at the Paris climate conference in 2015, which committed signatory countries to hold 'the increase in the global average temperature to well below 2°C above pre-industrial levels and to pursue efforts to limit the temperature increase to 1.5°C above pre-industrial levels'.[88] The IPCC is scheduled to produce a special report on the implications of the 1.5°C target in 2018, but preliminary analyses suggest that achieving this target may require emissions levels to peak very soon, perhaps as early as 2020, and then fall – though there is still considerable uncertainty over this, and longer timescales for peaking emissions have also been suggested.[89] Achieving the 1.5°C target is therefore likely to limit the use of biomass for energy to the shortest carbon payback periods.

Bioenergy with carbon capture and storage

Bioenergy with carbon capture and storage (BECCS) is a technology – as yet unproven – in which the carbon emissions from the burning of biomass for energy are captured before release into the atmosphere and permanently stored, thus removing them from the atmosphere and preventing their contribution to global warming. If it is assumed that biomass energy is carbon-neutral, BECCS generates negative carbon emissions.

The concept of BECCS emerged in the late 1990s and early 2000s.[90] In 2007, the IPCC identified BECCS as a potential option for stabilizing emissions or as a rapid-response prevention strategy for abrupt climate change. It cautioned, however, that:

> To date, detailed analysis of large-scale biomass conversion with CO_2 capture and storage is scarce… further research is necessary to characterise biomass's long-term mitigation potential… and opportunity costs… In particular, present studies are relatively poor in representing land competition with food supply and timber production, which has a significant influence on the economic potential of bio-energy crops.[91]

In 2011 a study published by the IEA reviewed the potential of BECCS in different forms, including dedicated biomass stations with CCS, co-firing with coal with CCS and liquid biofuel production with CCS.[92] It concluded that the technical potential existed for negative greenhouse gas emissions of up to 10 $GtCO_2$-eq annually (in comparison, total global emissions in 2012 were about 43 $GtCO_2$-eq), the

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[86] Miner, R. A. et al. (2014), 'Forest Carbon Accounting Considerations in US Bioenergy Policy'.

[87] See, for example, Drijfhout, S. et al. (2015), 'Catalogue of abrupt shifts in Intergovernmental Panel on Climate Change climate models', *Proceedings of the National Academy of Science*, 112:43, DOI: 10.1073/pnas.1511451112 (accessed 27 Dec. 2016); Cai, Y., Lenton, T. M. and Lontzek, T. S. (2016), 'Risk of multiple interacting tipping points should encourage rapid CO_2 emission reduction', *Nature Climate Change*, 6, DOI:10.1038/nclimate2964 (accessed 27 Dec. 2016).

[88] Paris Agreement, Article 2 (1) (a), https://unfccc.int/files/meetings/paris_nov_2015/application/pdf/paris_agreement_english_.pdf.

[89] See, for example, Carbon Brief (2016), 'Analysis: Only five years left before 1.5C carbon budget is blown', 19 May 2016, https://www.carbonbrief.org/analysis-only-five-years-left-before-one-point-five-c-budget-is-blown (accessed 27 Dec. 2016); Hare, B. (2016), 'No time to lose: the 1.5°C limit in the Paris Agreement', Berlin: Climate Analytics, 10 August 2016, http://climateanalytics.org/blog/2016/the-1-5c-limit-in-the-paris-agreement-why-there-is-no-time-to-lose.html (accessed 27 Dec. 2016); Carbon Brief (2016), 'Highlights: Day two at the 1.5C conference on climate change in Oxford' 22 September 2016, https://www.carbonbrief.org/day-two-at-the-1-5-c-conference-on-climate-change-in-oxford (accessed 27 Dec. 2016).

[90] See Hickman, L. (2016), 'Timeline: How BECCS became climate change's "saviour" technology', Carbon Brief, 13 April 2016, https://www.carbonbrief.org/beccs-the-story-of-climate-changes-saviour-technology (accessed 28 Dec. 2016).

[91] IPCC (2007), *Climate Change 2007: Mitigation of Climate Change,* Cambridge: Cambridge University Press, p. 211, https://www.ipcc.ch/pdf/assessment-report/ar4/wg3/ar4_wg3_full_report.pdf (accessed 28 Dec. 2016).

[92] Ecofys (2011), *Potential for Biomass and Carbon Dioxide Capture and Storage,* Paris: International Energy Agency, http://www.eenews.net/assets/2011/08/04/document_cw_01.pdf (accessed 28 Dec. 2016).

largest reductions coming from dedicated biomass power generation with CCS. The report identified the immaturity of the technology, uncertainty over the availability of sustainable biomass supply and secure and permanent carbon dioxide storage, and negative public perceptions (local opposition to CCS projects) as important barriers, though it considered that the association of CCS with biomass, as a renewable energy technology, could help overcome public resistance.

In 2014 the IPCC was more positive about the potential for BECCS than in its previous assessment report. Of the 116 scenarios it reviewed aiming to achieve stabilization of carbon at 430–480 parts per million (the level considered necessary to limit global warming to 2°C), 101 involved some form of negative emissions – either through BECCS or afforestation. Every scenario aiming to limit global warming to 1.5°C included BECCS.[93] The IPCC viewed BECCS as necessary in particular to compensate for residual emissions from sectors where mitigation was more expensive, or to return to the target emissions level after an overshoot. The synthesis report concluded that: ‘Many models could not limit *likely* warming to below 2°C if bioenergy, CCS, and their combination (BECCS) are limited (*high confidence*).’[94] Similarly, the full mitigation report observed that ‘CDR [carbon dioxide removal] technologies such as BECCS are fundamental to many scenarios that achieve low-CO_2-eq concentrations, particularly those based on substantial overshoot as might occur if near-term mitigation is delayed’.[95]

Overall, models reported by the IPCC estimated that the global technical potential for BECCS varied from three to more than 10 $GtCO_2$/year, while cost estimates ranged from around $60 to $250/tonne CO_2. Important limiting factors included land availability, a sustainable supply of biomass and storage capacity, and possible competition for biomass from other uses of bioenergy. The IPCC cautioned that:

> The potential role of BECCS will be influenced by the sustainable supply of large-scale biomass feedstock and feasibility of capture, transport, and long-term underground storage of CO_2 as well as the perceptions of these issues. The use of BECCS faces large challenges in financing, and currently no such plants have been built and tested at scale.[96]

As of the autumn of 2016, only one commercial BECCS project was under way: Archer Daniels Midland’s corn ethanol plant in Decatur, Illinois, in the US.[97] During its pilot phase in 2011–14 the plant sequestered one million tonnes of carbon dioxide from fermenting corn, which was injected into local porous sandstone formations lying beneath three layers of dense shale. With US government funding, the next phase (which was due to start in late 2016) aims to capture and store 2.26 million tonnes over two and half years. However, given the emissions produced from the energy needed to run the plant as well as to capture and store the carbon emissions, plus the carbon emitted when the ethanol itself is burnt, it is not clear whether the plant has in fact produced negative emissions. In addition, one of the aims of the project is to use some of the captured carbon dioxide for enhanced oil recovery, increasing the financial returns but further contributing to greenhouse gas emissions. Abengoa’s ethanol plant in Rotterdam in the Netherlands has been capturing carbon dioxide since 2011 (about 100,000 tonnes a year), but this is used in nearby greenhouses rather than stored.[98]

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[93] IPCC (2014), *Climate Change 2014: Mitigation of Climate Change.* Also see Fuss, S. (2016), ‘The role of BECCS in climate change mitigation: potentials and limits’, presentation to IEA BECCS Specialist Meeting, London, 23 June 2016.

[94] IPCC (2015), *Climate Change 2014: Synthesis Report,* Geneva: IPCC, p. 97, https://www.ipcc.ch/pdf/assessment-report/ar5/syr/SYR_AR5_FINAL_full_wcover.pdf (accessed 28 Dec. 2016).

[95] IPCC (2014), *Climate Change 2014: Mitigation of Climate Change,* Cambridge: Cambridge University Press, p. 480.

[96] Ibid., pp. 485–86.

[97] See Carbon Brief (2016), ‘Analysis: Negative emissions tested at world’s first major BECCS facility’, 31 May 2016, https://www.carbonbrief.org/analysis-negative-emissions-tested-worlds-first-major-beccs-facility (accessed 28 Dec. 2016).

[98] Kemper, J. (2016), ‘Status of biomass with carbon capture and storage (BECCS/Bio-CCS)’, presentation to IEA BECCS Specialist Meeting, London, 23 June 2016.

Overall, there are three main problems with the vision of BECCS as a major contributor to negative emissions.

First, as discussed above, the burning of biomass is not necessarily carbon-neutral at the point of combustion or even over the short or medium term – although, as discussed, it may be over the longer term depending on the carbon payback period. The surveys and models of the potential for BECCS, including those reviewed by the IPCC, simply assume that all bioenergy is carbon-neutral (provided that basic sustainability standards are in place, e.g. no conversion of forests to bioenergy crops). A 2015 survey was unable to find a single study that had calculated the potential for negative emissions based on any type of life-cycle greenhouse gas assessment that could have taken into account changes in the forest carbon stock as a result of harvesting for bioenergy.[99] The IPCC in 2014 acknowledged the potential for significant emissions from land-use change and increased nitrous oxide emissions from greater fertilizer use, but did not consider any of the wider factors discussed above.[100] In reality, since BECCS assumes that forests are planted specifically for use as energy, carbon payback periods are likely to be at the higher end of those discussed above, though it can be assumed that much of the new forest would be fast-growing softwood plantations, for which the carbon payback period is rather lower (depending partly on what the forest replaced).

> The technology has proved more expensive and less effective than originally expected and, as in other areas, the falling prices of renewable energy technologies, particularly solar PV and wind, have undercut the appeal of CCS as a low-carbon option and accelerated the complete phase-out of coal.

Second, CCS technology is proving more difficult to commercialize and deploy than originally predicted. By the spring of 2016, there were 15 large-scale CCS projects in operation worldwide, capturing 28 million tonnes of carbon dioxide a year. By the end of 2017, this was projected to increase to 22 projects capturing about 40 million tonnes a year.[101] While significant, this is far off the trajectory needed to satisfy the IEA's 2015 prediction that CCS would capture two billion tonnes a year by 2030. Furthermore, most of the projects currently operating are producing carbon dioxide for enhanced oil recovery rather than permanent storage. In general, the technology has proved more expensive and less effective than originally expected and, as in other areas, the falling prices of renewable energy technologies, particularly solar PV and wind, have undercut the appeal of CCS as a low-carbon option and accelerated the complete phase-out of coal, thus removing one of the sources of fossil fuels CCS was intended to operate alongside. CCS equipment can be fitted to gas-fired power plants and industrial processes, but the benefits in terms of reducing carbon emissions are lower, and therefore the cost per tonne of carbon captured is higher. Further technological development can be expected, but it is difficult not to conclude that the current speed of development and deployment of CCS is too low to justify the reliance placed on BECCS by the IPCC.

Third, as noted by the IPCC and others, the availability of land for bioenergy is a limiting factor. The highest estimates of BECCS assume that 15–18 $GtCO_2$ could be removed per year, with energy production of 200–400 EJ per year. This comprises 80–100 EJ/year from the by-products of

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[99] Ernsting, A. and Munnion, O. (2015), *Last-ditch Climate Option or Wishful Thinking? Bioenergy with carbon capture and storage,* Biofuelwatch, http://www.biofuelwatch.org.uk/wp-content/uploads/BECCS-report-web.pdf [Accessed 28 Dec. 2016).

[100] IPCC (2014), *Climate Change 2014.*

[101] Global CCS Institute (undated), 'Large Scale CCS Projects', http://www.globalccsinstitute.com/projects/large-scale-ccs-projects.

agriculture and forest industries, and the remaining 180–300 EJ/year from dedicated energy crops.[102] (These are very large quantities; in comparison, world energy production was roughly 575 EJ in total in 2014.)[103] A review in 2015 calculated that production of 100 EJ/year could require up to 500 million hectares of land (assuming an average biomass yield of 10 tonnes of dry biomass per hectare annually). The top end of the projections for BECCS would therefore require two billion hectares – an area greater than the total global land area currently planted with agricultural crops (about 1.5 billion hectares in 2015) and about half the total global forest area (about 4 billion hectares).[104] Scenarios like this also tend to assume radical changes in behaviour, including a major shift away from eating meat (releasing much of the land currently used for pasture, about 3.4 billion hectares), together with rapid increases in food yields (sufficient to meet global food demand, which is projected to double over the next 50 years). Neither of these developments seems at all likely.

Another study that focused on using switchgrass for feedstock estimated that 200 million hectares (about half the total cropland of the US) would be needed to remove 3.7 $GtCO_2$ per year (about one-fifth of the volume estimated in the highest projections for BECCS).[105] The process would also consume 20 per cent of global fertilizer production and require 4,000 km^3/year of water, equal to current global water withdrawals for irrigation.

For all these reasons, the prospects for the development of BECCS at scale seem highly unlikely; and, in any case, its impacts on the climate would not necessarily be positive in the short term. The reliance on BECCS of so many of the climate-mitigation scenarios reviewed by the IPCC is of major concern, potentially distracting attention from other mitigation options and encouraging decision-makers to lock themselves into high-carbon options in the short term on the assumption that the emissions thus generated can be compensated for in the long term.[106]

Conclusions and recommendations

Changes in the forest carbon stock must be fully accounted for in assessing the climate impact of the use of woody biomass for energy. It is not valid to claim that because trees absorb carbon as they grow, the emissions from burning them can be ignored. This is true whether or not the forest from which the biomass is sourced is sustainably managed, or whether it is growing in size, or whether forests as a whole are expanding. All these approaches either treat what happens to the trees after they are harvested as irrelevant, or ignore the carbon sequestration forgone when the trees are harvested, or both. As the European Commission Joint Research Centre concluded:

> in order to assess the climate change mitigation potential of forest bioenergy pathways, the assumption of biogenic carbon neutrality is not valid under policy relevant time horizons (in particular for dedicated harvest of stemwood for bioenergy only) if carbon stock changes in the forest are not accounted for.[107]

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[102] US National Research Council (2015), *Climate Intervention: Carbon Dioxide Removal and Reliable Sequestration,* p. 54, Washington, DC: National Academies Press, http://dels.nas.edu/resources/static-assets/materials-based-on-reports/reports-in-brief/climate-intervention-brief-final.pdf (accessed 28 Dec. 2016).

[103] IEA (2016), *Key World Energy Trends 2016,* Paris: IEA, https://www.iea.org/publications/freepublications/publication/KeyWorldEnergyTrends.pdf (accessed 28 Dec. 2016).

[104] Food and Agriculture Organization United Nations (FAO) (2016), *State of the World's Forests 2016, Forests and agriculture: land-use challenges and opportunities,* Rome: FAO, http://www.fao.org/3/a-i5588e.pdf (accessed 28 Dec. 2016).

[105] Reviewed in US National Research Council (2015), *Climate Intervention.*

[106] See also Anderson, K. and Peters, G. (2016), 'The trouble with negative emissions', *Science,* 14 October 2016, DOI: 10.1126/science.aah4567 (accessed 28 Dec. 2016).

[107] Agostini, A., Giuntoli, J. and Boulamanti, A. (2013), *Carbon accounting of forest bioenergy*, p. 77.

Along with changes in forest carbon stock, a full analysis of the impact on the climate of using woody biomass for energy needs to take into account the emissions from combustion (which are generally higher than those for fossil fuels) and the supply-chain emissions from harvesting, collection, processing and transport. There is still some uncertainty over some of these factors, including levels of supply-chain emissions, the impact on soil carbon and tree growth of using forest residues, and levels of methane emissions produced during the storage of wood pellets and wood chips. The rate of carbon absorption by mature trees is routinely ignored by many of the models used to predict climate impacts. More research into all these issues would be helpful.

There is also uncertainty over market dynamics. While it may be the case that the growth of the woody biomass industry could lead to greater investment in forests, and therefore a higher rate of tree planting, which can help to offset higher emissions from combustion, the evidence for this happening is so far largely lacking. In any case, the models that predict this often assume that old-growth forests are replaced by fast-growing plantations, which in itself leads to higher carbon emissions, together with negative impacts on biodiversity.

Notwithstanding all this, harvesting of whole trees for energy will in almost all circumstances increase net carbon emissions very substantially compared to using fossil fuels, because of the loss of future carbon sequestration from the growing trees and because of the loss of soil carbon consequent upon the disturbance. This is particularly true for mature trees in old-growth forests, whose rate of carbon absorption can be very high.

The use of sawmill residues for energy has lower impacts, because it involves no additional harvesting as it is waste from other wood industry operations. The impact will be most positive for the climate if they are burnt on-site for energy without any associated transport or processing emissions. However, mill residues can also be used for wood products such as particleboard; if diverted instead to energy, this will raise carbon concentrations in the atmosphere. The current high levels of use of mill residues mean that this source is unlikely to provide much additional feedstock for the biomass energy industry in the future (or, if it does, it will be at the expense of other wood-based industries). Black liquor, a waste from the pulp and paper industry, can also be burnt on-site for energy and has no other use; in many ways it is the ideal feedstock for biomass energy.

The use of forest residues for energy also implies no additional harvesting, so its impacts on net carbon emissions can be low. This depends mainly on the rate at which the residues would decay and release carbon if left in the forest, which can vary substantially. If slow-decaying residues are burnt, the impact would be an increase in net carbon emissions, potentially for decades. In addition, removing residues from the forest can adversely affect soil carbon and nutrient levels as well as tree growth rates.

The carbon payback approach argues that, while they are higher than using fossil fuels, carbon emissions from burning woody biomass can be absorbed by forest regrowth. The time this takes – the carbon payback period before which carbon emissions return to the level they would have been at if fossil fuels had been used – is of crucial importance. There are problems with this approach, but it does help to highlight the range of factors that affect the impact of biomass, and focuses attention on the very long payback periods of some feedstocks, particularly whole trees, which is a matter of considerable concern given the potential existence of climate tipping points and the near-term targets for carbon emission reductions agreed in Paris in 2015.

For all these reasons, the provision of financial or regulatory support to biomass energy on the grounds of its contribution to mitigating climate change needs to be strictly controlled. Only those feedstocks that reduce carbon emissions over the short term should be eligible. This topic is considered further in Chapter 3.

Finally, while interest is growing in BECCS, its future development at scale seems highly unlikely, given the slow rate of commercialization of CCS technology and likely limits on the availability of land. In addition, the studies of options for BECCS almost always assume that biomass is zero-carbon at the point of combustion – which, as argued above, is not a valid assumption. The reliance on BECCS of so many of the climate-mitigation scenarios reviewed by the IPCC is, accordingly, of major concern, potentially distracting attention from other mitigation options and encouraging decision-makers to lock themselves into high-carbon options in the short term on the assumption that the emissions thus generated can be compensated for in the long term.

2. Accounting for Biomass Carbon Emissions

This chapter examines the way in which biomass is treated as carbon-neutral at the point of combustion because it is assumed that its emissions are accounted for in the land-use sector, and not in the energy sector, under international rules for greenhouse gas emissions. The following issues are discussed:

- Reporting and accounting rules for biomass under the UNFCCC and Kyoto Protocol, and the impact of parties' choice of forest-management reference levels.
- An analysis of the different ways in which biomass energy emissions can go unaccounted for, or 'missing'.
- A summary of the forest-management reference levels adopted by Annex I parties to the UNFCCC, and the levels of emissions from the use of solid biomass for energy.
- National case studies of the UK, the US, Finland and France, identifying where biomass emissions may go unaccounted for.

Reporting and accounting

This treatment is essentially an artefact of the approach taken by the Intergovernmental Panel on Climate Change (IPCC) to greenhouse gas reporting and accounting. Greenhouse gas *reporting* under the UN Framework Convention on Climate Change (UNFCCC) is the process of estimating and compiling national emissions data in order to describe the amounts of, and trends in, countries' emissions. *Accounting*, by contrast, involves applying a set of predetermined rules and conventions to reported data so as to assess countries' progress towards their national emissions targets under the Kyoto Protocol (or any other climate regime with targets).[108] While reporting is a necessary precursor to accounting under the UNFCCC, the two processes are distinct. Not all emissions included in a country's greenhouse gas *reports* will necessarily be reflected in its greenhouse gas *accounts*.

In principle the changes in carbon emissions resulting from the harvesting of woody biomass and its burning for energy could be reported in either the land-use sector, at the point of harvesting and removal from the forest, or in the energy sector, at the point of combustion. In order to ensure consistency and avoid double-counting, the IPCC determined that countries should report emissions from biomass combustion only in their land-use sectors. It is this categorization of emissions that has led many policymakers to perceive biomass as a carbon-neutral energy source (although this was not the IPCC's intention).

The IPCC's approach is logical in the context of greenhouse gas *reporting*, for which countries estimate and report emissions from all sectors. However, problems start to arise when countries *account* for changes in their greenhouse gas emissions against their national targets under the Kyoto Protocol. Accounting for emissions from the land-use sector has always been a complex issue as,

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[108] Canaveira, P. (2014), *Options and Elements for an Accounting Framework for the Land Sector in the Post-2020 Climate Regime*, Lisbon: Terraprima, www.terraprima.pt/pt/file_download/172 (accessed 28 Dec. 2016).

unlike other ones, this sector is subject to significant natural variation in emissions levels as a result of climatic impacts on growth as well as of fires, insect infestations and diseases. There has been considerable debate over how to account for the associated emissions, leading to specific sets of rules for land use, land-use change and forestry, which have been applied at a different pace than the rules for emissions accounting in other sectors. Problems can arise when a country does not account for land-use sector emissions at all, or accounts for them only incompletely, or accounts for its land-use and energy sectors using different benchmarks.

Accounting in the Kyoto Protocol's first commitment period

In the first commitment period of the Kyoto Protocol (2008–12), UNFCCC Annex I parties (essentially, developed countries) could choose whether or not to account at all for emissions from forest-management activities.[109] Of the 38 parties to the protocol, 24 chose to include forest-management emissions; the land-use sector accounts of those 24 parties therefore at least partially reflected changes in emissions attributable to the use of forest biomass for energy. Emissions associated with forest-based bioenergy were not reflected anywhere in the accounts of the other 14 parties.

It is possible, however, to calculate the total volume of biomass-related emissions, as under the UNFCCC, Annex I countries are requested to report carbon dioxide emissions from biomass used for energy as a separate line item (referred to as a 'memo item') in their greenhouse gas inventories. As noted, these are not included in the total reported emissions for the energy sector, as it is assumed they are reflected in the land-use emissions inventory.[110] Over the five years of the first commitment period, carbon dioxide emissions from biomass energy use in Annex I countries totalled approximately 4.16 Gt. This figure includes emissions from solid, liquid and gaseous biomass used for energy in all sectors of the economy – solid biomass includes wood and wood waste, black liquor, other primary solid biomass (such as municipal solid waste) and charcoal. The proportion of total biomass energy emissions attributable to solid biomass varied widely between countries, from 0 per cent to 100 per cent; on average it comprised approximately 78 per cent of all biomass energy emissions in 2012.

Accounting in the Kyoto Protocol's second commitment period

For the Kyoto Protocol's second commitment period (2013–20), parties agreed to adopt mandatory accounting of emissions from forest management. Parties were permitted to choose the reference level of emissions against which they accounted for changes, subject to agreed parameters and processes. This is different from how changes in emissions in the energy and other sectors are assessed, which is against a historical baseline of emissions in 1990. Of the 37 parties that adopted targets for the protocol's second commitment period, 32 chose to account for changes in forest-management emissions against a business-as-usual baseline and three chose a historical baseline; the other two did not submit a forest-management reference level.

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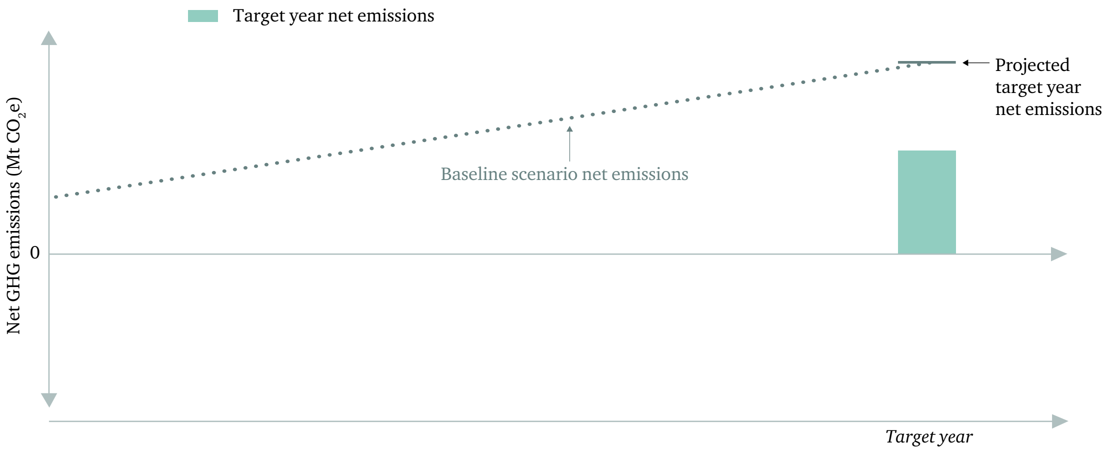
[109] This analysis focuses on Annex I countries, countries the UNFCCC classifies as 'developed', because: (1) these countries are more likely to have in place national policies encouraging the use of biomass for energy, and (2) these countries are required to submit annual greenhouse gas inventories including information on emissions from biomass energy.

[110] Non-CO_2 greenhouse gas emissions from burning biomass (e.g. methane) for energy *are* reported in the energy sector, as they do not exist in the land-use sector.

A business-as-usual baseline is expressed as average annual forest-management emissions projected over the second commitment period (see Figure 3).

Figure 3: Business-as-usual accounting in the land-use sector



Source: World Resources Institute (2014), *Greenhouse Gas Protocol Mitigation Goal Standard: An accounting and reporting standard for national and subnational greenhouse gas reduction goals,* p. 82, https://www.wri.org/sites/default/files/Mitigation_Goal_Standard.pdf.

Parties choosing a business-as-usual baseline generally did so in order to minimize the potential for non-anthropogenic and/or non-additional emissions entering their national greenhouse gas accounts. However, in practice, using this baseline also allows a country to avoid accounting for a portion of emissions from biomass energy use (and other forest-management practices).

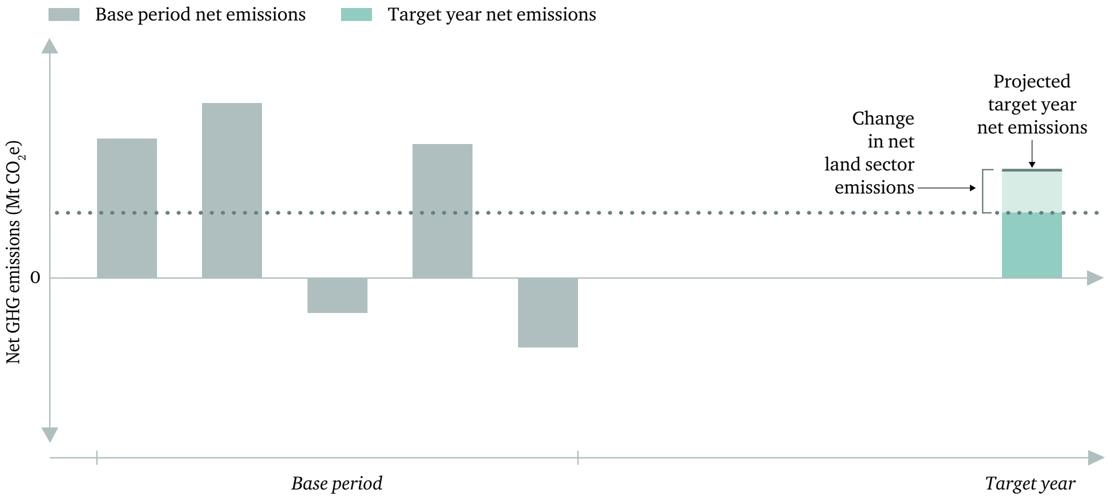
A business-as-usual baseline accounts for forest management relative to a *projection* – a prediction of net emissions over the commitment period. This projection may include anticipated levels of harvesting of forest biomass for energy. If so, the associated emissions will not count towards the country's emissions target since they are already included in the baseline. (This is as long as the emissions are in line with the projection; if they are higher, then the difference between actual and projected emissions will be counted.) Only where a country does *not* include anticipated emissions from biomass energy in its business-as-usual baseline will it count *all* such emissions against its target.

This explanation assumes that all other emissions included in a business-as-usual reference level occur as projected. Accounting in the land-use sector does not differentiate between sources of emissions – for example, between emissions from forest biomass harvested for energy and emissions from harvests for wood pulp. It is therefore possible that increases in emissions from biomass energy could be balanced by falls in emissions from other activities. In this situation, a country would be able to register zero emissions in its account even though emissions from forest-based biomass energy were higher than predicted. The analysis below assumes that all non-bioenergy emissions occur as predicted in the business-as-usual projection, in order to highlight the impacts of forest-based biomass energy use on accounting.

The forest-management guidance for the Kyoto Protocol's second commitment period specifies that countries should not include the effects of policies adopted and implemented after 31 December 2009 in their reference levels. Thus, countries using business-as-usual baselines *will* count emissions attributable to post-2009 policies, including those promoting the use of forest-based bioenergy, against their emissions targets. Parties must also account for the effects of any changes to pre-2010 policies implemented after 2009. Policies adopted and implemented prior to 2010 may be included in the reference level, though EU member states have agreed not to include policies stemming from the implementation of the 2009 EU Renewable Energy Directive.

Countries choosing to use a historical baseline, rather than a business-as-usual one, account against their forest-management emissions in 1990 (in line with accounting for other sectors) or their average annual emissions over a historical period, e.g. 1990–2009 (see Figure 4). Parties may have opted to use a historical baseline to maintain continuity with past accounting practices or to maintain consistency with accounting in other sectors. Emissions levels from a historical baseline are also easier to determine. Depending on the circumstances, the level of historical emissions may in fact be the most accurate predictor of future emissions.

Figure 4: Historical base year/base period accounting in the land-use sector



Source: World Resources Institute (2014), *Greenhouse Gas Protocol Mitigation Goal Standard: An accounting and reporting standard for national and subnational greenhouse gas reduction goals, p. 81,* https://www.wri.org/sites/default/files/Mitigation_Goal_Standard.pdf.

Even accounting relative to a historical base year does not result in 'complete' carbon accounting since the quantity of emissions occurring in the base year is subtracted from emissions in the commitment period: it is only the *change* in emissions that appears in the country's greenhouse gas accounts. The full quantity of emissions appears only in a country's greenhouse gas inventory *reports*. However, using the same historical benchmark for the energy and land-use sectors at least puts emissions from forest biomass-based energy on the same footing as emissions from other energy sources, thus minimizing the potential for leakage between the sectors. When the accounting system values a tonne of emissions from biomass energy the same as it values a tonne of emissions generated from other energy sources, it is less likely that mitigation targets in the energy sector will drive perverse outcomes.

Countries without sufficient domestic resources to satisfy their biomass energy demand may import woody biomass for use in their energy sectors. Because the IPCC guidance provides that emissions from biomass energy are not accounted for within the energy sector, emissions from combusting imported biomass for energy are automatically precluded from appearing anywhere in an importing country's accounts. Whether the associated emissions are accounted for in the country of origin depends on whether the exporting country accounts for forest-management emissions, and, if so, what kind of reference level it uses.

The potential for ‘missing’ biomass energy emissions

The accounting framework described earlier creates the potential for biomass energy emissions to go unaccounted for, or ‘missing’, in three possible ways.

Imported forest biomass used for energy

The first and most obvious cause of unaccounted-for emissions is due to biomass imported from non-accounting countries. As noted, it is the exporting countries that should account for the carbon emissions, but this will not hold true when the countries growing and harvesting the biomass fall outside the accounting framework. This is the case for the US, Canada and Russia, all significant exporters of woody biomass that do not account for greenhouse gas emissions under the second commitment period of the Kyoto Protocol (though their emissions will be *reported* – as opposed to accounted for – under the UNFCCC).

Imports of forest biomass from countries that *do* account for greenhouse gas emissions within the land-use sector may also result in missing carbon emissions, depending on the exporting country’s reference-level approach.

Historical reference levels

A historical reference level reflecting past emissions that are higher than current levels will allow a country to increase its emissions over the commitment period up to that historical level without accounting for the increase. In fact, if a country remains below its historical emissions level it will receive credits – commonly referred to as ‘hot air’, or non-additional greenhouse gas reductions. In contrast, a country with a historical reference level reflecting a lower level of emissions than ultimately occur in the commitment period will account for emissions above the historical level.

Although a historical reference level that allows for unaccounted increases in emissions may result in ‘missing’ biomass energy emissions, this phenomenon is no different from greenhouse gas accounting in any other sector under the Kyoto Protocol. If the same historical year or period is used for the reference level in the land-use and energy sectors, and if the sectors are fungible, emissions from biomass energy are on an equal footing with emissions from other energy sources. In this case, the potential for leakage between sectors is minimized, also reducing the potential for biomass energy policies to drive perverse outcomes.

Business-as-usual (projected) reference levels

If a country’s projected reference level includes policies aimed at increasing the use of forest biomass for energy, it will not account for the emissions resulting from those policies (as long as they were adopted before 2010) against its greenhouse gas targets. An accounting framework that allows countries to build anticipated increases in forest harvests into their projections thus fails to reflect the true atmospheric impacts of forest-based biomass energy.

If its projected reference level does *not* include the impacts of bioenergy policies, a country will count emissions attributable to those policies against its allowable target level of emissions. However, even countries that have not explicitly included anticipated emissions increases due to bioenergy policies in their reference levels have often implicitly built some amount of bioenergy use into their business-as-usual projections. The resulting emissions will not count towards their emissions targets.

Harvested wood products

In addition, for countries using business-as-usual reference levels, accounting for emissions from harvested wood products may help to bring some emissions from forest-based biomass energy back into the accounting framework. The rules for harvested wood products were amended in the second commitment period to allow countries to assume that forest carbon can be stored in long-lived products. Under these rules, countries account for emissions from harvested wood products according to a set of first-order decay functions and default half-lives for three categories of products: paper (two years), wood panels (25 years), and sawnwood (35 years). (Carbon dioxide emissions from wood harvested for energy purposes are assumed to occur in the year of harvest.)[111]

Countries using business-as-usual reference levels generally allocate their future harvests to one of the four categories above – paper, wood panels, sawnwood or biomass for energy – based on their historical inputs into each product category. For example, if a country used 15 per cent of the volume of its domestic forest harvests for energy in the past, its reference level would assume that 15 per cent of the volume harvested over the commitment period would be used for energy. The emissions associated with the corresponding volume of biomass used for energy would not count against that country's target, as those emissions were included in the reference level and thus 'cancelled out' of accounting.

> Where a tonne of emissions from burning biomass for energy does not count against a country's emissions target but a tonne of emissions from fossil fuel energy sources does, there will be an incentive to use biomass energy rather than fossil fuels in order to reduce the country's greenhouse gas emissions.

Due to the differences in the timing of emissions between harvested wood products and biomass used for energy, however, a country that uses a greater proportion of its domestic harvests for energy than in the past may account for the marginal increase in emissions. Emissions from the creation of longer-lived harvested wood products – wood panels and sawnwood – do not occur in the commitment period and thus are not included in a projected reference level. However, if a country increases the proportion of harvested biomass it uses for energy and reduces its production of long-lived harvested wood products, the associated volume of carbon dioxide will now occur in the commitment period. Because the reference level did not include those emissions, a country that increases the portion of its domestic forest harvests used for energy may count the marginal increase in emissions against its emissions target.

Summary

There is a risk of carbon emissions going unaccounted for or 'missing' as long as (1) forest biomass-exporting countries remain outside the greenhouse gas accounting framework, (2) emissions in the land-use and energy sectors are accounted for using different approaches, or (3) countries build the emissions resulting from policies promoting biomass energy use into their accounting baselines.

This risks creating perverse policy outcomes. Where a tonne of emissions from burning biomass for energy does not count against a country's emissions target but a tonne of emissions from fossil fuel

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[111] UNFCCC decision 2/CMP.7, Annex paras. 29–32.

energy sources does, there will be an incentive to use biomass energy rather than fossil fuels in order to reduce the country's greenhouse gas emissions – even where this reduction is not 'real' in the sense that it is not accounted for in any country's land-use sector accounts.

Biomass energy emissions in the second commitment period

There are currently 43 Annex I countries under the UNFCCC.[112] Thirty-five of them have submitted reference levels to use for forest-management accounting in the second commitment period of the Kyoto Protocol (see Table 4). The remaining eight are either not parties to the protocol (Canada, the US), are parties without targets under its second commitment period (Japan, New Zealand, Russia, Turkey) or have not so far submitted a forest-management reference level (Monaco, which has no forests, and Kazakhstan).

Three of these 35 countries submitted forest-management reference levels based on historical emissions. Two account for changes relative to 1990 levels while the third accounts for changes relative to its average forest-management emissions in 1990–2009. The greenhouse gas accounts of these three parties will include any changes in emissions attributable to the use of forest-based biomass for energy relative to these historical levels.

The other 32 parties elected to use business-as-usual reference levels for forest-management accounting for the second commitment period. Sixteen used country-specific models or methodologies to calculate their business-as-usual scenarios: 14 EU member states relied on projections modelled by the European Commission's Joint Research Centre and two parties used a linear extrapolation of historical emissions data. As discussed above, the impacts of pre-2010 biomass energy policies may be included in these parties' reference levels, with the effect that emissions attributable to those policies will not be included in their accounting.

Of the 32 parties using business-as-usual reference levels for forest management, 21 explicitly included policies encouraging the use of biomass energy within their emissions projections. The remaining 11 countries did not model the impacts of such policies within their reference levels. This does not preclude the possibility that any increases in forest harvests and/or biomass utilization included in these countries' business-as-usual projections could be used for biomass energy, but there is no causal link within the reference level between anticipated biomass energy demand and forest harvests. Consequently, any increases in emissions built into the reference level (and therefore excluded from accounting) are not directly attributable to increased demand for biomass energy.

For the 21 countries that explicitly included the impacts of biomass energy policies, some quantity of emissions over the commitment period will result from biomass energy use, but these emissions will not count against the countries' national targets since they are included in the reference level. The question then is: how large is the quantity of unaccounted-for emissions?

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[112] Including Kazakhstan, which is an Annex I country for the purposes of the Kyoto Protocol though not the UNFCCC.

Table 4: Forest-management reference levels for the second commitment period of the Kyoto Protocol

	Type of reference level	Reference level includes policies driving biomass energy use?	Explanation
Australia	Country-specific projection	No	
Austria	Country-specific projection	Yes	Includes increase in demand for woody biomass for energy of 20 per cent from 2008–20; gross domestic consumption of woody biomass for energy from 18 million cubic metres (Mm^3) (145 petajoules – PJ) in 2009 to 21–22 Mm^3 (170–175 PJ) in 2020. Assumes ~20 per cent supply from imports.
Belarus	1990 (historical base year)	N/A	
Belgium	Joint Research Centre (JRC) projection	Yes	Projection includes demand for biomass and waste for electricity and thermal energy; cannot determine type or origin of fuel.
Bulgaria	JRC projection	Yes	Projection includes demand for biomass and waste for electricity and thermal energy; cannot determine type or origin of fuel.
Croatia	Country-specific projection	Yes	Biomass energy is a driver of increased harvests from 5.15 Mm3 in 2010 to 8.00 Mm3 in 2020, but not possible to calculate specific portion of increase due to energy policy.
Cyprus	Linear extrapolation	N/A	
Czech Republic	JRC projection	Yes	Projection includes demand for biomass and waste for electricity and thermal energy; cannot determine type or origin of fuel.
Denmark	Country-specific projection	No	
Estonia	JRC projection	Yes	Projection includes demand for biomass and waste for electricity and thermal energy; cannot determine type or origin of fuel.
Finland	Country-specific projection	Yes	Projection includes increased use of wood chips from 5.3 TWh in 2007 to 21 TWh in 2020, increased use of wood/wood pellets from 13.7 to 16 TWh. Black liquor, industrial wood residues, wood chips for biofuels included. Assumes increased harvesting and rate of harvesting logging residues and stumps; reduced dependence on imports.
France	JRC projection	Yes	Projection includes demand for biomass and waste for electricity and thermal energy; cannot determine type or origin of fuel.
Germany	Country-specific projection	No	
Greece	1990–2009 (historical base period)	N/A	
Hungary	JRC projection	Yes	Projection includes demand for biomass and waste for electricity and thermal energy; cannot determine type or origin of fuel.
Iceland	Country-specific projection	No	
Ireland	Country-specific projection	No	

	Type of reference level	Reference level includes policies driving biomass energy use?	Explanation
Italy	JRC projection	Yes	Projection includes demand for biomass and waste for electricity and thermal energy; cannot determine type or origin of fuel.
Latvia	JRC projection	Yes	Projection includes demand for biomass and waste for electricity and thermal energy; cannot determine type or origin of fuel.
Liechtenstein	Country-specific projection	Yes	Projection includes an increase in harvests, an unknown portion of which is attributable to increasing use of forest biomass for energy.
Lithuania	JRC projection	Yes	Projection includes demand for biomass and waste for electricity and thermal energy; cannot determine type or origin of fuel.
Luxembourg	JRC projection	Yes	Projection includes demand for biomass and waste for electricity and thermal energy; cannot determine type or origin of fuel.
Malta	Linear extrapolation	N/A	
Netherlands	JRC projection	Yes	Projection includes demand for biomass and waste for electricity and thermal energy; cannot determine type or origin of fuel.
Norway	1990 (historical base year)	N/A	
Poland	Country-specific projection	No	
Portugal	Country-specific projection	Yes	Projected increase in harvests of 6 per cent attributable to expansion of pulp and bioenergy sectors.
Romania	JRC projection	Yes	Projection includes demand for biomass and waste for electricity and thermal energy; cannot determine type or origin of fuel.
Slovakia	JRC projection	Yes	Projection includes demand for biomass and waste for electricity and thermal energy; cannot determine type or origin of fuel.
Slovenia	Country-specific projection	No	
Spain	JRC projection	Yes	Projection includes demand for biomass and waste for electricity and thermal energy; cannot determine type or origin of fuel.
Sweden	Country-specific projection	Yes	Projection includes increased use of forest residues and stumps for biomass energy from 8.6 TWh in 2010 to 13.3 TWh in 2020. Area of stump harvest increases from 4,800 hectares in 2010 to 23,400 hectares in 2020.
Switzerland	Country-specific projection	Yes	Projection includes 30 per cent increase in harvesting rates in 2013–20 relative to 1990–2007, an unknown portion of which is attributable to increasing use of forest biomass for energy.
Ukraine	Country-specific projection	No	
UK	Country-specific projection	No	

The volume of 'missing' biomass energy emissions

For the most part, the information provided in countries' forest-management reference level submissions is not sufficient to answer the question above. Ideally, these submissions would have specified the anticipated impact of biomass energy policies on the quantity of woody biomass utilized, the origins of that biomass (additional domestic forest harvests, increased use of domestic forestry residues or higher imports) and the resulting emissions. However, of the 21 countries whose reference levels explicitly included biomass energy policies, only three – Austria, Finland and Sweden – quantified their impacts. Several other countries indicated that they had built anticipated increases in biomass energy use into their reference levels, but did not provide sufficient data to quantify the resulting impact.

As noted above, however, it is possible to calculate carbon dioxide emissions from biomass from the emissions reported as a memo item in Annex I countries' greenhouse gas inventory reports. This covers emissions from biomass used for energy in all sectors, including energy, manufacturing and construction, transport, commercial and institutional, residential, agriculture, forestry and fisheries.

The 2006 IPCC Guidelines for National Greenhouse Gas Inventories divides biomass used for energy into three categories: solid, liquid and gaseous.[113] Solid biomass includes wood and wood waste, sulphite lyes (black liquor), other primary solid biomass such as plant matter, vegetal waste and animal materials and wastes, and charcoal. Liquid biomass includes biogasoline, biodiesel and other liquid biofuels. Gaseous biomass covers landfill biogas, sludge biogas and other biogas. The biodegradable fraction of municipal wastes is also included in the IPCC's definition of biomass fuels, though some countries have now started to report emissions from municipal solid waste separately.

Although the memo item for carbon dioxide emissions from biomass energy does not break down emissions by the source of biomass, most countries report the type of biomass used in a separate emissions calculation based on economy-wide fuel use.[114] Table 5 applies the proportion of emissions from solid biomass in this second calculation to each country's memo item emissions to estimate the proportion of carbon dioxide emissions attributable to the combustion of solid biomass.[115] Not all countries differentiate between emissions from solid, liquid and gaseous biomass, and some include municipal solid waste while others do not. This reinforces the fact that the figures cited here are estimates rather than precise figures.

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[113] IPCC (2006), *IPCC Guidelines for National Greenhouse Gas Inventories, Vol. 2: Energy,* Ch. 1: Introduction, pp. 1.15–16, http://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/2_Volume2/V2_1_Ch1_Introduction.pdf (accessed 29 Dec. 2016).

[114] Total reported carbon dioxide emissions from biomass energy in the memo item are calculated using the IPCC's bottom-up 'sector approach'. Biomass energy emissions in the second analysis are calculated using a top-down 'reference approach'. The emissions estimates resulting from the sector and reference approaches are very rarely, if ever, equivalent; it is not possible to compare these values directly.

[115] Not all countries included this second calculation always differentiate between categories of biomass fuels in their inventories. For countries and years for which this information is not available, the portion of emissions attributable to solid biomass is based on information included in those countries' National Inventory Reports, where available.

Table 5: Carbon dioxide emissions from total biomass and solid biomass

	1990			2000			2010			2014		
	Total biomass emissions ($MtCO_2$)	*% from solid biomass*	*Solid biomass emissions* ($MtCO_2$)	*Total biomass emissions* ($MtCO_2$)	*% from solid biomass*	*Solid biomass emissions* ($MtCO_2$)	*Total biomass emissions* ($MtCO_2$)	*% from solid biomass*	*Solid biomass emissions* ($MtCO_2$)	*Total biomass emissions* ($MtCO_2$)	*% from solid biomass*	*Solid biomass emissions* ($MtCO_2$)
Australia	15.14	100	15.14	19.24	98	18.86	18.51	97	17.95	18.04	96	17.32
Austria	9.93	98	9.70	12.48	95	11.87	23.25	87	20.12	23.35	81	18.92
Belarus	2.01	45	0.91	3.04	14	0.43	5.15	29	1.49	5.10	52	2.65
Belgium	2.30	76	1.75	2.96	75	2.21	11.60	73	8.50	11.00	71	7.82
Bulgaria	0.81	100	0.81	2.58	100	2.58	4.30	14	0.60	5.06	4	0.21
Canada	49.81	59	29.27	55.81	55	30.46	51.67	57	29.60	55.10	55	30.57
Croatia	5.13	100	5.13	4.70	100	4.70	5.94	100	5.91	5.25	97	5.10
Cyprus	0.02	100	0.02	0.03	100	0.03	0.14	59	0.08	0.14	53	0.08
Czech Republic	5.42	99	5.34	5.32	90	4.78	9.94	86	8.60	13.25	78	10.34
Denmark	4.57	73	3.33	6.84	64	4.36	14.90	77	11.52	14.72	73	10.73
Estonia	0.96	100	0.96	2.30	100	2.30	3.73	99	3.67	3.77b	99	3.72
Finland	19.33	100	19.33	29.45	100	29.40	36.38	98	35.79	39.38	96	37.87
France	44.27	83	36.90	42.83	78	33.50	60.00	78	46.80	57.30	73	41.57
Germany	21.80	100	21.80	34.25	100	34.25	108.51	100	108.51	98.53	100	98.53
Greece	2.08	100	2.08	2.73	100	2.73	2.83	NO	0.00	2.68	NO	0.00
Hungary	3.13	97	3.05	3.41	95	3.25	8.03	89	7.15	7.54	87	6.59
Iceland	NA, NO	NA	NA, NO	NA, NO	NA	NA, NO	NA, NO	NA	NA, NO	NA, NO	NA	NA, NO
Ireland	0.49	99	0.49	0.59	89	0.52	1.37	60	0.83	1.91	61	1.16
Italy	13.95	98	13.70	18.67	72	13.53	41.81	70	29.24	40.59	71	28.87
Japan	34.86	100	34.86	39.62	100	39.62	57.79	100	57.79	59.99	100	59.97
Kazakhstan	1.17	100	1.17	0.34	100	0.34	0.55	100	0.55	0.31	100	0.31
Latvia	3.03	100	3.03	4.37	100	4.37	5.15	97	5.02	6.46	96	6.18

	1990			2000			2010			2014		
	Total biomass emissions ($MtCO_2$)	*% from solid biomass*	*Solid biomass emissions ($MtCO_2$)*	*Total biomass emissions ($MtCO_2$)*	*% from solid biomass*	*Solid biomass emissions ($MtCO_2$)*	*Total biomass emissions ($MtCO_2$)*	*% from solid biomass*	*Solid biomass emissions ($MtCO_2$)*	*Total biomass emissions ($MtCO_2$)*	*% from solid biomass*	*Solid biomass emissions ($MtCO_2$)*
Liechtenstein	0.01	72	0.00	0.01	79	0.01	0.02	88	0.02	0.02	93	0.02
Lithuania	1.31	100	1.31	2.97	100	2.97	4.48	96	4.32	5.28	94	4.98
Luxembourg	0.16	NO	NO	0.15	50	0.08	0.45	44	0.20	0.57	43	0.25
Malta	IE, NO	NE	NE	IE, NO	NE	NE	0.00	NE	NE	0.02	NE	NE
Monaco	0.03	NO	NO	0.05	NO	NO	0.04	NO	NO	0.04	NO	NO
Netherlands	4.08	59	2.40	6.81	50	3.43	13.3	55	7.35	12.76	44	5.66
New Zealand	3.61	95	3.43	5.33	97	5.18	5.70	94	5.37	5.49	94	5.16
Norway	4.48	100	4.48	4.71	100	4.71	6.40	100	6.40	3.91	100	3.91
Poland	6.81	99	6.80	16.90	99	16.80	30.4	89	27.1	34.40	90	30.82
Portugal	11.40	86	9.75	11.68	78	9.12	12.90	67	8.60	11.17	60	6.67
Romania	2.76	100	2.76	12.95	100	12.95	18.96	98	18.58	17.47	97	16.89
Russia	62.57	100	62.27	18.55	98	18.15	14.85	100	14.85	13.62	100	13.62
Slovakia	1.74	99	1.72	3.15	75	2.36	5.54	80	4.45	7.85	73	5.75
Slovenia	2.18	100	2.18	1.98	100	1.98	3.16	93	2.95	2.86	93	2.65
Spain	18.23	100	18.20	16.97	95	16.17	24.82	80	19.78	26.78	82	22.00
Sweden	12.39	97	12.10	17.02	97	16.56	30.07	55	16.40	28.32	52	14.61
Switzerland	4.47	97	4.33	4.74	95	4.52	6.55	96	6.29	6.66	95	6.32
Turkey	32.82	100	32.82	29.56	100	29.56	20.87	100	20.84	15.25	98	14.98
Ukraine	1.19	100	1.19	2.66	100	2.66	3.70	100	3.70	4.82	100	4.82
UK	2.55	82	2.08	6.24	61	3.84	19.25	50	9.64	27.96	57	15.88
US	219.41	98	215.02	227.43	97	210.76	265.11	72	191.59	293.73	74	217.65
Totals	**632.41**		**591.61**	**681.42**		**605.90**	**958.12**		**768.15**	**984.68**		**781.15**

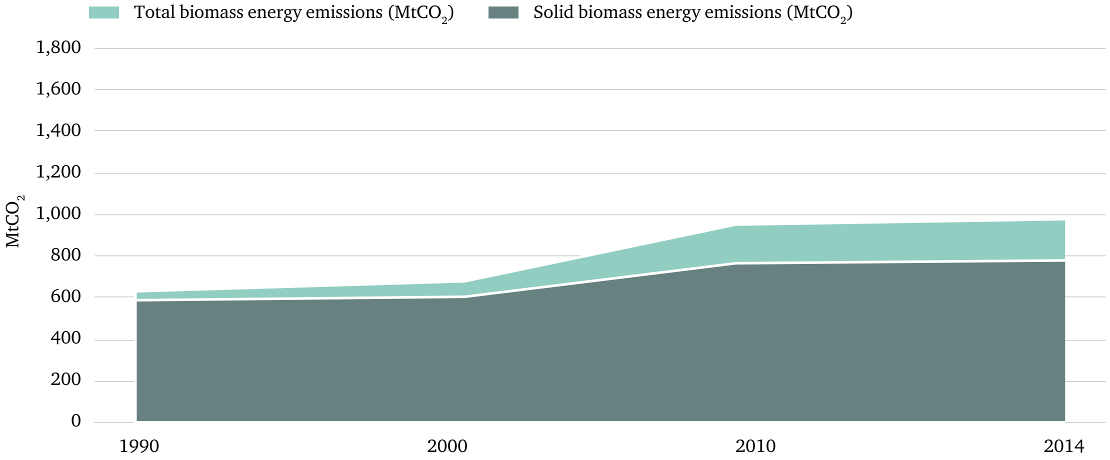
IE = included elsewhere; NA = not applicable; NO = not occurring; NE = not estimated
Source: National inventory submissions and national inventory reports to UNFCCC; aggregate greenhouse gas emission data on UNFCCC website.

Table 6: Biomass energy emissions (carbon dioxide) compared to total energy and economy-wide emissions, Annex I countries

	1990	2000	2010	2014
Total biomass energy emissions ($MtCO_2$)	632	681	958	985
Solid biomass energy emissions ($MtCO_2$)	592	606	768	781
Solid as % of total biomass energy emissions	93.5	88.4	80.2	79.3
Total energy emissions ($MtCO_2$)	14,073	13,644	13,421	13,118
Solid biomass emissions as % of total energy emissions	4.2	4.4	5.7	6.0
Total economy-wide emissions ($MtCO_2$)	15,006	14,446	14,186	13,983
Solid biomass emissions as % of total economy-wide emissions	3.9	4.2	5.4	5.6

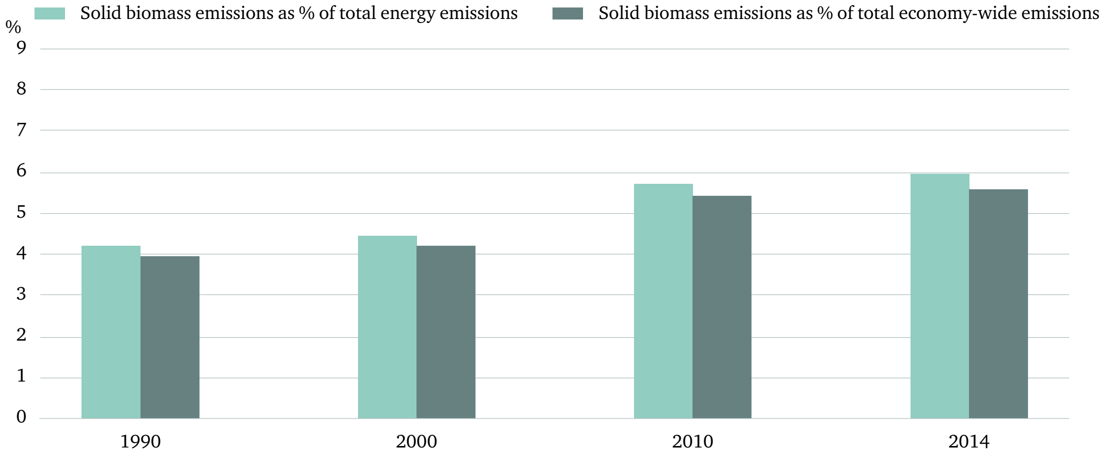
Source: National inventory submissions and national inventory reports to UNFCCC; aggregate greenhouse gas emission data on UNFCCC website.

Figure 5: Carbon dioxide emissions from biomass energy



Source: Table 6.

Figure 6: Biomass as proportion of energy and economy-wide emissions



Source: Table 6.

Table 6, and figures 5 and 6, present a summary of carbon dioxide emissions from total biomass and solid biomass in Annex I countries in 1990, 2000, 2010 and 2014, compared to total energy-sector and economy-wide emissions of carbon dioxide. As can be seen, total emissions from biomass energy and emissions from solid biomass have increased over the past two decades. While emissions from biomass have grown by more than 50 per cent from 1990 to 2014, however, emissions from solid biomass have grown by just over 30 per cent, thanks to faster rates of growth in liquid and gaseous biomass. The proportion of emissions accounted for by solid biomass fell from 93 per cent in 1990 to 79 per cent in 2014.

Nevertheless, in most countries, emissions from solid biomass constitute the vast majority of bioenergy emissions. In 2014, 23 of the 41 Annex I countries that reported having emissions from biomass-based energy derived 75 per cent or more of those emissions from solid biomass. The US accounts for almost 28 per cent of total Annex I solid biomass carbon emissions, while Germany, Japan and France account for a further 26 per cent. Neither the US nor Japan account for emissions from their land-use sectors under the Kyoto Protocol, Germany accounts against a business-as-usual projection that does not explicitly include bioenergy policies, and France uses a business-as-usual projection that includes bioenergy demand from policies up to, but not including, the 2009 EU Renewable Energy Directive. Woody biomass emissions from all these countries, therefore, have the potential to go unaccounted for.

National case studies

The UK

In 2014, the UK's total carbon dioxide emissions from fuel combustion (excluding emissions from biomass) in all sectors – energy, manufacturing and construction, transport, commercial/institutional, residential, and agriculture/forestry/fisheries – were 416 $MtCO_2$. Reported emissions from biomass energy were 28 $MtCO_2$, of which about 16 $MtCO_2$ were from solid biomass.[116] Biomass for power and heat are the most significant renewable energy sources in the UK after wind, and biomass for electricity generation has been growing rapidly, due mainly to the conversion of units at the Drax power station from coal to biomass. The UK's 2012 Bioenergy Strategy projected that by 2020 the share of biomass in power generation would account for 8–11 per cent, rising to 10–14 per cent by 2030.[117] Current demand for biomass power is in line with these projections. In 2015 bioenergy, mostly from biomass power plants, accounted for 8.9 per cent of total electricity generation.[118]

For the second commitment period of the Kyoto Protocol, the UK accounts for its domestic forest-management emissions against a projection of business-as-usual emissions based on historical planting data. The projection is based on the assumption that managed forests are harvested according to their rotation intervals, when they reach their pre-determined age of maturity. It is therefore possible to determine the future schedule of forest harvests: emissions associated with them are included in the business-as-usual baseline and, accordingly, not accounted for against the UK's emissions-reduction target. The reference level also assumes that a portion of the biomass from planned harvests – up to

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[116] Solid biomass used for energy in the UK includes wood and wood waste, poultry litter and straw.

[117] UK Departments of Energy and Climate Change; for Environment, Food and Rural Affairs; and of Transport (2012), *UK Bioenergy Strategy*, https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/48337/5142-bioenergy-strategy-.pdf (accessed 29 Dec. 2016).

[118] UK Department of Energy and Climate Change (2016), *Renewables Statistics, Section 6: Renewables,* London: Department of Energy and Climate Change, https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/579527/Renewables.pdf (accessed 29 Dec. 2016).

17 per cent – will be used for biomass energy; emissions associated with any higher use of domestic forests for energy (and, correspondingly, less carbon stored in harvested wood products) would count towards the UK's emissions target.[119]

The UK is heavily reliant, however, on imported woody biomass, primarily from the US, Canada, Latvia and Portugal. During the 12 months to the end of June 2016, it imported about 1.2 million tonnes of wood pellets from Latvia and about 0.3 million tonnes from Portugal.[120] Like many EU countries, Latvia and Portugal account for forest-management emissions against business-as-usual projections that include 'background' levels of biomass energy demand.[121] It is not possible to determine the level of forest harvests in exporting countries attributable to the UK's demand for wood pellets. However, it is likely that a portion of the emissions associated with forest biomass imported by the UK is built into exporting countries' projections, and therefore will not appear in these or any other countries' greenhouse gas accounts.

> The UK's goals for biomass-based energy production, and its continued reliance on imports, mean that an increasing quantity of emissions are likely to be excluded from the international greenhouse gas accounting framework up to 2020.

Neither the US nor Canada are parties to the Kyoto Protocol, so none of the emissions associated with the harvest and combustion of woody biomass imported from those countries are included in accounting. During the 12 months to the end of June 2016, the UK imported about 4.1 million tonnes of wood pellets from the US and 1.4 million tonnes from Canada. Assuming that all 5.5 million tonnes were used to produce energy, 7.8 $MtCO_2$ associated with this biomass was 'missing', i.e. it was not included in any country's greenhouse gas accounts under the Kyoto Protocol. (This figure is calculated using the UK's estimated emission factor, which may be an under-estimate. Using the emissions figures reported by Drax for 2013 gives a figure of 9.7 $MtCO_2$.)[122]

The UK's goals for biomass-based energy production, and its continued reliance on imports, mean that an increasing quantity of emissions are likely to be excluded from the international greenhouse gas accounting framework up to 2020. Emissions from domestic forest biomass resulting from planned forest harvests will not be included in accounting and, depending on the biomass's country of origin, emissions associated with forest biomass imported may be accounted for, partially accounted for, or not accounted for at all.

The US

The US produces the world's highest volume of emissions from solid biomass burnt for energy, although its relative contribution to the country's total energy production is fairly low. In 2014, the US emitted 293 $MtCO_2$ from the combustion of all types of biomass for energy, compared to 5,378 $MtCO_2$ from total fuel combustion across all sectors (excluding biomass emissions). The US greenhouse gas

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[118] Submission *of information on forest management reference levels by United Kingdom of Great Britain and Northern Ireland in accordance with Decision 2/CMP.6,* 2 March 2011, http://unfccc.int/files/meetings/ad_hoc_working_groups/kp/application/pdf/uk_frml.pdf (accessed 29 Dec. 2016).

[120] Data based on Eurostat, http://epp.eurostat.ec.europa.eu/newxtweb/defaultquery.do.

[121] The Joint Research Centre model generates business-as-usual projections that include the effects of biomass energy policies and measures adopted before April 2009; i.e. not including the 2009 Renewable Energy Directive.

[122] The figure of 386.9 kgC/tonne biomass for wood is used in the UK's basic combustion model for the energy sector; see UK Department of Energy and Climate Change (2014), *UK Greenhouse Gas Inventory, 1990–2012: Annual Report for Submission Under the Framework Convention on Climate Change,* London: Department of Energy and Climate Change, Table A 3.2.5.

inventory calculates emissions specifically from wood used for domestic energy (including black liquor); in 2014, this amounted to 218 $MtCO_2$.[123] The industrial sector (mainly pulp and paper, wood processing, chemical production and food production) was by far the largest end user, emitting 124 $MtCO_2$ in 2014, followed by the residential sector with 60 $MtCO_2$, and electricity generation with 26 $MtCO_2$. Since the US is not a party to the Kyoto Protocol, none of these emissions are accounted for under it (though they are reported under the UNFCCC).

The US is not only a major producer of woody biomass but also a major exporter, almost entirely to the EU. Its exports of wood pellets to the EU rose from 1.5 to 4.6 million tonnes between 2012 and 2015 (about 90 per cent of which was to the UK).[124] The emissions resulting from combustion of these pellets will depend on where and under what conditions they are used. However, to the extent that the pellets were used to generate energy, the resulting emissions were not included in any country's greenhouse gas accounts. Using the US's emission factor for the combustion of wood for energy, these 'missing' emissions amounted to approximately 7.3 $MtCO_2$ in 2015.[125] (Using the Drax figures for the calculation gives emissions of 8.1 $MtCO_2$.)

This example highlights how emissions should be accounted for either in the land-use sector of the exporting country or the energy sector of the importing country, but not both. The US has indicated that under the Paris Agreement it will track its greenhouse gas mitigation, including in the land-use sector, against a 2005 baseline.[126] In 2005, US emissions from 'forest land remaining forest land'[127] were -800 $MtCO_2$ (a net carbon sink, represented as negative emissions). If the domestic or international demand for forest biomass drives an increase in forest harvests, or a more intensive use of forest residues results in increased emissions relative to the 2005 level, the fall in the forest carbon sink will be reflected as an emission (debit) in the US greenhouse gas accounts – though this could be offset by higher forest growth.

Finland

Finland's 2014 emissions from all types of biomass used for energy were 39 $MtCO_2$, almost all – 38 $MtCO_2$ – from solid biomass. This compares with 43 $MtCO_2$ from non-biomass fuel combustion across all sectors. Finland accounts for forest-management emissions in the Kyoto Protocol's second commitment period relative to a business-as-usual baseline that explicitly includes anticipated increases in emissions due to forest-based biomass energy use. The policies driving increased forest biomass demand were put in place in 2008 and therefore do not fall foul of the prohibition against including the impacts of post-2009 policies in forest-management reference levels. Finland's renewable energy policies include the goal of replacing coal in power plants with biomass and energy efficiency measures by 2025.

Finland's business-as-usual reference level includes the effects of a sharp increase in the demand for domestic roundwood. Domestic harvests in 2013 were approximately 56 million m^3, of which

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[123] 'Wood' includes wood, black liquor and other wood wastes. US Environmental Protection Agency (2016), *Inventory of US Greenhouse Gas Emissions and Sinks: 1990–2014*, Washington, DC: US Environmental Protection Agency, pp. 3-90–3-92, https://www3.epa.gov/climatechange/Downloads/ghgemissions/US-GHG-Inventory-2016-Main-Text.pdf (accessed 30 Dec. 2016).

[124] Based on the US International Trade Commission's 'Trade DataWeb', http://dataweb.usitc.gov/scripts/user_set.asp.

[125] The US uses the Energy Information Administration's emission factor of 0.434 million tonnes carbon/million tonnes wood. See US Environmental Protection Agency (2016), *Inventory of US Greenhouse Gas Emissions and Sinks*, p. 3–92.

[126] US Cover Note, Intended Nationally Determined Contribution submitted to the UNFCCC in advance of the Paris conference in December 2015, and accompanying Information, 31 March 2015, http://www4.unfccc.int/submissions/INDC/Published%20Documents/United%20States%20of%20America/1/U.S.%20Cover%20Note%20INDC%20and%20Accompanying%20Information.pdf (accessed 30 Dec. 2016).

[127] The category of 'forest management' emissions is relevant only for greenhouse gas *accounting* under the Kyoto Protocol. Countries *report* greenhouse gas emissions in the land-use sector on the basis of land-use category (e.g. forest land, grassland, cropland), rather than by activity.

8 million m^3, or 14 per cent, was for direct energy use. The country's target for 2020 is to harvest 65–70 million m^3 of wood from its forests, with 12 million m^3 – approximately 17–18 per cent – harvested specifically for direct energy use.[128] Because these harvests have been included in Finland's forest-management reference level, the emissions associated with burning the resulting biomass for energy will not count against its emissions target. Using the net calorific value and emission factor for solid wood fuels supplied in Finland's greenhouse gas inventory report, 10–21 $MtCO_2$ from burning domestically harvested wood for energy will not be counted towards its emissions target.[129]

Despite Finland's plans to increase forest harvests up to 2020, its anticipated harvest volume will still remain below the forest's annual growth increment. So, even though Finland's forest-management emissions do increase relative to current levels, its forests are predicted to remain a net carbon sink.

Although Finland harvests some biomass specifically for bioenergy, the majority of wood energy in the country is the by-product of forestry-based industries. The largest single source of wood energy is black liquor, the production of which is driven primarily by demand for pulp and paper rather than demand for energy. For the remaining portion, Finland's forest-management reference level documentation indicates that it expects approximately 54 per cent of feedstock to derive from stemwood, 32 per cent from logging residues, and 14 per cent from stumps and roots. The discussion in Chapter 1 is relevant to the impact of the use of this feedstock on the climate; the length of the carbon payback period depends on what would have happened to the wood if it had not been used for energy, the rate of decay of residues, stumps and roots and other similar factors.

France

In 2014, France had the fourth highest carbon dioxide emissions from solid biomass use among Annex I countries after the US, Germany and Japan. It emitted 42 $MtCO_2$ from burning solid biomass, compared to 313 $MtCO_2$ from non-biomass fuel combustion.

France is one of the 14 EU member states whose forest-management reference levels were calculated using the European Commission's Joint Research Centre's approach. This used projections of, *inter alia*, global timber and bioenergy demand to drive its predictions of forest harvests in each of the countries modelled.[130] Although France's reference level does not include emissions from biomass used pursuant to the EU's Renewable Energy Directive, it does reflect the country's earlier decision to support the development of wood-based bioenergy by increasing domestic harvests and the utilization of sawmill residues. Because France has explicitly included emissions attributable to these bioenergy policies in its reference level; it will not count those emissions toward its emissions target.

However, France also acknowledged the difficulty of accurately predicting future demand for forest biomass, and therefore future emissions. Its reference level submission noted that, despite its goal of increasing bioenergy use, practical considerations such as mobilization costs, the price of timber and the accessibility of wood may prevent it from fully achieving this. Therefore, although the

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[128] Finland Ministry of Agriculture and Forestry (2010), *Finland's National Forest Programme 2015: Turning the Finnish Forest Sector Into a Responsible Pioneer in Bioeconomy*, Helsinki: Ministry of Agriculture and Forestry, https://www2.uef.fi/documents/1192563/1939367/NFP_2015_Finlands_National_Forestry_Programme_2015_2010.pdf/544ffbb6-d760-485f-b12b-7f70a5c5ac56 (accessed 29 Dec. 2016); Matti Kahra (senior specialist, Finland Ministry of Agriculture and Forestry), personal communication with the original author of this chapter, 12 May 2015.

[129] Net calorific value for solid wood fuels = 7.8–16 GJ/t; emission factor = 109.6 gCO_2/MJ for solid wood fuels. Statistics Finland (2016), *Greenhouse Gas Emissions in Finland 1990–2014*, Helsinki: Statistics Finland, Table 3.2-4, p. 72 https://www.stat.fi/static/media/uploads/tup/khkinv/fi_un_nir_2014_20160415.pdf (accessed 29 Dec. 2016).

[130] *Submission of information on forest management reference levels by France*, April 2011, http://unfccc.int/files/meetings/ad_hoc_working_groups/kp/application/pdf/awgkp_france_2011.pdf (accessed 29 Dec. 2016).

government's goal is to increase annual harvests of woody biomass for renewable energy and timber by 12 million m^3 by 2020, the reference level conservatively assumes that harvests will actually increase by less than 5 million m^3 compared to 2010.[131] (Forest harvests in 2010 were approximately 59 million m^3, and are projected to rise to approximately 63 million m^3 in 2020.) Emissions associated with increases in forest harvests beyond the 5 million m^3 included in the reference level will therefore be counted toward France's emissions target. While this approach is still likely to result in unaccounted for carbon dioxide emissions, it should bring at least a portion of France's bioenergy emissions into its accounting framework.

Conclusions and recommendations

The international greenhouse gas reporting and accounting frameworks established under the UNFCCC and Kyoto Protocol assume that the carbon emissions associated with using woody biomass for energy are fully reported and accounted for in the land-use sector, and therefore should not be included in the energy sector. This tends to reinforce the assumption, commonly found in national policy frameworks, that biomass energy is zero-carbon at the point of use.

It is clear, however, that for the first and second commitment periods of the Kyoto Protocol, emissions from the use of woody biomass for energy have not been accurately reflected in countries' greenhouse gas accounts. The problem of 'missing', or unaccounted-for, emissions arises when a country using biomass for energy:

- Imports biomass from a country outside the accounting framework – such as the US, Canada or Russia, all significant exporters of woody biomass that do not account for greenhouse gas emissions under the second commitment period of the Kyoto Protocol;
- Accounts for its biomass emissions using a historical forest-management reference level that includes higher levels of biomass emissions than in the present; or
- Accounts for its biomass emissions using a business-as-usual forest-management reference level that (explicitly or implicitly) includes anticipated emissions from biomass energy; these emissions will not count against its national target.

In each of these scenarios, the accounting framework allows countries to avoid accounting for biomass energy emissions in both the energy and land-use sectors. However, such an absence of emissions from biomass energy is merely an artefact of the greenhouse gas accounting framework. It is a fall in emissions on paper only and does not change those emissions' impacts on the atmosphere. This risks creating perverse policy outcomes: where a tonne of emissions from burning biomass for energy does not count against a country's emissions target but a tonne of emissions from fossil fuel energy sources does, there will be an incentive to use biomass energy rather than fossil fuels in order to reduce the country's greenhouse gas emissions – even where this reduction is not 'real', in the sense that it is not accounted for in any country's land-use sector accounts.

The quantity of emissions missing from the international greenhouse gas accounting framework is impossible to calculate directly, but is likely to be significant. The data gaps and ambiguities highlighted above emphasize the need for more detailed reporting on the types, sources and countries of origin of biomass used for energy. Although many countries already collect these data, they are not

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[131] Ibid.

currently available in a form that allows for a complete understanding of the impact of biomass energy use on global or national emissions.

One solution would be to account for carbon dioxide emissions from biomass burned for energy within the energy sector, not the land-use sector. While additional rules would be required to ensure emissions were not double-counted in the energy and land-use sectors, this could be a viable solution given sufficient data and guidance to promote transparency. It would, however, require a major revision of accounting rules, so it is probably more practical to keep biomass emissions within the land-use sector. Four steps could then be taken within the existing framework to reduce the potential for missing emissions.

First, all countries should include the land-use sector in their national accounting. If carbon dioxide emissions from bioenergy continue to be reflected only in the land-use sector, then the practice of allowing biomass-producing countries to exclude their land-use sectors from accounting has the potential to create major accounting gaps with potentially perverse outcomes. The entry into force of the 2015 Paris Agreement – for which many details remain to be negotiated – affords an opportunity to revise the accounting system to incentivize all countries to report and account fully for emissions from their land-use sectors, including their forests.

Second, forest-management reference levels should contain detailed information on projected emissions from using biomass for energy, the origins of that biomass (additional domestic forest harvests or increased use of domestic forestry residues) and the resulting emissions.

Third, countries that import biomass for energy should be required to report on whether and how the country of origin accounts for biomass-based emissions. Importing biomass from a country that does not account for such emissions, or from one that has built biomass energy demand into its accounting baseline, will result in ‘missing’ emissions and is likely to promote the importing country’s potentially perverse reliance on biomass energy. Emissions associated with this imported biomass should therefore be fully accounted for by the importing country.

Fourth, countries using domestic biomass for energy should reconcile their energy and land-use sector accounting approaches in order to put emissions from each sector on a par with each other. If possible, accounting for greenhouse gas emissions in the energy and land-use sectors should use the same benchmarks – either a historical reference year/period or a business-as-usual scenario – to avoid emissions leakage between the sectors, and this should be uniform across all countries. If this is not feasible, additional methodologies and rules should be devised to bring biomass energy emissions back into the accounting framework and treated in the same way.

Although these options represent departures from current greenhouse gas reporting and accounting conventions, the scale of emissions at stake and the perverse incentives the current system creates require reform of the current system to reflect more accurately the atmospheric impacts of relying on biomass for energy.

3. Sustainability Criteria

Chapter 1 highlighted the way in which the impacts on the climate of the use of woody biomass for energy vary significantly depending on the feedstock and the way in which the forest from which the feedstock is sourced is managed. One means of avoiding (or, at least, ameliorating) these impacts is to apply preconditions that biomass installations are required to meet before they are eligible for the regulatory and financial support afforded to renewable energy sources. This topic has been under discussion within the EU for several years, and the European Commission published proposed sustainability criteria for solid biomass in November 2016.

This chapter:

- Analyses the evolution of sustainability criteria for solid biomass in the EU, including the commission's latest proposals;
- Summarizes the sustainability criteria applied to date in some EU member states;
- Looks briefly at sustainability criteria applied by governments outside the EU; and
- Analyses the sustainability criteria applied under voluntary schemes, in particular that of the Sustainable Biomass Partnership.

The EU

The EU's 2009 Renewable Energy Directive contained sustainability criteria for liquid biofuels, designed to ensure that their use delivered significant greenhouse gas savings compared to the fossil fuels they replaced (mainly for transport). There was nothing similar for solid (or gaseous) biomass, however. Instead, the directive contained a commitment to report on the requirements for such a sustainability scheme by the end of 2009.

Over the following six years the European Commission changed its view several times. In 2010 it concluded that no EU-wide criteria for solid biomass were necessary; in 2013 that they were; in 2014 that they were not; and finally in 2014 that they were. Proposals were finally published in 2016. These changes in views took place against the background of disagreements between member states. Supporters of the introduction of sustainability criteria included the main importers of biomass for energy (the UK, Belgium and the Netherlands) as well as France, Germany and Poland. Opponents tended to be those mostly reliant on their own domestic production (Austria, Finland and Sweden) that feared the potential impact on their forest industries.[132]

The European Commission's initial decision, included in a report published in 2010, that no binding criteria were necessary at the EU level was based on the wide variety of biomass feedstocks in use at the time, together with the low sustainability risks relating to domestic biomass production from wastes (municipal solid waste, post-consumer recovered wood, etc.) and agricultural and forestry

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[132] See Toop, G. (2013), 'Overview of EU criteria and national initiatives', www.danskelbil.dk/~/media/Biomasse/Praesentationer/6Ecofys_GemmaToop.ashx (accessed 29 Dec. 2016).

residues, where no land use change occurred.[133] Instead, member states desiring to introduce their own national schemes were encouraged to develop them in line with the directive's requirements for biofuels. The life-cycle assessment methodology whose use it encouraged considers emissions from the cultivation, harvesting, processing and transport of the biomass feedstocks, and includes direct land-use change where the land has changed category since 2008 (e.g. from forest to annual cropland). However, the methodology does not account for changes in the carbon stock of a forest, foregone carbon sequestration of land or any indirect impacts on carbon stocks in other areas of land. The report was published when the focus of the debate on the sustainability of bioenergy was primarily on liquid biofuels rather than solid biomass, and in particular their direct and indirect impacts on land use.

A 2012 European Commission survey of the effect of national schemes found that, while 20 member states had introduced some sort of requirements covering the sustainable production or efficient use of biomass, the vast majority of these related to end-use efficiency, either requiring mandatory minimum efficiencies for the production of heat or electricity or both, or providing financial incentives to stimulate higher efficiencies or heat recovery.[134] Only the UK had introduced regulations referring to the biodiversity and land-use-change criteria recommended in the commission's 2010 report, though this did not include any criteria relating to changes in carbon stock on existing forest land. Against this background the commission became convinced that EU-wide sustainability criteria would be valuable and in 2013 a draft set was discussed internally. No agreement could be reached within the commission, however, so further development was halted.

In 2014 the European Commission reviewed the issue again and concluded that there was still no need for any EU-wide criteria since national sustainability schemes did not appear to be creating any internal market barriers and most (more than 90 per cent in 2012) biomass supply was sourced domestically, mostly from processing and harvesting residues.[135]

However, the discussions over the EU's 2030 climate and energy package and the development of the European Energy Union, as well as the growth of imports of biomass for energy into the EU and the debates over the sustainability criteria for biofuels in the light of their increasingly clear impacts on forests (which ended with the decision to remove all support for land-based biofuels after 2020), highlighted the lack of consistency between the treatment of biofuels and of biomass. Accordingly, in 2014, the commission concluded once again that EU-wide criteria would be necessary to ensure genuine greenhouse gas savings and to allow for fair competition between the various uses of biomass.[136] The biomass policy also aimed to help deliver sustainable management of forests, in line with the EU's Forest Strategy. Published in 2013, the Forest Strategy included support for the cascading use of wood as a way of maximizing resource efficiency, implying that wood should be used in the following order of priority: wood-based products, extending their service life, re-use, recycling, bio-energy and disposal.[137]

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[133] European Commission (2010), *Report from the Commission to the Council and the European Parliament on sustainability requirements for the use of solid and gaseous biomass sources in electricity, heating and cooling,* Brussels: European Commission, http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52010DC0011&from=EN (accessed 29 Dec. 2016).

[134] Pelkmans, L. et al. (2012), *Benchmarking biomass sustainability criteria for energy purposes,* Mol: Belgium, https://ec.europa.eu/energy/sites/ener/files/documents/2014_05_biobench_report.pdf (accessed 29 Dec. 2016).

[135] European Commission (2014), *State of play on the sustainability of solid and gaseous biomass used for electricity, heating and cooling in the EU,* Brussels: European Commission, p. 17 http://ec.europa.eu/energy/sites/ener/files/2014_biomass_state_of_play_.pdf (accessed 29 Dec. 2016).

[136] European Commission (2014), *A Policy Framework for Climate and Energy in the Period from 2020 to 2030,* Brussels: European Commission, p. 7, http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52014DC0015&from=EN, (accessed 29 Dec. 2016).

[137] European Commission (2013), *A New EU Forest Strategy: for forests and the forest-based sector*. Brussels: European Commission, pp. 4–5, http://eur-lex.europa.eu/resource.html?uri=cellar:21b27c38-21fb-11e3-8d1c-01aa75ed71a1.0022.01/DOC_1&format=PDF (accessed 29 Dec. 2016).

New proposed criteria for solid and gaseous biomass were finally published in November 2016, as part of a substantial package of policies to support renewable energy, centring on a proposed revision of the Renewable Energy Directive. The proposed criteria, which apply to installations of capacity of 20 MW and greater, include the following requirements.[138]

- The country or forest from which the forest biomass was sourced has systems in place to ensure that harvesting is carried out legally, harvested forest is regenerated, areas of high conservation value (including wetlands and peatlands) are protected, the impacts of harvesting on soil quality and biodiversity are minimized, and harvesting is limited to the long-term production capacity of the forest.
- The country from which the forest biomass is sourced is a party to the Paris Agreement and has submitted a Nationally Determined Contribution to the UNFCCC covering emissions and removals from agriculture, forestry and land use ensuring either that changes in carbon stock associated with biomass harvests are accounted towards the country's climate commitments or that there are laws in place to conserve and enhance carbon stocks and sinks. (If evidence for these requirements is not available, forest-management systems must be in place to ensure that forest carbon stock levels are maintained.)
- Minimum greenhouse gas savings compared to fossil fuels of 80 per cent for installations starting operation after 2020 or 85 per cent for installations starting after 2025 must be achieved. This relates only to supply-chain emissions, not to changes in forest carbon stock. (Suggested default values are provided for different types of feedstock and different transport distances.)
- Electricity must be produced from highly efficient cogeneration technology for installations starting operation three years after the date of adoption of the new directive (it is not clear whether this applies to old coal plants converting to or co-firing with biomass; and the delay is in any case subject to further discussion).

Member states are to be permitted to apply additional sustainability requirements over and above these EU-wide criteria. Proof of compliance with the criteria is to be provided by the plant operators, subject to independent auditing as defined by the member states. It is open to the European Commission to decide that voluntary schemes comply with the criteria (see below) and to member states to establish national schemes to do the same.

The impact assessment published alongside the draft directive explained the commission's thinking behind the proposals. It fully recognized the climate impacts of changes in forest carbon stock, noting:

> Recent studies have found that when greenhouse gas emissions and removals from combustion, decay and plant growth (so-called biogenic emissions from various biological pools) are also taken into account, the use of certain forest biomass feedstocks for energy purposes can lead to substantially reduced or even negative greenhouse gas savings compared to the use of fossil fuels in a given time period (e.g. 20 to 50 years or even up to centuries).[139]

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[138] European Commission (2016), *Proposal for a Directive of the European Parliament and of the Council on the promotion of the use of energy from renewable sources (recast)*, Brussels: European Commission, Article 26, https://ec.europa.eu/energy/sites/ener/files/documents/1_en_act_part1_v7_1.pdf (accessed 29 Dec. 2016).

[139] European Commission (2016), *Impact Assessment: Sustainability of Bioenergy, Accompanying the document Proposal for a Directive of the European Parliament and of the Council on the promotion of the use of energy from renewable sources (recast),* Brussels: European Commission, p. 16, http://eur-lex.europa.eu/resource.html?uri=cellar:1bdc63bd-b7e9-11e6-9e3c-01aa75ed71a1.0001.02/DOC_1&format=PDF (accessed 29 Dec. 2016).

While considering that most current biomass use in the EU confers substantial greenhouse gas savings – since the feedstock is mostly industrial residues, harvest residues and traditional fuel wood – the commission recognized the potential for change if demand continued to grow, including additional harvesting rather than forest residue removal and the increased use of small roundwood and stumps. 'Hence, and as shown by a recent study… an increase in use of forest biomass for energy may lead to limited greenhouse gas savings or to an increase in emissions.'[140] Modelling conducted for the study also showed that, in the absence of sustainability criteria or other safeguards, growth in the use of forest biomass for energy would result in zero or small additional greenhouse gas emission reductions by 2030, or even, because of changes in forest carbon stock, an increase. And if demand continued to grow to 2050, emissions would increase in all scenarios.[141]

Despite this, however, the European Commission concluded that it was not possible to include changes in forest carbon stock in the calculation of life-cycle emissions to be used for the minimum greenhouse gas savings requirements in the sustainability criteria. Pointing to the wide variation in estimates of the climate impacts, the difficulty in attributing greenhouse gas performance to specific consignments of forest biomass and the problems of evaluating the counterfactuals, it concluded that:

> a reliable assessment of life-cycle biogenic emissions of specific consignments or pathways of forest biomass would be extremely difficult, notably because it would have to be based on subjective choices. In addition, it would pose difficulties linked to verification. Therefore, this option is discarded.[142]

Even in the absence of the inclusion of changes in forest carbon stock in the sustainability criteria, the models used in the impact assessment predicted that the proposals would lead to a slight reduction in net greenhouse gas emissions by 2030, though there was a chance of a slight rise by 2050.[143] This was due mainly to a projected fall of 3.3 per cent in total demand for bioenergy by 2030, compared to business as usual, because of restrictions on sourcing from high-risk countries (a 45 per cent fall in imports into the EU was projected in one model, a 4–19 per cent fall in another) and of increased harvesting and use of domestic roundwood within the EU, which pushed up prices for wood products. The models are subject, however, to considerable levels of uncertainty.

The European Commission considered but discarded other options for constraining forest biomass use, including the following:

- The introduction of limits on the use of forest residues, in order to protect biodiversity and soil fertility. The commission considered that this would be too difficult given the degree of variability in local conditions and, in some regions, the need to remove residues to prevent fire. In addition, it considered that 'forest residues are also normally not traded over a long distance and are not turned into pellets'.[144] (This is notwithstanding the claims of biomass companies such as Drax.)
- Promoting the cascading use of wood, in line with the EU Forest Strategy. The commission considered that a single EU-wide approach was not appropriate given the different circumstances of each member state. Non-binding guidance on the cascading use of wood is expected to be published by 2018.[145]

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[140] Ibid.

[141] Ibid., p. 31.

[142] Ibid., p. 37.

[143] The impact assessment modelled the impacts of four options for constraints on biomass use. Although it did not choose between them, Option 3 is nearest to the proposals contained in the draft directive. For this option, projected cumulative changes in net greenhouse gas emissions are -8 to -34 $MtCO_2$-eq (-0.04 to -0.20 per cent) over 2021–30 and -10 to +17 $MtCO_2$-eq (-0.03 to +0.05 per cent) over the period 2031–50. Ibid., p. 47.

[144] Ibid., p. 126.

[145] Ibid.

- Applying sustainable forest-management requirements to all forest biomass, regardless of origin. The criteria proposed in the draft directive require countries or forests to have particular systems (for legality, the protection of high conservation value areas, etc.) in place rather than requiring operators to ensure that every consignment of biomass is verified as sustainably produced (probably via certification schemes). As the impact assessment explains, this is a risk-based approach designed to minimize costs to forest owners, many of whom are not certified under any forest-certification scheme.[146]

The draft directive, including the proposed sustainability criteria, has entered a period of debate and discussion between the European Parliament and member-state governments.

EU member states

Pending the development of EU-wide criteria, an increasing number of member states have developed their own for eligibility to subsidies or other support mechanisms.[147] As noted above, many member states have possessed relevant requirements for some time, including the following:

- Requirements for minimum levels of efficiency; for example, France requires a minimum conversion efficiency of at least 75 per cent, which rules out anything other than combined heat and power (CHP) plants, whereas Spain gives higher levels of support to biomass plants achieving higher energy efficiency through cogeneration.
- The provision of greater levels of support for small-scale plants; examples include Finland and Germany.
- Encouragement for or requirements that feedstock be sourced from sustainably managed forests; examples include France, Germany, Hungary and Slovenia.
- Support for domestically sourced feedstock instead of imports; examples include Austria, the Czech Republic and Italy.
- Restrictions on certain types of feedstock. For example, France does not allow stemwood; in Hungary feedstock cannot be of higher quality than firewood and no subsidies are provided for bioenergy produced from stemwood of a diameter above 10 cm; and Poland only allows the use of forestry residues and requires a minimum (increasing) share of agricultural biomass.

For all member states, domestically produced or imported woody biomass is also subject to the EU Timber Regulation (995/2010, in force since 2013), which prohibits the placing on the EU market of products that have been illegally produced and requires companies that first place wood products on the EU market to have in place a system of 'due diligence' to minimize the risk of them handling illegal material. If fully enforced, this is likely to act as a constraint on the supply of woody biomass, in particular from Eastern European countries (including, possibly, some EU member states) and Russia.

To date, the most detailed sets of criteria have been developed in Belgium, Denmark, the Netherlands and the UK. In some cases these borrow from existing public-sector procurement policies designed to

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[146] Ibid., p. 37.

[147] Except where noted, information taken from Pelkmans, L. et al. (2012), *Benchmarking biomass sustainability criteria for energy purposes*; Toop, G. (2013), 'Overview of EU criteria and national initiatives'; Junginger, M. (2015) 'Sustainability regulation for solid biomass for energy in NL, BE & UK', presentation to Conference on Biomass and Sustainability, Copernicus Institute, Utrecht University 19 October 2015, Copenhagen; and Richter, K. (2016), *A Comparison of National Sustainability Schemes for Solid Biomass in the EU,* Fern, http://www.fern.org/sites/fern.org/files/comparison%20of%20national%20sustainability%20schemes.pdf (accessed 30 Dec. 2016).

purchase wood products that are legally produced and from sustainably managed forests.[148] In general they have two components – requirements for minimum levels of greenhouse gas savings compared to fossil fuels, and requirements (often called 'land criteria') relating to the legality and sustainability of forest management. Sometimes other criteria, such as restrictions on types of feedstock or on minimum plant energy efficiency levels, are also included.

Belgium

Energy policy in Belgium is devolved to the country's three regions: Brussels, Flanders and Wallonia. All three require electricity suppliers to supply a prescribed proportion of renewable energy, underpinned by a system of tradable green certificates, though the three systems are not fully compatible with each other.

In Flanders, the value of a certificate for bioenergy is calculated according to its life-cycle energy balance, whereas in Brussels and Wallonia, eligibility to green certificates depends on the greenhouse gas saving compared to the best available natural gas system. In all cases, however, changes in the forest carbon stock are ignored (i.e. the combustion of biomass is assumed to be zero-carbon); only emissions from production, processing and transport are taken into account.

In addition, in Flanders biomass streams suitable for other uses – e.g. wood that could be used by the pulp and paper or wood-processing industries, except for bark, sawdust, fine pruning wood with a diameter less than 4 cm, twigs of tree crowns with a diameter less than 4 cm, and stumps up to 30 cm above the ground – are not entitled to receive green certificates. To determine whether specific products may be used for bioenergy, the Flemish Energy Agency seeks consent from the Public Waste Agency of Flanders and the federations of the paper and wood-using industries. (Fearing competition for raw materials, Belgium's paper and wood-processing industries have been generally hostile to the expansion of the biomass energy sector). A more comprehensive set of criteria is being developed.

Wallonia requires feedstock to be 'sustainable', i.e. the use of the resource must not compromise its use by future generations. This is subject to audit.

Denmark

In Denmark, woody biomass for energy is included in the government's timber-procurement policy, most recently revised in 2014, although its application to bioenergy is voluntary throughout the public sector. The policy sets out detailed definitions of 'legal' and 'sustainable' (very similar to those in the British and Luxembourg policies). Products certified under the two main international forest certification schemes – those of the Forest Stewardship Council (FSC) and Programme for the Endorsement of Forest Certification (PEFC) – satisfy the criteria. These schemes aim to ensure that the ways in which forests are managed and harvested meet criteria for legality and sustainability, but they do not include any criteria – such as greenhouse gas savings relative to fossil fuels – relating to the use of the products for energy.

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[148] For more detail, see Brack, D. (2014), *Promoting Legal and Sustainable Timber: Using Public Procurement Policy*, Research Paper, London: Royal Institute of International Affairs, https://www.chathamhouse.org/sites/files/chathamhouse/field/field_document/20140908PromotingLegalSustainableTimberBrackFinal.pdf (accessed 29 Dec. 2016).

In 2015, in response to a request from the government, the Danish District Heating Association and the Danish Energy Association introduced a voluntary sustainability standard for biomass.[149] This includes similar requirements for legality and sustainability as the government's procurement policy, and products certified under the FSC, PEFC or Sustainable Biomass Partnership (see below) schemes are considered to meet them. The standard also requires greenhouse gas reduction levels of 70 per cent by 2015, 72 per cent by 2020 and 75 per cent by 2025, compared to fossil-fuel reference levels according to the Renewable Energy Directive methodology. This does not include emissions from changes in forest carbon stock or indirect land use change, though the industry is working to develop further criteria to cover these. The standard also aims not to use biomass where there is regionally competing demand for high-value wood resources or if the supply of those resources derives from deforestation or inappropriate conversion of forest to agriculture.

As noted, application of the standard is voluntary (and only applies to stations with capacity above 20 MW), but the associations aim to increase the level of compliance with the requirements of CHP installations (the only large-scale consumers of biomass for energy in Denmark) from 40 per cent in 2016 to 100 per cent in 2019. The standard will be reviewed in 2018.

The Netherlands

The framework for the Netherlands' renewable energy policy was set in 2013, when government, industry, unions and NGOs negotiated the Energy Agreement for Sustainable Growth, setting out the means of reaching the country's targets for renewable energy.[150] This included an upper limit of 25 PJ on energy production from biomass co-firing, and the application of sustainability criteria to co-fired biomass.

The criteria were to be negotiated by the energy sector and environmental organizations, and a first draft was published in 2015. The criteria, which apply to industrial boiler steam production from wood pellets as well as to biomass used in co-firing (though only to larger plants – dedicated biomass above 10 MW and, for co-firing, coal stations above 100 MW), include the following:[151]

- A minimum average reduction of 70 per cent of greenhouse gas emissions compared to fossil fuels, calculated according to the Renewable Energy Directive methodology. While this does not account for any changes in forest carbon stock, evidence must be provided to show that the forest is managed 'with the aim of retaining or increasing carbon stocks in the medium or long term' and with a low risk of indirect land use change.
- Restrictions on the types of feedstock: stumps are not allowed, but tops, branches, residues and roundwood are permitted, as long as on average less than half the volume of the annual roundwood harvest from the forest is processed as biomass for energy. In addition, wastes, such as mill residues or post-consumer wood waste, are permitted.
- The exclusion of biomass sourced from high-conservation-value or converted forest land or peatland or where soil and water quality have not been maintained.

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[149] Dansk Energi and Danske Fjernvarme (2015), 'Industry agreement to ensure sustainable biomass (wood pellets and wood chips)', www.danskenergi.dk/~/media/Biomasse/IndustryAgreement_Biomass-20150909.ashx (accessed 29 Dec. 2016).
[150] Energie Akoord and Sociaal-Economische Raad (2013), *The Agreement on Energy for Sustainable Growth: A Policy in Practice*, http://www.energieakkoordser.nl/doen/engels.aspx (accessed 29 Dec. 2016).
[151] Netherlands Enterprise Agency (2016), *SDE+ sustainability requirements for solid biomass*, http://english.rvo.nl/sites/default/files/2016/03/SDE%20Sustainability%20requirements%20for%20solid%20biomass.pdf (accessed 29 Dec. 2016).

- Requirements for sustainable forest management, mainly taken from the country's timber-procurement policy, including the maintenance and enhancement of biodiversity and the health and production capacity of the forest and its contribution to the local economy.

A detailed system for the verification of compliance with these criteria, including elements that must be included in the sustainable forest-management system and a chain of custody system, is still under development and should be finalized in 2017.[152] The Dutch system has the most detailed of all the national sustainability criteria, and some doubt has been expressed that the requirements can actually be satisfied in practice.[153]

The UK

Since 2015 the UK has applied sustainability criteria for solid biomass under its three main support programmes for renewable energy: for electricity, the Renewables Obligation and the Contracts for Difference system that is now replacing it, and for heat the Renewable Heat Incentive.

There are two sets of criteria. The greenhouse gas criteria, which aim to account for the life-cycle greenhouse gas emissions of the biomass, include targets for emissions per unit of electricity: a minimum of 60 per cent emissions saving by 2017, compared to the 1990 level, increasing to 75 per cent savings by 2025. This is calculated according to the Renewable Energy Directive methodology, which excludes changes in forest carbon stock (apart from direct land-use change) and emissions from indirect land-use change.

The land criteria focus on the land from which the biomass is sourced. These requirements are built on the environmental and social criteria for legal and sustainable forest products contained in the government's timber procurement policy. FSC and PEFC-certified products satisfy the criteria in this respect, but since much of the biomass sourced from the US is not certified (the uptake of forest certification schemes in the US is relatively low), the regulations also allow operators to supply credible evidence of a low risk of non-compliance against all the criteria for a defined region (an area across which relevant legislation is the same, e.g. a US state) or a smaller area if they can trace it back.[154] As in the timber-procurement policy, up to 30 per cent of the biomass used in a facility can be non-compliant with the sustainability requirements (though it must be legal).

In addition, in 2013, the UK announced a cap on approvals for new dedicated biomass plants in the face of a steep increase in the number of applications. No contracts for biomass power were awarded under the first auction for the new Contracts for Difference in February 2015. The next round, which is scheduled to begin in April 2017, will be open to bids for dedicated biomass with CHP. Three contracts have been awarded without auction, however: to Drax for the conversion of its third unit and to two other power stations, one a coal-to-biomass conversion and one a new dedicated biomass CHP plant.

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[152] For an outline of the proposals and responses to a public consultation on them, see Netherlands Enterprise Agency (2016), *Report on the consultation of the draft verification protocol 'Sustainability solid biomass',* http://english.rvo.nl/sites/default/files/2016/07/Report-on-the-consultation-of-the-draft-verification-protocol-sustainability-solid-biomass-June-2016.pdf (accessed 29 Dec. 2016).

[153] Griffiths, J. (2016), 'Background Paper for Scoping Dialogue on Sustainable Woody Biomass for Energy', p. 10.

[154] See UK Department of Energy and Climate Change (2014), *Risk Based Regional Assessment: A Checklist Approach*, London: UK Department of Energy and Climate Change, https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/390148/141222_Risk_Based_Regional_Assessment_-_A_Checklist_Approach_-_Guidance_final.pdf (accessed 30 Dec. 2016).

Other government standards

No other national biomass sustainability standards have been developed. In many cases countries regulate domestically produced biomass for energy in accordance with their own national regulations for forestry or agriculture – and sometimes apply their timber-procurement policies – but these do not include carbon-saving requirements.

In the US, the state of Massachusetts introduced sustainability criteria in 2012. Biomass will only be eligible for subsidies under the state's Renewable Portfolio Standard if it is an eligible fuel – which includes predominantly timber harvest residues, including tops and branches, rather than whole trees – and as long as sufficient woody material is left on the forest floor to replenish soil nutrients and protect wildlife. In addition, biomass plants must demonstrate emissions reductions of at least 50 per cent over 20 years on the basis of life-cycle emissions analyses, including a carbon debt emissions factor, and must satisfy a minimum efficiency level.

Voluntary certification schemes

Voluntary forest certification systems – of which FSC and PEFC are the main global schemes – have come to act as the principal means of proving compliance with many governments' timber-procurement policies and are often used as proof of meeting some of the biomass sustainability criteria described above. These schemes do not yet contain criteria for greenhouse gas emissions and carbon stocks, however, although this possibility is under discussion. Some biomass and biomass energy companies are certified under one or both of these schemes.

Other schemes have been developed with the aim of including climate impacts alongside other criteria. The Green Gold Label standard, for example, builds on other certification systems in aiming to cover the production, processing, transport and final energy transformation of biomass.[155] Founded in 2002 and certifying biomass for the production of bio-based chemicals and other products as well as for energy, it has limited coverage: by November 2016, just 14 companies had been certified, six in the US, three in Canada and five in the EU.

The Sustainable Biomass Partnership

The main biomass certification scheme that has emerged so far is that of the Sustainable Biomass Partnership (SBP), established in 2013 by seven major European utility companies using biomass with the aim of influencing and meeting EU and member-state sustainability criteria for biomass for energy.[156] This built on the criteria included in several national timber-procurement policies and biomass sustainability requirements; some of the companies were also developing their own codes of practice for sustainable sourcing.[157]

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[155] See the Green Gold Label website, http://www.greengoldcertified.org.

[156] See the Sustainable Biomass Partnership website, http://www.sustainablebiomasspartnership.org.

[157] See, for example, DONG Energy (2014), *DONG Energy Programme For Sustainable Biomass Sourcing,* http://assets.dongenergy.com/DONGEnergyDocuments/com/Responsibility/Documents/2014/DONG_Energys_Programme_for_Sustainable_Biomass_Sourcing_EN.pdf?WT.mc_id=sustainable_biomass_sourcing_2015 (accessed 30 Dec. 2016).

The SBP standard includes the following principles and criteria:[158]

- Definition of the supply base to ensure feedstock can be traced back to its source area.
- Compliance with all relevant laws, including traditional and civil rights, drawing on criteria in the UK's timber-procurement policy.
- Sustainable management of the forest and forest operations, and protection for labour and community rights, again drawing mainly on the UK's timber-procurement policy.
- 'Regional carbon stocks are maintained or increased over the medium to long term' (principle 2.9). This includes not sourcing feedstock from areas that had high carbon stocks in January 2008 and no longer have them, and sourcing only 'where analysis demonstrates that feedstock harvesting does not diminish the capability of the forest to act as an effective sink or store of carbon over the long term'.
- No use of genetically modified trees.

The SBP standard includes a calculation of the energy and carbon balance of the biomass used for energy, to be carried out by the end user using data from the supplier.[159] While this includes a requirement to record the type of feedstock (primary feedstock from forests (products or residues), woody energy crops, wood industry residues or post-consumer wood; and classification by physical form: sawdust, woodchips, roundwood, wood logs, bark, etc.) and detailed calculations of the energy used in the supply chain (harvesting, production, transport and storage), it does not include a calculation of any change in forest carbon stock.

The SBP does not set precisely what evidence must be provided to demonstrate compliance with each indicator on the grounds that this will vary among different operations, though it does include examples for each of its criteria. Verification involves a regional risk-based approach, based on a desk-based assessment against the criteria leading to a risk rating for each indicator. Where risks are identified, appropriate mitigation measures must be defined, implemented and monitored.

Risk assessments for Estonia, Latvia and Lithuania were published in 2015. Operations in all three countries were found to have a low risk of non-compliance, with risks identified with just three out of 38 criteria: possessing procedures to address potential threats to high-conservation-value areas (all three countries were found to be at risk), possessing procedures for identifying high-conservation-value areas (Latvia) and means to ensure the protection of forest workers' health and safety (Latvia and Lithuania).

No figures are yet available on the extent of the biomass energy supply chain covered by SBP certification, but given that the system was set up by several major European energy companies, it has significant potential at least in the European market. The British and Danish authorities have confirmed that SBP certification meets the requirements of their national criteria. As of the autumn of 2016, six bodies had been accredited to carry out certification against the SBP standard, and certificates had been issued to over 60 organizations.[160] This did not include Enviva, the pellet company most commonly associated with accusations from NGOs of unsustainable practices.

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[158] Sustainable Biomass Partnership (2015), *SBP Framework Standard 1: Feedstock Compliance Standard*, http://www.sustainablebiomasspartnership.org/docs/2015-03/sbp-standard-1-feedstock-compliance-standard-v1-0.pdf (accessed 30 Dec. 2016).

[159] Sustainable Biomass Partnership (2016), *SBP Instruction Document 5B: Energy and GHG Data,* Version 1.1, http://www.sustainablebiomasspartnership.org/docs/Instruction-Document-5B-Energy-and-GHG-Data-v1-1-Oct16.pdf (accessed 30 Dec. 2016).

[160] See the section on 'Approvals and Certifications' on the Sustainable Biomass Partnership website, http://www.sustainablebiomasspartnership.org/approvals-and-certifications.

Conclusions and recommendations

In principle, applying sustainability criteria to the provision of regulatory and financial support to biomass energy is a potential way of tackling the problems discussed in Chapter 1, and of restricting support to those uses with zero or low carbon payback periods as well as to those where the feedstock originates from legally and sustainably managed forests.

However, the existing schemes in EU member states, the draft criteria included in the proposed new Renewable Energy Directive and the voluntary certification schemes now developing, including that of the Sustainability Biomass Partnership, are not satisfactory. Most importantly, they fail to account, comprehensively or at all, for changes in forest carbon stock (apart from direct land-use change), which, as discussed in Chapter 1, is a crucial element in determining climate impacts. Effectively, these criteria permit the provision of financial and regulatory support to policy options that could increase carbon emissions in the short, medium and possibly long term.

The requirements in the Dutch criteria that the forest is managed ‘with the aim of retaining or increasing carbon stocks in the medium or long term’, and in the SBP’s standard that ‘regional carbon stocks are maintained or increased over the medium to long term’ are too vague. Forest carbon stock levels may stay the same or increase for reasons entirely unconnected with use for energy; the important issue is what levels they would have reached in the absence of biomass energy use. In addition, as discussed in Chapter 1, from the point of view of mitigating climate change, there is a major difference between the medium term and the long term; arguably, anything longer than the short term is too long.

The inclusion in the draft new Renewable Energy Directive of a requirement for the country from which the forest biomass is sourced to be a party to the Paris Agreement that accounts for changes in carbon stock associated with biomass harvests is a step in the right direction, ensuring that the emissions resulting from the biomass use count against climate targets. However, the phrase ‘accounted towards the country’s climate commitments’ needs to be carefully defined. As explained in Chapter 2, the choice of forest baseline against which countries account can mean that some biomass-related emissions effectively go unaccounted for. In addition, as discussed in Chapter 1, the full climate impact of the use of forest residues may be significantly underestimated in current models, given its potential effects on soil carbon levels and tree growth rates. If a country is not a party to the Paris Agreement or does not account for biomass-related carbon stock changes, the draft criteria specify that laws must be in place in the country of origin to ‘conserve and enhance carbon stocks and sinks’. This begs the same kind of questions as the terminology used in the Dutch and SBP criteria discussed above, and is equally unsatisfactory.

Robust sustainability criteria must deal with the impact on greenhouse gas emissions as well as the legality and sustainability of forest management. One option would be for the greenhouse gas element to be underpinned by a comprehensive life-cycle analysis for each type of feedstock, including changes in the forest carbon stock alongside supply-chain emissions associated with harvesting, processing and transport (including methane emissions from storage, as discussed in Chapter 1). This is not a straightforward process – varying with the type of tree species, the location of the forest, the characteristics of the technology involved, transport distances and so on – but the UK’s BEaC calculator, among other means of estimating payback periods, provides a potential methodology. A similar approach could be applied to calculate default values for different biomass feedstocks (the draft Renewable Energy Directive contains default values, but only taking into account supply-chain emissions). However, as discussed in Chapter 1, the impact of biomass energy use also depends on the counterfactual: what would have happened to the wood, and the forest from which it was sourced, if it had not been used for energy? Since this is not a fixed element, it is virtually impossible for sustainability criteria to incorporate it.

A more practical approach would be to limit the types of feedstock that can be used, as several EU member states and the US state of Massachusetts already do. The aim would be to restrict eligibility for support to those feedstocks that are most likely to reduce net carbon emissions (or have low carbon payback periods): primarily mill residues, together with post-consumer waste. Fast-decaying forest residues could also fit into this category, but in practice this is small-diameter material that is likely to contain too much moisture and dirt to render it usable by biomass plants; and it would be very difficult for policy to distinguish easily between fast and slow-decaying residues.

An additional element could be a requirement for a minimum level of efficiency of the plant in which the biomass is burnt (again, as in a number of EU member states and, for new installations, in the draft Renewable Energy Directive), maximizing the energy delivered per unit of carbon emitted. In practice, this should restrict financial and regulatory support for biomass use to combined heat and power installations.

Even when restricted in this way, policies should ensure that subsidies do not encourage the biomass industry to divert raw material (such as mill residues) away from alternative uses (such as fibreboard), which have far lower impacts on carbon emissions. This may require the sustainability criteria to be adjusted from time to time depending on market conditions. The cascading principle included in the EU Forest Strategy, in which combustion for energy is the last use of wood after a series of other uses, is a good one and it is regrettable that it is not reflected in the new draft Renewable Energy Directive.

Alongside these emissions criteria, land criteria – applying the same kind of requirements for legal and sustainable sourcing already found in many timber-procurement policies and the FSC and PEFC – play an important role in protecting the way in which the forests are managed. Most national and voluntary sustainability criteria already contain these kind of requirements, but they face a problem in sourcing from areas such as the US southeast, where the uptake of forest certification is very low and most forests are largely unregulated. It remains to be seen whether the risk-based approach found in the UK requirements, the SBP standard and the draft Renewable Energy Directive can deliver products that reliably meet the criteria. Desk-based assessments should be supplemented by on-the-ground inspections, ensuring, for example, that support is not given where whole trees are used, and in particular where old-growth forests are being logged for energy or converted to plantations.

Conclusion

The use of woody biomass for energy cannot be considered to be automatically carbon-neutral under all circumstances, though most policy frameworks treat it as though it is. In reality, carbon dioxide and methane will be emitted from the combustion of woody biomass (generally at higher levels than from the fossil fuels it replaces) and from its supply chain of harvesting, collecting, processing and transport. In addition, where the feedstock derives from harvesting whole trees, net carbon emissions will increase from the foregone carbon sequestration that would have occurred had the trees been left growing.

Some types of biomass feedstock can be carbon-neutral, at least over a period of a few years, including in particular sawmill residues. These are wastes from other forest operations that imply no additional harvesting, and if otherwise burnt as waste or left to rot would release carbon to the atmosphere in any case. Black liquor is a waste from the pulp and paper industry that would otherwise have to be disposed of. It can make sense to burn these types of woody biomass for energy (particularly on-site, with no need for processing or transport), and in any case in many instances this will be economic without the need for subsidy. Fast-decaying (small-diameter) forest residues are unlikely to be usable by biomass plants, and burning slowly decaying forest residues for energy may mean that carbon emissions stay higher than if fossil fuels had been used for decades, which is a matter of considerable concern given the current rate of global warming. If mill residues are diverted from use as wood products to use as energy, net carbon emissions will be higher as a result.

Policies providing financial and regulatory support to woody biomass should discriminate between the different feedstocks on this basis. It cannot make sense to support practices that raise greenhouse gas concentrations over the short, medium and sometimes long term. Yet this is precisely what most existing policy frameworks do, ignoring changes in forest carbon stock and providing support to all biomass feedstocks irrespective of their impact on the climate. The international rules designed to account for changes in forest carbon levels in the land-use sector do not do this comprehensively, and some of the emissions from woody biomass may go unaccounted for.

Although comparisons are generally made between the use of woody biomass and the use of fossil fuels, particularly coal, in practice biomass energy may be more likely to displace other sources of renewable energy rather than fossil fuels. This is particularly the case where governments have adopted national targets for the growth of renewables (as in the EU) and where they have limited budgets for providing subsidies (as in, for example, the UK). In these cases, if biomass is not available, is constrained by sustainability criteria or is not subsidized, other forms of renewable energy may grow faster. (This raises questions of the costs of competing renewables – which for many, particularly wind and solar PV, are falling much faster than those of biomass – and the role of biomass as a system balancer, being a dispatchable rather than a variable source – which will be considered at more length in the companion paper, *Woody Biomass for Power and Heat: Global Patterns of Demand and Supply*.)

For all these reasons, current biomass policy frameworks are not fit for purpose. Sustainability criteria should be used to restrict support to mill residues that are produced from legal and sustainable sources (as defined in many timber procurement policies and forest certification schemes) and do not divert raw material away from wood products. This requires substantial changes in current policies in the EU and elsewhere to ensure that biomass policies contribute to mitigating climate change rather than exacerbating it.

About the Author

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His areas of expertise include international forestry policy, forest governance and the timber trade, climate policy, low-carbon investment, bioenergy, public procurement, the interaction between environmental regulation and trade rules, ozone depletion and the Montreal Protocol, and international environmental crime, particularly illegal logging and the trade in illegal timber.

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