Forest Research

Carbon impacts of biomass consumed in the EU

Supplementary analysis and interpretation for the European Climate Foundation

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The Research Agency of the Forestry Commission

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Project report for ECF

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Executive Summary

This report was commissioned from Forest Research by the European Climate Foundation (ECF) to provide an elaborated analysis to clarify the findings of a project undertaken for the European Commission (DG ENER), known as Carbon Impacts of Biomass Consumed in the EU, and latterly referred to as the "Bioimpact Project".

The ECF asked Forest Research to further analyse the results gained from the Bioimpact Project to deliver insights on 3 key questions pertinent to EU bioenergy policy design:

Comparison of Bioenergy Scenarios - Based on the Bioimpact Project, provide simplified conclusions on the types of bioenergy scenario that will deliver relatively higher or lower GHG reductions compared to the baseline scenario.

Statement of Risk of EU Bioenergy Policy - Based on the answer to the first question, provide a statement of the risks associated with EU bioenergy policy, both with and without specific measures to ensure sustainable supply.

Criteria to ensure GHG reductions - Provide a practical set of sustainability criteria to ensure that those bio feedstocks used to meet EU bioenergy goals deliver GHG reductions, and assess whether the RED II covers these issues.

1 Comparison of Bioenergy Scenarios

The scenarios used in this project were the same as in the original Bioimpact project. These scenarios were subjected to Consequential Life Cycle Analysis (CLCA). The purpose of CLCA is to determine the total collective consequences of a course of action or a policy, compared to a counterfactual situation (i.e. in which the action or policy is not pursued), without attempting to attribute specific GHG emissions to individual components of the system (e.g. specific biomass feedstocks). The following summarises the modelling results:

The scenario of unconstrained bioenergy use (B) and the scenario with higher imported wood (C1) achieve the lowest GHG reductions because they emphasize forest management and wood utilization practices involving additional harvesting and they place less emphasis on the utilization of small/early thinnings, forest residues and industrial residues (which deliver higher GHG reductions).

The scenario that emphasizes domestic forest bioenergy (C3) performs relatively well because it emphasizes forest management and wood utilization practices involving utilization of small/early thinnings, forest residues and industrial residues (which deliver higher GHG reductions) and places less emphasis on additional harvesting above baseline levels.

The scenario that backs away from bioenergy (D) performs best in terms of GHG reductions because the level of forest bioenergy production is lower than in the Reference Scenario as a result of the de-prioritization of bioenergy consumption. However, there are additional financial costs associated with this scenario.

The essential implications of these conclusions are that:

Bioenergy production involving additional harvesting, even if that involves co-production as part of additional harvesting, can involve significant risks of high GHG emissions.

Bioenergy production involving utilization of small/early thinnings, forest residues and industrial residues involves low risks and should lead to low GHG emissions.

2 Statement of Risk of EU Bioenergy Policy

If a cautious position were to be taken, the project findings lead to the following tentative conclusion:

Unless appropriate policy measures are taken to support sustainable bioenergy supply (in terms of impacts on GHG emissions), particularly in the case of forest bioenergy supply, a significant increase in bioenergy use in the EU is likely to lead to a net increase, rather than decrease, in GHG emissions being contributed from bioenergy sources.

Whilst such a conclusion is reasonable based on the project findings, it should be clarified that, strictly, the results should not be interpreted to imply that the increased use of bioenergy in the EU must ***inevitably*** involve increased GHG emissions. Rather, the results strongly indicate that there are ***significant risks*** of increases in GHG emissions associated with greater bioenergy use, in particular forest bioenergy use, ***unless*** there are appropriate checks and balances on the supply and consumption of bioenergy sources with regard to associated GHG emissions. Hence, the corollary of this conclusion is that:

If specific measures are taken to ensure only sustainable bioenergy (in terms of impacts on GHG emissions) is incentivized, a net decrease, rather than increase, in GHG emissions is likely to be associated with bioenergy sources.

3 Criteria to ensure GHG reductions

The key findings and conclusions of this project would appear to suggest two major policy options with regard to renewable energy and the potential contribution of bioenergy towards achieving significant near-term reductions in GHG emissions compared to fossil fuels.

One option would involve de-prioritizing bioenergy in order to avoid potential risks associated with some bioenergy sources, whilst noting that this would be likely to require at least some of the following:

- The increased use of other renewable energy sources (particularly solar and wind power)
- More concerted efforts towards energy efficiency or demand-side response in the EU region across all sectors, but particularly in the residential and transport sectors
- Increased use of nuclear power (involving both current and assumed future technologies)
- Increased reliance on imports of natural gas, nuclear fuels and electricity into the EU region from elsewhere
- Some increased deployment of carbon capture and storage technologies (compared with scenarios involving higher bioenergy use).

The **alternative option** would be to carry on with supporting a contribution from bioenergy sources towards targets for renewable energy and GHG emissions reductions, whilst putting in place a policy framework capable of ensuring that bioenergy sources genuinely lead to significant near-term reductions in GHG emissions compared to fossil fuels.

If this alternative bioenergy option were to be pursued, it is important to recognize that this study has identified that bioenergy, and forest bioenergy in particular, can be a potential contributor to increased GHG emissions. However, this is not inevitable if a framework is adopted to ensure only agricultural and forest biomass sources that deliver genuine emissions reductions are used for energy purposes. The following 15 criteria have been proposed provisionally as the basis for such a framework. There are 5 criteria concerned with forest management that are optional to take into account. There are 2 criteria concerned with wood supply and feedstocks which must be considered. If the optional forest management criteria are not applied, and in some circumstances depending on the outcome of applying these criteria, then 8 conditional criteria related to feedstocks must also be taken into account.

Optional forest management criteria

1) Deforestation - Disallow supplies of forest bioenergy that lead to deforestation

2) Afforestation - Strongly favour supplies of forest bioenergy where these are explicitly associated with afforestation activities. However, avoid afforestation activities:

- On soils with existing high organic carbon content
- That lead to high risks of indirect land-use change.

3) Improvement of growing stock - Strongly favour supplies of forest bioenergy where these are explicitly associated with activities to conserve and enhance forest growing stock, carbon stocks and forest productivity

4) Growth rate - Disfavour forest bioenergy production from forest areas with low growth rates. Tentatively, low growth rate is defined as 2 m^3 ha^{-1} yr^{-1} or less. Possible exemptions in some cases, e.g. disease infested forest areas.

5) Thinning and clear felling - If the level of supply of forest bioenergy from thinning and felling activities in forest areas is consistent with long-term historical levels, and with the principle of sustainable yield, then risks of issues with GHG emissions are low. If the level of forest bioenergy from thinning and felling activities in forest areas involves increased supply compared with long-term historical levels, then favour production from thinning over production from felling, with the aims of:

- Improving the quality of the remaining growing stock
- Minimising disturbance of litter and soil carbon.

If, and only if, the level of forest bioenergy from thinning and felling activities in forest areas involves increased supply compared with long-term historical levels, then it is necessary to consider the conditional criteria as well as the mandatory criterion regarding use of wood feedstocks for bioenergy.

Mandatory wood supply and feedstock criteria

6) Scale of forest bioenergy use - Aim for levels of forest bioenergy use that are well within the long-term sustainable-yield capacity of the supplying forest areas. When setting levels for bioenergy use, take account of the consumption of biomass for other uses (i.e. materials) and levels of biomass consumption outside the EU region.

7) Stumps including roots - Strongly disfavour supplies of forest bioenergy from stumps including roots.

Conditional wood feedstock criteria

8) Post-consumer waste wood - Strongly favour supplies of forest bioenergy from post-consumer waste wood. Particularly favour such sources where the waste wood would otherwise be burnt or put in landfill without energy recovery. Also favour use of waste wood at levels that do not compete with current levels of consumption of such feedstocks for material uses (e.g. wood-based panels).

9) Industrial residues - Strongly favour supplies of forest bioenergy from industrial residues. Particularly favour such sources where the residues would otherwise be burnt as waste without energy recovery. Also favour use of industrial residues at levels that do not compete with current levels of consumption of such feedstocks for material uses (e.g. wood-based panels).

10) Forest residues - Strongly favour supplies of bioenergy from fast-decaying forest residues (i.e. apart from stumps including roots or other large residues) provided this avoids levels of extraction of forest residues that lead to high risks of degradation of site/soil quality.

11) Salvage logging - Favour supplies of wood biomass from salvage logging where a simply calculated but robust estimate of GHG emissions meets a defined minimum threshold.

12) Whole tree stems - Restrict supplies of forest bioenergy from whole tree stems to small/early thinnings with the aim of improving the quality of the remaining growing stock. Favour situations in which, otherwise, there would be limited incentives to thin and improve forest stands.

Alternatively, favour supplies of wood biomass from small/early thinnings where a simply calculated but robust estimate of GHG emissions meets a defined minimum threshold.

13) Small Roundwood - Favour supplies of forest bioenergy from small roundwood at levels that do not compete with current levels of consumption of such feedstocks for material uses. Particularly favour such sources where the small roundwood would otherwise be burnt without energy recovery or sent to landfill.

14) Sawn timber - Strongly disfavour supplies of forest bioenergy from wood feedstocks suitable for use for sawn timber products.

15) Co-production - Strongly favour the supply of forest bioenergy as a by-product of wood harvesting for the supply of long-lived material wood products. However, it is very important to ensure that flanking measures are in place to ensure that other feedstock criteria above are met and to encourage the disposal of material wood products at end of life with energy recovery and/or in a way that ensures low GHG emissions.

The ECF asked Forest Research to review the RED II in its current form and to give an indication of whether the above criteria are represented. The RED II makes no specific provisions for 9 out of the 15 recommended criteria. For 3 of the 15 recommended criteria the RED II might be expected to deliver some indirect, but non-specific, support. In 3 of the 15 recommended criteria, the RED will deliver a direct policy signal.

It is important that those countries seeking to implement the RED II are aware of the relevance of the above sustainability criteria for the implementation of the RED II, because if the EU bioenergy policy is to meet its stated goal of reducing GHG emissions, such criteria will need to be implemented within national policy.

1. Introduction

This report was commissioned from Forest Research by the European Climate Foundation (ECF) to provide an elaborated analysis to clarify the findings of a project undertaken for the European Commission (DG ENER), known as Carbon Impacts of Biomass Consumed in the EU, and latterly referred to as the "Bioimpact Project".

The original project was commissioned by the European Commission (EC) to gain a better understanding of the greenhouse gas (GHG) emissions associated with the use of biomass for energy in the EU. The project was a consortium of research institutions in the EU consisting of: Forest Research (UK), North Energy Associates (UK), Alterra (Netherlands) and VTT Technical Research Centre of Finland.

In recent years reports of life cycle assessment (LCA) studies of biomass for energy have been published that arrive at differing, and sometimes conflicting conclusions about the net impact on GHG emissions, and the timescale over which these impacts (negative or positive) may be experienced. At face value it appeared that there was considerable uncertainty in the scientific community as to whether the use of bioenergy could lead to genuine reductions in GHG emissions or not. The Bioimpact Project aimed to:

- Clarify the causes of variability in published estimates of GHG emissions from bioenergy use (through a critical review of relevant scientific literature), and
- Evaluate the potential for bioenergy to contribute towards achieving GHG emissions reductions in the EU (through life cycle assessment of selected scenarios for future bioenergy use in the EU).

The outcomes of the project have been documented in a Task 1 report[1], presenting the review of literature and in a final project report[2]. The size of these reports and the scale and complexity of the analyses presented can make it difficult to identify the key conclusions and messages about the benefits or otherwise of specific bioenergy sources, in terms of impacts on GHG emissions. The purpose of this report is to provide further

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[1] Matthews, R., Sokka, L., Soimakallio, S., Mortimer, N., Rix, J., Schelhaas, M-J., Jenkins, T., Hogan, G., Mackie, E., Morris, A. and Randle, T. (2014a) Review of literature on biogenic carbon and life cycle assessment of forest bioenergy. Final Task 1 report, EU DG ENER project ENER/C1/427, 'Carbon impacts of biomass consumed in the EU'. Forest Research: Farnham. At: http://ec.europa.eu/energy/sites/ener/files/2014_biomass_forest_research_report_.pdf.

[2] Matthews, R.W., Mortimer, N.D., Lesschen, J.P., Lindroos, T.J., Sokka, L., Morris, A., Henshall, P.A., Hatto, C., Mwabonje, O., Rix, J., Mackie, E.D., and Sayce, M. (2015) Carbon impacts of biomass consumed in the EU: quantitative assessment. Final project report, project: DG ENER/C1/427. Part A, Main Report and Part B, Appendices. Forest Research: Farnham, United Kingdom. At:
https://ec.europa.eu/energy/sites/ener/files/documents/EU%20Carbon%20Impacts%20of%20Biomass%20Consumed%20in%20the%20EU%20final.pdf
https://ec.europa.eu/energy/sites/ener/files/documents/EU%20Carbon%20Impacts%20of%20Biomass%20Consumed%20in%20the%20EU%20Appendices%20final.pdf

analysis and exploration of the project result, highlighting the critical findings and points arising from the project regarding bioenergy use in the EU as a contribution towards achieving reductions in GHG emissions. The implications of the conclusions are also considered in the context of relevant legislation under development and implementation in the EU.

2. Aim of the project

The aim of the Bioimpact Project was to perform a *qualitative* and *quantitative* assessment of the direct and indirect GHG emissions associated with the different types of solid and gaseous biomass used in electricity and heating/cooling in the EU under a number of scenarios, focussing on the period to 2030 but with indicative projections up to 2050, in order to provide objective information on which to base further development of policy on the role of biomass as a source of energy with low associated GHG emissions. The *qualitative* assessment was based on the literature review published as the Task 1 report and the *quantitative* assessment involved the LCA of a set of defined scenarios for future bioenergy use in the EU, published in the main report.

It is very important to recognize the aims that the qualitative and quantitative assessments were intended to address, and also what these assessments could not directly or comprehensively address.

The qualitative assessment aimed to draw insights about the causes of variability in published estimates of GHG emissions associated with the use of specific bioenergy sources. The scope of the qualitative assessment was restricted to forest bioenergy sources which were the subject of considerable debate at the time of the project. Because of the scope specified, and because the assessment was based on a review of existing literature, it did not provide a comprehensive and systematic analysis of the sensitivity of GHG emissions with respect to different biomass feedstocks and production pathways.

The quantitative assessment aimed to evaluate the impacts on global GHG emissions resulting from certain specified future scenarios for bioenergy use in the EU. The scenarios were defined to explore sensitivities to choices amongst major bioenergy feedstocks (e.g. types of agricultural biomass and forest biomass) and approaches to managing land to include biomass production. These scenarios represented illustrative cases for future bioenergy use in the EU; the project did not attempt to identify or model possible optimal scenarios in terms of GHG emissions reductions.

3. Approach to quantitative assessment

The quantitative assessment undertaken in the Bioimpact Project set out to identify the total impact on global GHG emissions as a result of adopting a number of alternative scenarios for bioenergy use, and comparing these with a reference scenario representing the current trajectory, with no additional measures introduced after 2020. The task was to assess the total consequence on GHG emissions of adopting each scenario, including all direct and indirect emissions, and movements of biogenic carbon between reservoirs including the atmosphere.

3.1. Life cycle assessment (LCA)

The quantitative assessment involved the application of life cycle assessment (LCA). LCA is a powerful tool that can be used for different purposes and in different ways but it is vital it is used correctly. If an LCA study is to be of value there are a number of critical components that must be in place, without which the results will be ambiguous, open to misinterpretation, or simply not provide the information intended or expected.

To be of value it is vital that the LCA purpose is stated, and the goal and scope are unambiguously defined in the context of this purpose, and this requirement forms part of the ISO 14040 Standard[3] for LCA. Insufficient attention to defining the purpose, goal and scope can lead to LCA studies giving results that are ambiguous, open to misinterpretation, or simply not providing the information intended or expected.

The project purpose, or aim, set by the EC (see Section 2) was translated into an LCA goal, which was formally stated as: *to quantify the global emissions of prominent GHGs (CO_2, CH_4 and N_2O) from all relevant sources, resulting from implementation of possible EU policies, represented by defined scenarios adopted for supplying and consuming energy, especially bioenergy, in the EU between 2010 and 2050*.

This goal implicitly specified that the quantitative assessment needed to be based on a particular approach to LCA known as consequential LCA (CLCA). The purpose of CLCA is to determine the total collective consequences of a course of action or a policy, compared to a counterfactual situation (i.e. in which the action or policy is not pursued), without attempting to attribute specific GHG emissions to individual components of the system (e.g. specific biomass feedstocks). It is important to distinguish CLCA from another major LCA approach known as attributional LCA (ALCA). The purpose of ALCA is to attribute and quantify impacts (e.g. emissions) to individual products or services. ALCA, therefore, is most appropriate when attempting to choose a preferred product or service, such as in the context of a regulatory measure; CLCA is most appropriate when assessing policy options to inform policy development and was therefore appropriate to apply in this project. However, as will be seen in Section 5.2, the adoption of CLCA, in conjunction with the specified research goal, meant that the results of the project were suitable for addressing some key questions about bioenergy but not optimal for addressing certain other questions.

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[3] “Environmental Management – Life Cycle Assessment – Principles and Framework” ISO 14040, International Organisation for Standardisation, Geneva, Switzerland, 1997, revised 2006

3.2. Models

The quantitative assessment involved integrating the outputs of a number of different models and tools.

The VTT-TIAM model is a model of the global energy system. It attempts to calculate an equilibrium situation based on minimizing costs, within the constraints of the inputs, making use of an extensive database of energy technologies. As inputs it requires the quantities and marginal costs of energy resources, data on energy and emissions reduction technologies, including costs, lifetimes, emissions factors etc., energy demands, and the policy environments, including energy taxes and emissions targets. In addition to these inputs, further constraints may be introduced, such as GHG emissions reduction targets, prices for emissions and any limits of certain types of technologies.

For each scenario the VTT-TIAM model produces outputs including energy flows and GHG emissions (for each energy source, region, time step, etc.), information about energy and emissions reduction technologies employed, atmospheric GHG concentration, radiative forcing and temperature increase.

Alongside VTT-TIAM, the MITTERA-Europe model from Alterra and the CARBINE model from Forest Research were used to model changes in vegetation and soil carbon stocks and future carbon sequestration associated with the provision of agricultural and forest bioenergy feedstocks both from within the EU and beyond.

Finally, detailed LCA calculation workbooks developed by North Energy Associates were used to evaluate the indirect GHG emissions from all relevant bioenergy pathways.

3.3. Approach to modelling land-based carbon impacts

When wood is harvested from forests, for use as bioenergy or for other applications, this can have impacts on the overall reservoirs of carbon in forests (the “carbon stocks”), and also on the capacity of the forests to absorb CO_2 and retain more carbon in the future (“carbon sequestration”).

When wood is harvested from forests, for use as bioenergy or for other applications, this has impacts on the overall reservoirs of carbon in forests (the “carbon stocks”), and also on the capacity of the forests to absorb CO_2 and retain more carbon in the future (“carbon sequestration”).

There can be similar impacts on the carbon stocks and potential future carbon sequestration of cropland and grassland, particularly in relation to soil carbon, if such land is managed to produce bioenergy.

The Bioimpact project took great care to include the modelling of these impacts as part of the quantitative assessment, indeed this was a clear requirement based on the research question that was posed.

Currently, the subject of the impacts of bioenergy production on land-based carbon stocks and carbon sequestration is still very contentious and discussions on the subject amongst stakeholders can be very intense and occasionally acrimonious. It is important to understand the basis of the conflicting positions taken by stakeholders and to clarify how relevant issues were handled in the modelling for the Bioimpact project. This is best explained by taking some of the arguments often put forward by different stakeholders on this subject and then clarifying the position taken in the project with regard to each of them. The ensuing discussion of such issues tends to focus on forests, forest harvesting and the use of wood for bioenergy, as currently this is a strongly contested area and also best illustrates the arguments expressed by stakeholders and the extent to which scientific understanding supports them.

Different stakeholders hold strongly differing views on the impacts of wood harvesting on forest carbon stocks and sequestration and the key examples of positions argued for can be labelled as follows:

- The “virtuous circle” argument
- The “no-use option” argument
- The “maintaining/strengthening vigour” argument
- The “growth more than harvest” argument
- The “no stemwood/roundwood” argument.

These critical points are considered briefly in turn below. As will be seen, there is some truth in each of them, but none tells a complete story. The first four points are closely related and a full understanding of relevant issues is best obtained by considering the combined discussion of all four points.

Further discussion of many points underlying this subject can be found in the Task 1 Report of the Bioimpact project.

3.3.1. The “virtuous circle” argument

This argument essentially states that, “when trees are harvested from forests, new trees grow (or are planted) in their place, so there is no net impact on forest carbon stocks or sequestration”.

In simple terms, this statement is true, provided that forest management ensures that trees regenerate or are replanted to replace trees that are harvested. It is also necessary to ensure that the extraction of wood from forests, including in the form of forest residues, does not deplete the productive potential of the forests (e.g. through depletion of nutrient inputs to soils). Such conditions are generally considered to be amongst essential requirements for forest management to be regarded as "sustainable".

Whilst the "virtuous circle" argument is true *in simple terms*, it conceals the fact that there can be significant impacts on forest carbon stocks and sequestration when the level or intensity of harvesting in forests is changed, as compared with harvesting as practised historically. The details depend on timescale and the existing status and management of the affected forest areas and how forest management is changed to produce more wood from the forests. In some situations, forest carbon stocks and rates of sequestration may be *increased* as a result of active forest management to produce more wood. However, there are many situations in which carbon stocks and possibly rates of carbon sequestration will be *reduced* as a result of increased wood production, even when the associated forest management is fully consistent with the principles of sustainability. (This point is clarified further in Sections 3.3.3 and 3.3.4.)

In the Bioimpact project, the modelling of forests, croplands and grasslands reflected the understanding of the "virtuous circle" argument outlined above as follows:

- Where the projected supply of forest biomass (for bioenergy or other uses), as represented in the project scenarios, did not involve changes in the management of forest areas (compared with historical practice), it was assumed there were no consequent impacts on GHG emissions as a result of changes in forest carbon stocks and sequestration.
- However, impacts on forest carbon stocks and sequestration needed to be assessed in situations where forest management practices were changed to meet projected increases (or decreases) in supplies of forest bioenergy.
- On a separate related point, it was also necessary to consider whether changes occurred in patterns of wood utilisation as a result of demand for bioenergy, for example diverting it from use for paper or wood-based panels, and whether this would lead to impacts on overall GHG emissions.
- Similarly, and in the same way as for the modelling of forests, where the management of cropland or grassland was assumed not to change as a result of the demand for agricultural biomass for energy, there were assumed to be no consequent impacts on GHG emissions as a result of changes in land-based carbon stocks or sequestration.
- However, impacts on land-based carbon stocks and sequestration needed to be considered in situations where the management of cropland and/or grassland was changed to meet projected increases (or decreases) in supplies of agricultural biomass.
- It was also necessary in the modelling to consider whether changes occurred under the different bioenergy scenarios in the supply of agricultural biomass for other

purposes (e.g. for animal feed) and whether this would lead to impacts on overall GHG emissions.

3.3.2. The "no-use option" argument

An experienced forestry and bioenergy researcher has commented, 'when someone asks the question, "what are the impacts on GHG emissions of using forest bioenergy?" I always reply, "compared to what?"…'.

Essentially, the "no-use option" argument states that, "the scenario against which to compare harvesting or extraction of biomass for use as energy should always be the scenario of *not using* the biomass for energy".

Some stakeholders interpret "no use" even more narrowly as meaning "no harvesting of trees" or "leaving trees in the forest".

The case for comparing bioenergy use against the alternative scenario of not using the bioenergy is consistent with a key principle of CLCA, i.e. that the impacts of a scenario in which a specified policy or commercial decision is taken (in this context, to produce or use a defined level of bioenergy), should be compared against a *counterfactual* scenario in which the policy or commercial decision is *not taken*. The "no-use option" argument asserts that the counterfactual scenario when assessing the utilisation of biomass for energy should always be not using biomass for energy or more narrowly not producing or harvesting biomass. This is extended by some stakeholders, including some researchers, to mean no use of any bioenergy at all (i.e. not even at historically produced levels) and also no harvesting of wood for any purposes.

As already discussed, the principles of CLCA were adopted for the quantitative assessment of the Bioimpact project. Hence, the policy scenarios involving increased or decreased biomass energy consumption were always compared against a consistent counterfactual scenario (the baseline scenario) in which no such changes occurred. It is important to distinguish this approach from comparison against a counterfactual scenario of absolutely no use or harvesting. The choice of counterfactual scenario depends on the system being studied and, crucially, the LCA research question being addressed. It is suggested here that the more generally valid research question to pose (such as adopted for this project) should take the generic form:

"What are the impacts on GHG emissions of producing and consuming a specified source of biomass for energy, *compared to what would have happened otherwise*?"

In some situations, "what would have happened otherwise" might indeed involve not producing or consuming the biomass at all, and might mean not harvesting the biomass at all, but this does not hold universally. For example, in some situations, "producing and consuming a specified source of biomass for energy" might be exactly the same as "what would have happened otherwise". In such situations, the modelling of the biomass use would assume no net impacts on GHG emissions (neither increases, nor reductions).

The research question as formulated above informed the approach taken to the quantitative assessment of the Bioimpact project and the selection of the counterfactual scenario to bioenergy consumption:

- In situations (occurring within scenarios) where levels and types of biomass consumed as energy were consistent with historical practice, this was taken to imply no change from the counterfactual scenario, hence there was no requirement to consider impacts on GHG emissions arising from changes in land-based carbon stocks or sequestration. In effect, the "virtuous circle" argument was taken to apply in these situations. However, by the same token, there are no "savings" of GHG emissions (relative to the baseline) in such situations as a result of the use of the biomass for energy.
- In situations (occurring within scenarios) where levels and types of biomass consumed for energy involved a change from historical practice (i.e. the baseline), this was assessed by comparison with a counterfactual scenario involving no such change. Depending on the detailed modelling of cropland, grassland and forests within a scenario, in some situations the level of biomass harvesting was higher (and sometimes lower) than for the counterfactual scenario. This could also involve changes to the timing with which trees were harvested in the case of forests. In other situations it involved changes in the utilisation of the biomass for other purposes, e.g. agricultural biomass for animal feed or harvested wood for paper or wood-based panels. Assumptions related to this aspect of the modelling were particularly important for forest bioenergy sources and this subject is discussed further in Section 4.2.2.

It is important to stress the *absolute necessity* of making assessments relative to a counterfactual scenario when undertaking CLCA. For example, by analogy, when deciding whether to make a commercial investment using economic analysis, it is standard practice to include the opportunity costs of the investment decision as part of the balance of costs and revenues, i.e. to take account of the counterfactual scenario of *not making* the investment. The counterfactual scenario in CLCA serves a similar purpose and not referring to one would mean that the full impacts of a policy or commercial decision would not be properly evaluated.

"No use" and forest disturbance

The disturbance of forest areas (e.g. as a result of storms, disease, fire) generally has negative consequences for carbon stocks. The risks of significant, large-scale disturbance events tend to be mitigated by the systematic control of levels of growing stock in forest stands, which is associated with management involving harvesting. It is particularly important to consider the possible consequences of disturbance when assessing the option of minimising or complete avoidance of forest management (notably harvesting).

There is limited knowledge of future forest carbon sequestration under scenarios in which all harvesting is avoided.

In the Bioimpact project, the modelling of forests represented disturbance processes, where these were relevant to the project scenarios, and allowed for the possibility that some areas of disturbed forest might be "salvage-logged" for wood production, with some of the harvested biomass being utilized for energy.

3.3.3. The "maintaining/strengthening vigour" argument

This argument applies more specifically in the context of forestry and is ultimately based on the observation that, as populations of trees grow older, their rates of growth and carbon sequestration decline significantly when compared with younger trees (i.e. stands of trees less than approximately 50 to 70 years old in the context of temperate and boreal forests). In essence, the argument states that, "the sustainable management of forests for wood production is essential for maintaining and strengthening carbon sequestration by forests". In this context, "sustainable forest management" is equated with sustainable tree harvesting for wood production.

There is some truth in this argument. If stands of relatively old or mature trees are felled and replaced by actively regenerated or replanted younger stands of trees, then within 10 to 20 years these younger stands will grow at faster rates than the older stands they replace, so they will sequester carbon at faster rates. For example, in a paper[4] arguing the case for wood production from sustainably managed forests, a graph is presented that shows how the mean rate of biomass growth in forests representative of Northern Europe varies with the rotation age (i.e. age of clearfelling) applied to the stands forming the forest. The graph in the paper appears to draw attention to the possibility of shortening the rotations of relevant spruce stands in Sweden from 100 years to 70 years, indicating a consequent increase in the rate of carbon sequestration. Relevant results, derived from Figures 1 and 2 in the paper, are shown in Table 3.1. For rotation ages of 70 and 100 years, the mean rates of carbon sequestration in forest biomass over the rotation are 2.1 and 1.7 tonnes carbon per hectare per year, respectively.

By implication, shortening the rotation ages in such forests to 70 years where they are currently managed on rotations of 100 years should increase the rate of carbon sequestration.

At the same time, managing rotations in the way described above can increase the level of overall wood production from forests (see Table 3.1). The harvested wood can be used to provide a range of useful products. Some of these, like bioenergy, will be consumed and release the sequestered carbon immediately but others (such as

[4] Hektor, B., Backéus, S. and Andersson, K. (2016) Biomass and Bioenergy **93** 1-5.

structural timber) may be very long-lived and will continue to retain the carbon sequestered in the original trees.

Table 3.1 Dependence of forest carbon sequestration, stemwood production and mean carbon stocks on rotations in spruce stands in Sweden[1]

Stand age or rotation (years)	Carbon sequestration rate in year[2] (tC ha^{-1} yr^{-1})	Mean carbon sequestration rate over rotation[2] (tC ha^{-1} yr^{-1})	Stemwood production over rotation (m^3 ha^{-1} yr^{-1})	Mean carbon stock over rotation (tC ha^{-1})
100	0.8	1.7	5.1	87
70	1.2	2.1	5.4	74
Gain/loss[3] (+/-)	+0.4	+0.4	+0.3	-13.6
% gain/loss	+44%	+21%	+6%	-16%

Notes to Table 3.1:

1 All results derived from Figures 1 and 2 in Hektor *et al.*, (2016), see footnote 4. Original results were based on all above ground forest biomass but these have been converted to units of carbon and adjusted to allow for contributions from roots.

2 These results represent rates of carbon sequestration in forest biomass *before subtracting losses of forest biomass as a result of harvesting.*

3 Gain or loss as a result of adjusting rotation from 100 years to 70 years

What the "maintaining/strengthening vigour" argument ignores is that carbon stocks in older/more mature forests are, by nature much larger than carbon stocks in young forests. Increasing the rate of harvesting in older forests and replacing them with younger forests inevitably leads to a reduction in the average age of the trees in the forests, hence to a reduction in the average carbon stocks of the forests (potentially in soil and litter as well as in living trees). This is true even if the management of forests is to the highest standards of sustainability. The impact on carbon stocks in forest biomass of shortening rotations from 100 years to 70 years in the example spruce stands in Sweden is shown in Table 3.1.

It is also important to recognize that, whilst the management of forests involving shortening of rotations can significantly increase the rate of carbon sequestration over the medium term, the harvesting of sequestered carbon is also increased, so that the net impact on forest carbon stocks and sequestration is not so beneficial when the balance between increased sequestration and increased harvesting is allowed for.

It should be recognized that there are also some cases in which increasing wood production from forests can lead to the maintenance of, or an increase in, forest carbon stocks (see for example Section 4.2.2). Whilst these cases are quite specific, there are real-life examples where such outcomes have been achieved.

When forest management is changed, for example by adjusting the rotations of forest stands as illustrated, this can have impacts not only on carbon stocks and rates of carbon sequestration and wood production in the forest, but also on:

- The amount of carbon sequestered in harvested wood products (i.e. the carbon physical contained in products such as sawn timber, wood-based panels and paper)
- The GHG emissions associated with the counterfactuals to wood products, for example plastic, steel, brick or concrete products that may be displaced by using wood products instead, or that may be consumed if wood is not produced.

Hence, it is necessary also to consider these contributions to overall changes in GHG emissions that may occur when changing forest management.

Carbon sequestered in harvested wood products

An initial question thus arises: If older stands of trees are replaced with younger stands of trees through harvesting and regeneration/replanting, what is the overall impact on carbon stocks, allowing for the carbon in forests and also for carbon physically contained in harvested wood products, including those that are long-lived?

In fact this question was answered nearly 30 years ago in some of the initial research on the role of forests and their management in the carbon balance[5]. A significant body of relevant research shows that, even after allowing for the carbon retained in harvested wood products, in many situations the overall effect of “intensifying” forest management to increase wood production is a net reduction in carbon stocks.

Interactions between wood and counterfactual products

In the context of the Bioimpact project, the full assessment of any scenario for increased forest biomass supply and consumption needed to allow for the effects of intensified forest management on:

- Forest carbon stocks and sequestration
- Carbon physically sequestered in wood products
- The potential savings of GHG emissions through the increased utilisation of wood as a source of bioenergy and materials, in place of fossil fuels and alternative (counterfactual) materials such as metals, plastics, bricks and concrete.

[5] See for example: Thompson, D.A. and Matthews, R.W. (1989) *The storage of carbon in trees and timber*, Forestry Commission Research Information Note 160, Forestry Commission, Edinburgh; Harmon, M.E., Ferrell, W.K. and Franklin, J.F. (1990) Effects on carbon storage of conversion of old-growth forests to young forests, *Science*, **247**, 699-702; Matthews, R.W. (1991) *Biomass production and carbon storage by British forests*, In: Aldhous, J.R. (ed.) Wood for energy: the implications for harvesting, utilisation and marketing, Proceedings of ICF discussion meeting, 5-7 April 1991, Heriot-Watt University, Edinburgh, ICF, Edinburgh, 162-177.

Research on this subject indicates that the outcomes of increased harvesting and utilisation of wood are very sensitive to the mix of specific applications for which the wood is consumed (e.g. energy, paper, wood-based panels and structural timber) and the counterfactual energy sources and materials displaced (see Section 3.3.5).

Overall approach of Bioimpact project

In the Bioimpact project, the assessment of GHG emissions impacts in relation to changes in forest management to supply more (or less) biomass for energy allowed for all of the effects outlined above, i.e. in summary:

- Increased rate of forest carbon sequestration in cases where forest management was changed to increase wood production (but also recognising that much if not all of this additional sequestered carbon would be harvested)
- Where relevant, reduced carbon stocks in forests, for example where forest rotations were adjusted to enhance forest growth and wood production
- Where relevant, increased carbon stocks and sequestration in wood products co-produced with increased biomass supplied for use as energy
- Impacts of increased supply of biomass from forests for energy, and associated co-products, through the displacement of counterfactual energy sources and material products.

Possible forest management approaches that might lead to maintained or enhanced carbon stocks in association with increased bioenergy production from forests were not represented in the main Bioimpact project scenarios, but were considered to an extent in a set of alternative scenarios, as part of a sensitivity analysis. Further details of assumptions about forest management made in the Bioimpact project are given in Sections 4.2.2 and 4.2.3.

3.3.4. The “growth more than harvest” argument

This argument states that, ‘the production of biomass from crops or forests for utilisation as energy is “carbon-neutral” (i.e. no net GHG emissions as a result of burning the biomass) or better, provided that the rate of growth of the crops or forests is greater than or equal to the level of harvesting’.

Alternatively, the argument can be stated ‘the production of biomass from crops or forest for utilisation as energy is “carbon-neutral” or better, provided that the rate of carbon sequestration of the crops or forest is greater than or equal to the amount of carbon removed by harvesting’.

The rationale for this argument is derived from a basic measure of sustainable forest management and is best illustrated by an example, as follows.

Consider a large area of forest, formed of a population of many stands of trees of different ages. Suppose that surveys of the forest have shown that in the recent past (say, the previous 10 years), the forest area has grown on average by 4.8 cubic metres of stemwood per hectare per year. (Note that this measure of the growth of trees does not allow for any losses of stemwood as a result of harvesting, which are calculated as a separate measure.)

Suppose also that trees were harvested from the forest during the previous 10 years (through thinning or clearfelling) at an average rate of 3.6 cubic metres of stemwood per hectare per year.

The "growth more than harvest" argument asserts that any wood being harvested from the forest area is "carbon-neutral" or better, provided that the first measure described above (4.8 in this case) is greater than or equal to the second measure (3.6 in this case).

The two measures are sometimes expressed as a ratio, in this case 4.8/3.6 = 1.33. The ratio is known as the "growth-drain" ratio and may be used as an indicator of sustainable management, the aim generally being to keep the ratio at 1.0 or above.

Note that similar measures could be calculated for the forest based on tree biomass or carbon, expressed in tonnes of wood (about 1.9 and 1.4) or carbon (about 0.96 and 0.72) per hectare per year.

The balance between the rate of growth and level of harvesting in individual stands forming a forest area may vary considerably from this average result: harvesting greatly exceeding growth in older stands that are clearfelled during the 10 year period referred to in the above example, whilst growth may greatly exceed harvesting in younger stands. However, it is argued that what matters is the overall balance between growth and harvesting across all the stands forming the complete forest area.

It is undeniable that achieving a good balance between growth (or carbon sequestration rate) and the harvesting (or carbon losses) of agricultural and forest land is a fundamental indicator of, and minimum requirement for, sustainable management. However, it is a serious mistake to assume that this guarantees the "carbon-neutrality" of any biomass produced from crops or forest. When dealing with climate change, what matters is the impact of actions on net emissions to, or sequestration from the atmosphere. This point is best illustrated by continuing the example described above.

In the example, the trees forming the forest area absorbed about 0.96 tonnes carbon per hectare per year on average over the previous 10 years. The average level of harvesting was 0.72 tonnes carbon per hectare per year. In this case, it could be argued that the impact of harvesting the wood may be regarded as at least "carbon-neutral", noting that there was net carbon sequestration of 0.96 – 0.72 = 0.24 tonnes carbon per hectare per year over the previous ten years.

This could also be argued for future wood production in certain circumstances. For example, suppose that in the forthcoming 10 year period, the forest is expected to continue to absorb 0.96 tonnes carbon per hectare per year and the level of harvesting is also expected to remain at about the same level as in the previous 10 year period (0.72 tonnes carbon per hectare per year). In this situation, again it could be argued that the wood that is planned to be harvested from the forest could be regarded as at least “carbon-neutral”.

Now suppose that plans have been made to increase the level of wood harvesting to 0.93 tonnes carbon per hectare per year (e.g. as part of efforts to “develop a bioeconomy”). If the rate at which the forest absorbs carbon does not change, then the net carbon sequestration from the atmosphere will be 0.96 – 0.93 = 0.03 tonnes carbon per hectare per year, whereas otherwise the net sequestration would have been 0.96 – 0.72 = 0.24 tonnes carbon per hectare if the decision to increase harvesting had not been taken. In other words, because wood harvesting from the forest is to be intensified compared to historical levels, there will be negative impact on the net carbon sequestration contributed by the forest. Note also that if all the extra wood harvested is used for energy, the carbon in this harvested wood will be released to the atmosphere very quickly. These conclusions are consistent with the observations already made regarding the “virtuous circle” argument (see Section 3.3.1).

Some stakeholders may challenge the above discussion by pointing out that generally it will be wrong to assume that the rate of carbon absorption by the forest (0.96 tonnes carbon per hectare per year in this example) will be unchanged and that, in fact, carbon absorption should be increased by intensified forest management. This is the “maintaining/strengthening vigour” argument (see Section 3.3.3). However, as already explained in Section 3.3.3, this argument ignores the negative impacts on forest carbon stocks which are likely to be involved in intensifying the management of forests to enhance growth and carbon absorption. Furthermore, claiming higher carbon sequestration rates associated with intensified forest management overlooks the fundamental motivation for intensifying management, which is to utilize more of the potential of forests to produce wood, i.e. to narrow the gap between levels of harvesting and the potential for wood production implied by rates of growth (and carbon absorption) of forests. Continuing the previous example, intensified forest management might increase the rate of carbon absorption of forests from 0.96 to 1.73 tonnes carbon per hectare per year, whilst the associated level of harvesting could be very close to this, say 1.70 tonnes carbon per hectare per year, giving net carbon sequestration of 0.03 tonnes carbon per hectare per year. Hence intensified management is likely to reduce net carbon sequestration (compared to what would have occurred in the absence of intensification) even if carbon absorption is enhanced by management.

It is clear from the preceding account (see also Sections 3.3.1 and 3.3.3) that decisions to change forest management, or consume more (or less) harvested wood have impacts on the balance between rates of forest carbon sequestration (or “carbon sinks”) and rates of carbon loss (or "carbon sources"). The same point applies for other types of managed land such as cropland and grassland. This point is particularly pertinent to commitments made by countries under the Paris Agreement (see Article 4.1) which entered into force in 2016,

"to achieve a balance between anthropogenic emissions … and … sinks of greenhouse gases in the second half of this century …"

Putting aside the possibility of developing industrial-scale carbon capture and storage technologies, the only major global carbon sink over which humans can exercise some direct control is that due to land-based vegetation and soil. Hence, a key goal of the Paris Agreement could be missed if the intensification of biomass harvesting goes too far, without putting in place suitable safeguards to sustain land-based carbon stocks and potential future carbon sequestration.

It remains the case that a key criterion for sustainable land management involves ensuring that harvesting does not exceed growth, when assessed over an *appropriate* time period. However, fundamentally, a simplistic comparison of rates of growth and levels of harvesting is not a robust way to ensure low impacts of bioenergy sources on GHG emissions.

In the Bioimpact project, the assessment of GHG emissions impacts allowed for the factors outlined above by adopting a methodology as already described in Sections 3.3.1 to 3.3.3.

3.3.5. The "no stemwood/roundwood" argument

This argument states that, "harvesting and utilising tree stemwood or roundwood for energy is bad for climate change because of the lost forest carbon sequestration involved".

Sometimes the same argument is also expressed referring to "whole trees" or "complete trees".

Any discussion of this argument depends on good definitions for terms such as "stemwood", "roundwood", "whole trees" and "complete trees". Definitions for "stemwood" and "roundwood" and a number of other terms referred to in the following discussion, such as "sawlogs", are provided later in this report (see Section 4.2.2, in particular Box 1). In this discussion, the terms "whole trees" and "complete trees" refer to the majority of tree biomass above ground, i.e. in the main stem, bark, and branches, either with or without foliage attached, but generally not including tree stumps and roots (see Box 1 for definitions of these latter terms).

For the purposes of the discussion below, the term "stemwood" is used to refer interchangeably to stemwood and roundwood.

One of the origins of this argument was a position paper[6] which presented an interpretation of some LCA research results for wood production from UK forests, from an earlier report written by members of the Bioimpact project team[7]. The position paper focused on one result, for a scenario in which *all wood* (including all stemwood) harvested from forests at all times during the life cycle of forest stands *was utilized for energy only* (i.e. no wood was utilized to produce materials). It was very apparent from the original report that this particular scenario involved the highest GHG emissions compared with all other scenarios, including a scenario of not harvesting any wood from the forests. This was true even if the harvested wood was consumed as energy instead of burning coal.

The position paper omitted to discuss the fact that the original research report presented results for nearly 120 scenarios for wood production from UK forests, of which between one third and more than one half (depending on the timescale considered) involved net GHG emissions savings, or were “at least as good”, compared to not harvesting wood from forests. Furthermore, nearly all of these “low-emissions” scenarios involved the consumption of *some* stemwood for energy (either directly from raw stemwood or indirectly as a by-product of the manufacture of sawnwood products), with approximately one quarter of these scenarios involving some direct use of stemwood for energy.

It follows that the consumption of stemwood for energy is neither universally good nor universally bad in terms of impacts on GHG emissions. The results can be variable, depending on the details, and this issue requires careful consideration.

A thorough interpretation of the *full* results of the original research has suggested that, generally, over climate policy relevant timescales (30 years, and in most cases significantly less):

- Using all of the stemwood from forests (i.e. from all of early thinnings, later thinnings and from clearfelling) directly for energy leads to net increases in GHG emissions, even compared to burning coal.
- Using all of the sawlog part of stemwood directly for energy leads to net increases in GHG emissions. However, using the industrial residues (generated by producing sawn timber from sawlogs) as an energy source can lead to net decreases in GHG emissions compared to fossil fuels, provided that this does not involve significant negative

[6] Searchinger, T. (2012) *Sound principles and an important inconsistency in the 2012 UK Bioenergy Strategy*. Position paper. At: http://ww2.rspb.org.uk/Images/Searchinger_comments_on_bioenergy_strategy_SEPT_2012_tcm9-329780.pdf

[7] Matthews, R., Mortimer, N., Mackie, E., Hatto, C., Evans, A., Mwabonje, O., Randle, T., Rolls, W., Sayce, M. and Tubby, I. (2014) *Carbon Impacts of Using Biomass in Bioenergy and Other Sectors: Forests*. Final Report for Department of Energy and Climate Change. Revised 2014. Forest Research: Farnham.

impacts on the availability of industrial residues as a feedstock for manufacturing certain material products, e.g. wood-based panels.

- Using the small roundwood part of stemwood directly for energy can lead to net GHG emissions savings compared to fossil fuels, particularly if this occurs in conjunction with co-producing sawn timber from sawlogs and other materials from industrial residues, such as wood-based panels, alongside consumption of some industrial residues for energy.
- Using forest residues as an energy source can lead to net GHG emissions savings compared to fossil fuels, provided that the extraction of residues from forest sites is constrained to minimize negative impacts on the carbon balance, nutrient status and acidity of forest soils, as well as ensuring protection of habitats.

The full results also indicated that the GHG impacts of utilising forest biomass for energy were also sensitive to certain other factors, in particular the types of forest involved in wood production, as characterized by tree species, potential growth rates, existing carbon stock levels and approaches taken to forest management (e.g. the rotation between clearfelling, regeneration or replanting events).

Despite the large number of scenarios considered in the original research, there were some important cases that were not covered. One case that was excluded involved the extraction of tree stumps and roots for use as a bioenergy feedstock. This case was regarded as involving such evident negative impacts on soil carbon processes and other soil properties that modelling was not needed to establish the impacts on GHG emissions.

There was an entire class of scenarios that was not considered in the original research, involving patterns in the way wood is utilized from the various harvesting events over the life cycle of trees forming a forest. An important example of such a case consists of:

- The stemwood of small/early thinnings utilized for energy
- The stemwood (possibly including small roundwood) of later thinnings utilized to produce sawn timber, wood-based panels and other material products, with some industrial residues utilized for energy
- The stemwood harvested from clearfelling utilized in the same way as later thinnings.

The above type of scenario could be relevant in situations where there are limited market incentives for undertaking early thinning operations. It can be important to encourage thinning in young stands of trees to improve the quality of the remaining growing stock, thereby ensuring the stands of trees produce high quality timber later in the rotation, suitable for manufacturing long-lived products.

The harvesting of trees as thinnings reduces the carbon stocks in forest stands, certainly in the short term. Often the remaining trees will respond to the growing space released by the thinning, and their rate of growth (and rate of carbon absorption) will be increased. This can provide some compensation for the impacts of the thinning on carbon stocks, also in the relatively short term.

There are some situations in which utilising harvested wood for energy, as part of more general measures to develop a bioeconomy, can lead to net GHG emissions savings, regardless of which parts of the tree (above ground) are used for this purpose. Generally these are situations where the forest management associated with wood production leads to improvements in rates of carbon sequestration and neutral or positive impacts on carbon stocks. The main relevant examples are:

- Afforestation of marginal land through tree planting or regeneration, with the objective of increasing wood production
- Enhancing the growth rates of existing forest areas through tree species selection or tree breeding and, in some situations fertilisation of forest soils.

There are real-life examples of such practices taking place but it must be acknowledged that these are specific cases.

All of the factors described above were represented in the modelling for the Bioimpact project and further information is given in Section 4.2.2 of this report.

As explained above, ignoring certain specific cases, if all of the stemwood harvested from a forest were to be utilized exclusively to produce energy, this is very likely to lead to significant increases in GHG emissions compared to burning fossil fuels including coal. A key question is: *Would/does such a scenario ever actually occur in practice?* At present, this subject is strongly contended, with some stakeholders insisting that such practices would never occur or would be exceptional, whilst others are claiming that this is already happening. There is a critical need for an impartial assessment of the existing extent or likelihood (and if relevant the potential scale) of such activities. This was well beyond the scope of the Bioimpact project.

3.4. Approach to representing ILUC

The possibility of ILUC has been presented by some scientists and commentators as a crucial influence on the overall GHG impacts of certain land use and land management options aimed at mitigation of GHG emissions. The focus tends to be on the agriculture sector and in particular the potential impacts of converting land used for production of food over to production of biomass crops for energy use. Questions regarding ILUC can also occasionally arise when considering forestry.

Studies which have attempted to quantify the potential impacts arising from ILUC on activities aimed at reducing GHG emissions, generally through management of agricultural land, have shown that results are highly sensitive to the detailed assumptions made in carrying out analyses, with estimated emissions arising from ILUC ranging from zero to very large.

The issue of ILUC is most likely to arise in scenarios involving land use change as an essential theme, e.g. where demands for bioenergy are met through planting of biofuel or energy crops (or for that matter afforestation activities) that result in land use change elsewhere, e.g. increased deforestation or reduced re-forestation. The approach taken in the Bioimpact project to dealing with ILUC for such scenarios was to constrain the relevant activities with the intention of avoiding significant risks of ILUC. This was done by:

- Not allowing for the importation of solid agricultural biomass to the EU for use as energy
- Not allowing for afforestation activities outside the EU in the main project scenarios (see Section 4.2.2)
- In the EU region, limiting the planting of biofuel or energy crops and afforestation activities in all scenarios to an area estimated to be consistent with avoiding negative impacts on future food supply, as informed by the assessments in several studies[8].

4. Scenarios

Six scenarios, labelled A, B, C1, C2, C3 and D, were developed for the purposes of this project as described in the ensuing discussion. Each scenario was designed to represent a specific, realistic, self-consistent approach to energy decarbonisation, with differences chosen to allow the relative impact of certain components of biomass use for energy to be compared. These were not intended to be predictions but to represent possible pathways, consistent with existing modelling that could provide insights into the overall impacts of a few specific classes of biomass. The six different scenarios developed for this project consisted of a reference scenario representing existing policies (Scenario A) and five decarbonisation scenarios that each delivered emissions reductions by 2050 of 80%] but that took different approaches to bioenergy use (Scenarios B to D).

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[8] Elbersen, B.S., Staritsky, I., Hengeveld, G., Schelhaas, M.J., Naeff, H. and Böttcher, H. (2012) Atlas of EU biomass potentials. Deliverable 3.3: *Spatially detailed and quantified overview of EU biomass potential taking into account the main criteria determining biomass availability from different sources*. Report for Task 3 in Biomass Futures project. At: http://www.biomassfutures.eu/work_packages/WP3 Supply/D_3_3__Atlas_of_technical_and_economic_biomass_potential_FINAL_Feb_2012.pdf; Elbersen, B., Fritsche, U. Petersen, J.-E., Lesschen, J.P., Böttcher, H. and Overmars, K. (2013) Assessing the effect of stricter sustainability criteria on EU biomass potential. *Biofuels, Bioproducts and Biorefining*, **7**, 173–192; European Commission (2013) *Prospects for Agricultural Markets and Income in the EU 2013-2023*. Directorate-General for Agriculture and Rural Development: Brussels; Britz, W. and Witzke, P. (2012) *CAPRI Model Documentation 2012*. Bonn University: Bonn. At: http://www.capri-model.org/docs/capri_documentation.pdf

The LCA goal of this project specified that GHG emissions needed to be quantified for "*defined scenarios* [emphasis added] adopted for supplying and consuming energy, especially bioenergy, in the EU between 2010 and 2050" (see Section 3.1). For this reason the success of the project depended upon the comprehensive and thorough specification of the scenarios to be assessed.

Each scenario was defined in terms of:

- **Overall bioenergy consumption**
- **Approaches to** the **management** of forests and agricultural land to supply the biomass
- **Interactions** between the **use of biomass** for energy and its use for other purposes (e.g. for animal feed, soil remediation or to manufacture paper, wood based panels or sawn wood).

When interpreting the results of this project it is critically important to understand what assumptions were made in developing the scenarios, firstly about the overall levels of biomass consumption, and secondly about the approaches to forest and agricultural land management and interactions amongst different uses of biomass. These two aspects of scenario definition are discussed in Sections 4.1 and 4.2 below.

4.1. Definition of scenarios: overall bioenergy consumption

The setting of overall biomass use in each scenario involved defining, for each year until 2050:

- The total quantity of biomass consumed in the EU for energy
- The relative emphasis on biomass supply from either crops or forests
- The relative emphasis on biomass supply from different geographical origins to the EU.

In terms of overall targets set for the six different scenarios developed for this project:

- **Scenario A ('Reference')** represented the continuation of **existing EU energy policy and measures up to 2020**, but with no additional measures to be adopted thereafter. Hence existing 2020 targets for GHG emissions and renewable energy consumption were assumed to be met, after which annual biomass consumption increased only very slightly up to 2050. Certain other efforts towards GHG emissions reductions were assumed to continue to deepen after 2020, through the continued tightening of targets set as part of the EU Emissions Trading System (ETS), which is why this scenario involves modest ongoing reductions in GHG emissions over time after 2020. This was chosen as a baseline with which other scenarios could be compared, representing business as usual.

- **Scenarios B, C1-3 and D** were all ‘decarbonisation’ scenarios, in which the model was required, amongst other things, to meet a 2050 emissions reduction target of 80%, which is the lower end of the range mentioned in the 2050 Roadmap that the Commission published in 2011. They differed from one another with regard to the assumptions or constraints on bioenergy, as described below.
- **Scenario B (‘Carry on, unconstrained use’)** represented increased bioenergy consumption after 2020 compared to Reference Scenario A, with the **highest use** of biomass for energy from all sources and with **limited constraints** on the types of sources consumed. Essentially, the consumption of biomass sources for energy was determined principally by the relative estimated costs of different biomass feedstocks, otherwise placing no emphasis on consumption of specific feedstocks (e.g. agricultural or forest biomass). The main additional constraints involved limiting the consumption of solid agricultural biomass to sources originating within the EU, not allowing the supply of woody biomass for energy through activities leading to deforestation, avoiding the use of tree stumps and roots, avoiding the use of woody biomass suitable for use in long-lived structural products, and assuming that the consumption of biomass for energy provided no stimulus for enhanced afforestation activities in the EU or elsewhere (in the main project scenarios, see Section 4.2.2).
- **Scenario C1 (‘Carry on, imported wood’)** represented increased bioenergy consumption after 2020 compared to Reference Scenario A whilst emphasizing the consumption of **imported forest bioenergy**, allowing for some constraints. Examples of constraints applied in the scenario in addition to those applied in Scenario B included limiting the planting of biofuel or energy crops in the EU with the intention of avoiding significant risks of indirect land-use change (see Section 3.4).
- **Scenario C2 (‘Carry on, domestic crops’)** represented increased bioenergy consumption after 2020 compared to Reference Scenario A whilst emphasizing the consumption of bioenergy from **biofuel or energy crops and agricultural biomass** grown in the **EU region**, with some constraints as discussed for Scenario C1.
- **Scenario C3 (‘Carry on, domestic wood’)** represented increased bioenergy consumption after 2020 compared to Reference Scenario A whilst emphasizing the consumption of **forest bioenergy**, supplied from forests in the **EU region**, with some constraints as discussed for Scenario C1.
- **Scenario D (‘Back off’)** represented a situation in which the consumption of **bioenergy** as a renewable energy source would be **de-prioritized after 2020**. Hence the overall biomass consumption in the EU associated with meeting GHG emissions and renewable energy targets for 2020 was assumed to be met, after which annual biomass consumption was constrained and required to decrease compared to

Reference Scenario A. Consequently, the scenario also involved greater use of other low-carbon solutions after 2020 than in the Reference scenario, including energy efficiency and various non-biomass low-carbon energy sources.

The setting of overall levels for bioenergy consumption for the six scenarios, as well as constraints or emphasis placed on consumption of specific bioenergy sources in each scenario, was the subject of extensive consultation with the European Commission and the characteristics of (and differences between) the scenarios were stated unambiguously.

4.2. Definition of scenarios: approaches to land management and biomass utilization

Whilst it was very important to set clear and agreed overall levels of bioenergy consumption in defining the six scenarios, it was equally important to define what approaches to land management and biomass utilization would be involved in achieving the overall GHG emissions and renewable energy targets. It will be appreciated that agricultural land management and forest management at the scale of whole countries or regions is highly complex. For example, the management of forests for wood production will not be uniform across forest areas within a country but will reflect many factors such as accessibility, forest type (e.g. tree species), growth rate etc. It was therefore necessary for this heterogeneity to be represented in the modelling undertaken for this project. It is difficult to provide a simple and accessible summary description of all of the assumptions involved in this aspect of defining the scenarios, however an attempt is made below to provide such a description, because this is absolutely essential to the subsequent interpretation of the results.

For the purposes of this project, the term “approach” was used to refer to a set of assumptions about the ways in which agricultural land and forests would be managed, and/or particular biomass feedstocks might be utilized (for energy and/or for other purposes), as part of meeting the overall levels of biomass consumption (from all sources) specified in the scenarios.

In theory there is an almost infinite number of approaches that might be taken in different countries to supply the biomass needed to meet the levels of bioenergy consumption set for the six scenarios specified in this project. It is unclear how to identify confidently those approaches that are “most likely” to be involved in supplying biomass for energy use in the EU in the future, as opposed to those approaches that are “unlikely”. Indeed, this subject continues to be vigorously debated by stakeholders. However, it is known with reasonable certainty that the choice of approaches to biomass supply for energy use can lead to widely varying impacts on GHG emissions, ranging from significant net GHG savings to significant increases in GHG emissions.

Two contrasting approaches were defined for the purposes of the Bioimpact project, with the aim of giving an indication of the possible range of outcomes in terms of GHG emissions impacts. These two approaches were called the “**Precautionary**” approach, representing basic sustainability safeguards, and the “**Synergistic**” approach, representing a more intensive approach to ensuring sustainability and the mitigation of negative impacts. The scenarios and ultimate results based on the Precautionary approach were regarded as the main scenarios and results of the Bioimpact project, literally taking a *precautionary* position of *not allowing* for the possibilities for more intensive efforts towards sustainability (and the use of mitigating measures) as part of the consumption of biomass for energy in the EU.

4.2.1. Agricultural land management

In all scenarios, it was assumed that supplies of bioenergy from agricultural sources would be produced from within the EU region. The management of agricultural land was represented in the same way in both the Precautionary and Synergistic approaches, since the two approaches were intended to investigate sensitivities to ways of supplying forest bioenergy sources.

Potentials and costs were estimated for a range of agricultural sources of bioenergy, including a number of dedicated biofuel or energy crops, residues from agricultural production and manure. The use of these various bioenergy sources in each scenario was determined, via the VTT-TIAM model, by finding the combination of supplies of agricultural bioenergy sources that met the requirements for energy supply defined in each scenario at least cost (see earlier discussion).

It should be noted that, in all scenarios, the planting of biofuel/energy crops on agricultural land was constrained with the intention of avoiding indirect land-use change (ILUC), as already discussed in Section 3.4.

4.2.2. Forest management and wood utilization

The definitions of the Precautionary and Synergistic approaches focussed on forest biomass sources, as a result of the considerable interest amongst stakeholders regarding the role (positive or negative) of forest biomass. In essence:

- The **Precautionary** approach avoided some of the most extreme options for forest biomass supply (e.g. leading to deforestation, through failure to ensure replanting or regeneration of forest areas following harvesting or through subsequent conversion of felled forest areas to agricultural land or some other land use). Otherwise the supply was broadly related to the magnitudes of different potentials of forest biomass resources available within each country, with limited consideration of whether these different resources may lead to beneficial or deleterious outcomes in terms of impacts on GHG emissions.

- The **Synergistic** approach involved some very similar assumptions to the Precautionary approach but with a further constraint on options for forest biomass supply (specifically avoiding harvesting in forest areas with very low growth rates). In addition, it was assumed that the increased utilization of forest biomass for energy was accompanied by activities relating to forest management and biomass utilization that could lead to beneficial outcomes in terms of impacts on GHG emissions. Examples of such activities include afforestation (constrained with the intention of avoiding ILUC, see Section 3.4), improvement of the growing stock of degraded forest areas and greater emphasis on the supply of forest biomass for use as energy as a co-product of the supply of material wood products, as part of general efforts to build a bioeconomy (see Section 5.5). No assumption was made as to whether these activities take place because of economic incentives arising from additional demand for biomass, or as a result of regulatory measures. Rather, the Synergistic approach was intended to give an indication of the potential of such activities to influence the contribution to GHG savings that might be made by the forestry sector and forest bioenergy consumers.

All scenarios, including Reference Scenario A, were modelled for both the Precautionary and Synergistic approaches in all geographical regions represented in the project as supplying the EU region with bioenergy. As already explained, the scenarios and results based on the Precautionary approach were taken as the main scenarios and results of the Bioimpact project.

Regional differences between forest biomass sources

Separately from the Precautionary and Synergistic approaches, the modelling also took into account differences between supplying regions as regards forest management and wood utilisation practices. Table 4.1 gives a qualitative summary of the differences in emphasis in forest management practices and wood utilization assumed for the four regions supplying biomass to the EU, as modelled in this project (EU domestic wood production, Canada, the USA and Brazil). The table refers to abbreviated names for different aspects of forest management and wood utilization practices, which are defined in Box 1. These definitions are also referred to in Table 6.1 later in this report. The emphasis on different practices varies slightly between scenarios; the descriptions in Table 4.1 are based on the scenario which is most pertinent for each region, as indicated in the table.

More details of specific assumptions about forest management and wood utilization practices made for each supplying region are given Section 4.8.3 and 4.8.4 of the final project report. Table 4.1 also shows the weight given to the various practices in the synergistic approach within each region.

Table 4.1 Qualitative description of representation of forest management and wood utilization associated with forest bioenergy supply from different regions (see Box 1 for descriptions of abbreviated names)

Abbreviated name for practice	Geographical region supplying forest bioenergy (and scenario referred to)			
	EU (C3)	USA (C1)	Canada (C1)	Brazil (Any)
Additional harvesting	●	●●	●●●	0
Small/early thinnings	●●●	●●	●	0
Forest residues	●●●	●	●	0
Industrial residues	●●	●	●	0
Co-production	●	●●	●●●	0
Additional practices in the Synergistic approach				
Co-production	●●	●●●	●●●●	0
Afforestation	●●●	0	0	●●●
Improvement of growing stock	●●	●	0	0
Avoid very low growth rates	●	●	●	Not relevant

Key to qualitative descriptions in Table 4.1: 0 no representation; ● limited representation; ●● moderate representation; ●●● strong representation; ●●●● very strong representation.

Box 1. Definitions for abbreviated terms for forest management and wood utilization practices referred to in Table 4.1 (also Table 6.1) including definitions for supporting terms

Additional harvesting: Harvesting of trees (by thinning and particular clearfelling) to meet demand from bioenergy, that would not otherwise have been harvested (at any time).

Small/early thinnings: Trees harvested as thinnings with total stemwood volume having less than either 5% or 10% material of sawlog dimensions (depending on the scenario).

Forest residues: The woody biomass of trees which may be discarded in the forest following tree harvesting (if not extracted for use as a bioenergy feedstock) as being unsuitable for technical or economic utilisation for the manufacture of sawn wood, wood-based panels or paper, typically consisting of branchwood, stem tops, defective tree stem pieces and stem offcuts but excluding tree stumps and roots.

Co-production: As part of additional harvesting (see definition above), the production of an assortment of outputs, including both long and short lived wood products, and biomass for energy, rather than solely harvesting for bioenergy.

Industrial residues: Wood generated as a by-product by the wood processing and associated industries, including offcuts, sawdust, sawmill chips, etc., which may be disposed of or used as a feedstock for wood-based panels or bioenergy.

Afforestation: The establishment of new forest areas on marginal land (constrained with the intention of avoiding ILUC) with the purpose of producing forest bioenergy, either as a dedicated bioenergy product (Brazil) or through co-production (see above) when harvesting.

Improvement of growing stock: Activities to enhance the carbon stocks and the productive potential of forest areas, e.g. restoring the growing stock of degraded forest areas or increasing forest growth rates through tree species choices, soil fertilization, etc.

Avoid very low growth rates: Exclusion of forest areas with very low growth rates (e.g. 2 m^3 ha^{-1} yr^{-1} and lower) from the introduction of additional harvesting to produce bioenergy.

Sawlog: Roundwood of sufficient dimensions to be sawn lengthways for the manufacture of sawn wood or used for the production of veneer (mainly by peeling or slicing).

Roundwood: All stemwood, with or without bark, including wood in its round form, or split, roughly squared or in other form, which is extracted during harvesting operations in a forest. For the purposes of this project, roundwood can be regarded as the same as stemwood, as defined below.

Stemwood: Whilst other definitions exist, in this context, this is woody material forming the above ground main growing shoot(s) of a tree or stand of trees, including all woody volume above ground with a diameter greater than 7 cm over bark, and wood in major branches where there is at least 3 m of "straight" length to 7 cm top diameter.

Small roundwood (relevant to criteria in Table 6.1): Small roundwood may be defined as stemwood of small diameter, which does not fall into the category of sawlog, but which may typically be used to make fencing, or chipped to make wood-based panels, pulped to make paper, or used in bioenergy applications.

Stumps: The stemwood left above ground after a tree is felled, generally still attached to the roots.

Roots: In the context of this discussion, the main/coarse structural roots of a tree.

Regional differences under the Precautionary approach

For the Precautionary approach, as already noted, the supply of forest bioenergy from different regions was broadly related to the magnitudes of different potentials of forest biomass resources available within each country, with limited consideration of whether these different resources may lead to beneficial or deleterious outcomes in terms of impacts on GHG emissions. More specifically, the variation in assumptions for the different regions reflected the composition of the forest resources in each country (see Section 4.8.4 of the final project report). For example, whilst not universally the case, the forest resource in a significant number of EU Member States is already under quite intensive management, i.e. involving practices such as the regular thinning and felling of trees, with national-scale regulation to ensure regeneration or replanting of forests and the maintenance of a productive forest growing stock, as part of sustainable forest management. In comparison to the EU, generally, forests in Canada are also managed according to the principles of sustainable forest management, and some forest areas are managed in a very similar way to that described previously for certain EU Member States. However, there are also large area of forests in Canada which may not be under such regular intensive management, but in which harvesting (and subsequent regeneration) could still occur, if the right economic circumstances were to be met. Hence, one of the consequences for this project of the different compositions of forests in the EU and Canada was that there was more emphasis on bioenergy production from small early thinnings in forests in the EU region, whilst there was more emphasis on bioenergy production arising from additional harvesting in forests in Canada.

It should be apparent that the modelling of forest management and wood utilization to supply bioenergy from forests under the Precautionary approach took a “neutral” position with regard to the forest resource in each country; there was no selection of particular types of forest for supplying bioenergy, which might lead either to better or worse outcomes in terms of impacts on GHG emissions. In reality, if it were possible to identify those forest management and wood utilization practices that led to better outcomes, then these practices could be preferred over those that lead to worse outcomes. However, for defining the Precautionary approach in this project, the project team considered it inappropriate to make any presumption that certain forest areas or practices would be preferred over others in supplying forest bioenergy from the different countries.

Regional differences under the Synergistic approach

Regarding the positive activities assumed to take place under the Synergistic approach:

- Such activities were assumed to make a significant contribution towards bioenergy supply from forests in the EU region
- There was only limited representation of such activities in the USA. The main activity represented was increased co-production of wood for material uses alongside energy, with some representation of improvements to forest growing stock and no additional afforestation activities
- There was no representation of such activities in Canada, apart from increased co-production of wood for material uses alongside energy
- Afforestation activities related to bioenergy supply to the EU from outside the EU region were represented solely by assuming that the increased demand for bioenergy

in the EU region would lead to a market response involving the establishment of high-productivity plantations dedicated to bioenergy production on formerly degraded agricultural land in Brazil.

The varying assumptions for different regions reflected cautiousness in defining the activities represented in the Synergistic approach, notably with regard to Canada and the USA. Specifically, it was considered important not to overstate the potential for introducing or encouraging positive activities in the forest sector in conjunction with increased biomass supply from regions outside the EU.

The various assumptions made in defining the forest management and wood utilization practices involved in supplying bioenergy, from the different supplying regions and for the different scenarios, had consequences for the main project results, i.e. the estimated impacts on GHG emissions. This point is explored further in Section 5, in particular Section 5.3.

5. Key findings

As already explained in Section 4.2, the main results presented in the final project report were based on the scenarios involving the Precautionary approach to forest management and wood utilization. It follows that the main results do not allow for the possibility that increased supply of forest biomass for energy use could be accompanied by additional constraints or activities aimed at ensuring beneficial impacts on GHG emissions.

The main project results, and the key findings drawn from them, are summarized here in Sections 5.1 to 5.4 below.

5.1. Total annual GHG emissions

Figure 5.1 shows the results obtained for the trajectories of the total annual GHG emissions in the EU region over the period 2010 to 2050 for all scenarios, assuming basic sustainability safeguards (Precautionary approach). As the original report to the EC highlighted, in all cases the net result is of deepening emissions reductions over the period for all scenarios, with varying magnitude. In the case of the Reference Scenario (A), the continuing reductions in GHG emissions after 2020 are mainly as a result of strengthening of targets under the EU ETS.

It can also be seen that from 2020 onwards, all the four scenarios of continued bioenergy use, as well as the scenario that represents reduced bioenergy use, achieve greater total GHG emissions reductions than the Reference Scenario (A). This reflects the setting of much more ambitious targets for GHG emissions reductions after 2020 in the decarbonisation scenarios, requiring the adoption of more ambitious climate and energy policies and implementation mechanisms compared to the Reference Scenario. The deeper GHG emissions reductions achieved in the decarbonisation scenarios are related to changes in the types of bioenergy and non-bioenergy sources and conversion technologies that are represented in the energy mix in the different scenarios.

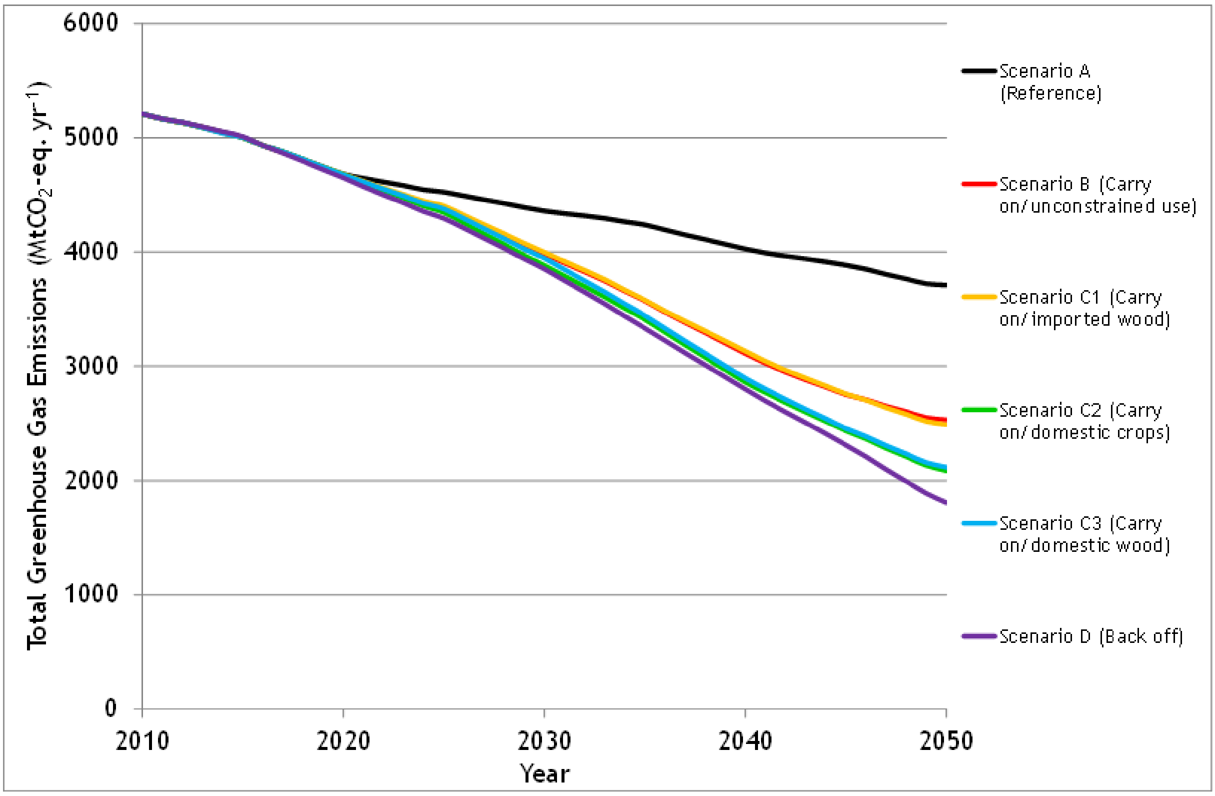

Figure 5.1. Total annual GHG emissions.

It is important to recognize that these results reflect the totality of all measures included in each scenario (i.e. with regard to both bioenergy use and the use of other energy sources or improvements in energy efficiency). **Hence it is not possible to tell directly from the figure whether bioenergy use in each of the scenarios is contributing towards, or detracting from, the estimated GHG emissions reductions.**

5.2. GHG impacts of key energy sources

In order to better inform the interpretation of the results of the Bioimpact Project, the project team undertook more detailed analysis of the results with the aim of clarifying the reasons for the differences between scenarios. However it must be recalled that a CLCA methodology was applied in this project, because the principal aim was to determine the total collective consequences of defined policy options. CLCA does not involve attributing specific GHG emissions to individual components of the system (e.g. specific biomass feedstocks or other sources of energy). Nevertheless it was possible to estimate the contributions to total GHG emissions reductions in the different decarbonisation scenarios, compared to the Reference Scenario, arising from broadly defined types of energy source of interest to this project, i.e. "Fossil", "Bioenergy" and "Other" sources. Table 5.1 shows the results obtained for the year 2030.

Table 5.1 Changes in total annual GHG emissions in 2030 relative to the Reference Scenario (A)

Scenario	GHG emissions 2030 ($MtCO_2$-eq.yr^{-1})			
	Fossil	Bioenergy	Other	Total
B (Carry on, unconstrained use)	-456	77	2	-378
C1 (Carry on, imported wood)	-458	108	-11	-360
C2 (Carry on, domestic crops)	-460	0	-17	-478
C3 (Carry on, domestic wood)	-460	64	-18	-415
D (Back off)	-454	-95	41	-508

It is necessary to clarify what the broad energy types referred to in Table 5.1 actually represent:

- "Fossil" consists of the GHG emissions reported in the project results as "EU emissions (non-biomass)" and consists mainly, but not entirely, of GHG emissions as a result of the use of fossil fuels
- "Bioenergy" consists of the sum of GHG emissions associated with bioenergy sources; specifically, the categories, "Agricultural biomass", "Energy crops" (which includes biofuel crops) and the various categories of "Wood Fuel/HWP Co-products", as reported in the project results
- "Other" consists of the sum of contributions for all other categories reported in the project results, notably "Imported Fossil Fuel and Nuclear Fuels, and Electricity".

The GHG emissions reported under the category Bioenergy include several contributions:

- Biogenic emissions due directly to the combustion of biomass
- Biogenic emissions/sequestration as a result of changes in vegetation, litter and soil carbon dynamics of agricultural and forest land, arising from bioenergy production (see detailed discussion in Sections 3.3 and 3.4)
- Emissions as a result of the processing of bioenergy sources and conversion systems
- Emissions arising from the manufacture of co-products of the bioenergy sources, including for example animal feed and notably wood co-produced for the manufacture of material products

- Changes in emissions, which may be a reduction, as a result of counterfactual products being displaced by the co-products of the bioenergy sources (see previous point)
- Biogenic emissions from the disposal of material wood co-products at end of life, also allowing for changes in emissions as a result of displacing of counterfactual products.

The results in Table 5.1 for the Bioenergy and Other categories do not include the GHG emissions savings achieved through the consumption of these energy sources in place of alternative (counterfactuals). These savings are included in the results for the Fossil category and contribute towards the GHG emissions reductions reported for this category.

5.2.1. Observations on results for 2030

The results in Table 5.1 show that:

- The GHG emissions in the Bioenergy category vary significantly between scenarios as a result of the amount and type of bioenergy assumed to be used. There is a strong positive relationship between these emissions and the level of bioenergy consumption in the scenarios, compared to the Reference Scenario, particularly forest bioenergy consumption (i.e. the higher the levels of forest bioenergy consumption in the scenario the higher the GHG emissions). For the scenarios that represent continued bioenergy use, the emissions vary between 0 $MtCO_2$-eq for the scenario with the lowest use of forest bioenergy in 2030 (C2) and 108 $MtCO_2$-eq for the scenario with the highest use of forest bioenergy in 2030 (C1).
- GHG emissions in the Fossil category are very similar for all scenarios, i.e. a reduction of the order of 460 $MtCO_2$-eq per annum. The reduction in emissions in this category is the result of all the activities contributing towards the intended policy targets assumed in each scenario, including increased or decreased consumption of bioenergy and other non-fossil energy sources. GHG emissions increases in the Bioenergy category for the Carry on scenarios are always of considerably smaller magnitude than the emissions reductions in the Fossil category. However, in the scenarios with relatively high forest bioenergy consumption, the emissions increases in the Bioenergy category represent between 14% and 24% of the emissions reductions in the Fossil category.
- In the scenario that represents backing away from bioenergy (D), GHG emissions in the Bioenergy category are reduced as a result of lower consumption of bioenergy (particularly forest bioenergy), compared with the Reference Scenario. However, emissions in the Other category are increased as a result of greater use of these energy sources, although the magnitude of this emissions increase is smaller than the increases in the Bioenergy category for the high bioenergy scenarios (with one exception).

5.2.2. Conclusions on results for broad contributions to GHG impacts

Bearing in mind the caveats attached to results presented in Table 5.1, based on the main results, it may be concluded that:

- The decarbonisation scenarios can be ranked according to the total GHG emissions reductions achieved
- Generally, the greater the contribution made by forest bioenergy, the smaller the magnitude of total GHG emissions reductions
- The scenario that represents backing away from bioenergy (D) delivers the greatest GHG emissions reductions
- All decarbonisation scenarios lead to fairly similar reductions in overall EU emissions ; at most, the difference between the best (scenario D) and the worst (C1) is only a 3% reduction in total EU GHG emissions
- In 2050, by which time the level of bioenergy consumption in the bioenergy scenarios is very high, the additional reduction in total GHG emissions achieved by Scenario D in comparison with Scenarios B to C3 is more significant, respectively, 20%, 18%, 8% and 8%.

Scenario D (Back off) achieves GHG emissions reductions with less bioenergy consumption, and instead involves greater efforts towards deployment of a range of other low-carbon energy solutions.

5.3. GHG impacts of forest bioenergy

One of the key findings of the discussion in Section 5.2 concerned the apparent importance of the contribution of forest bioenergy in determining the magnitude of GHG emissions reductions in the different decarbonisation scenarios. As a result this topic was further investigated through additional detailed analysis, as described in Section 6.9 of the final project report, in particular Section 6.9.4.

Looking in more detail at the impact of forest bioenergy specifically on the net difference in GHG emissions between the scenarios and Reference Scenario A shows some interesting variation. Figure 5.2, below, shows the net difference in GHG emissions relative to Reference Scenario A ***solely as a result of forest biomass consumption for energy.***

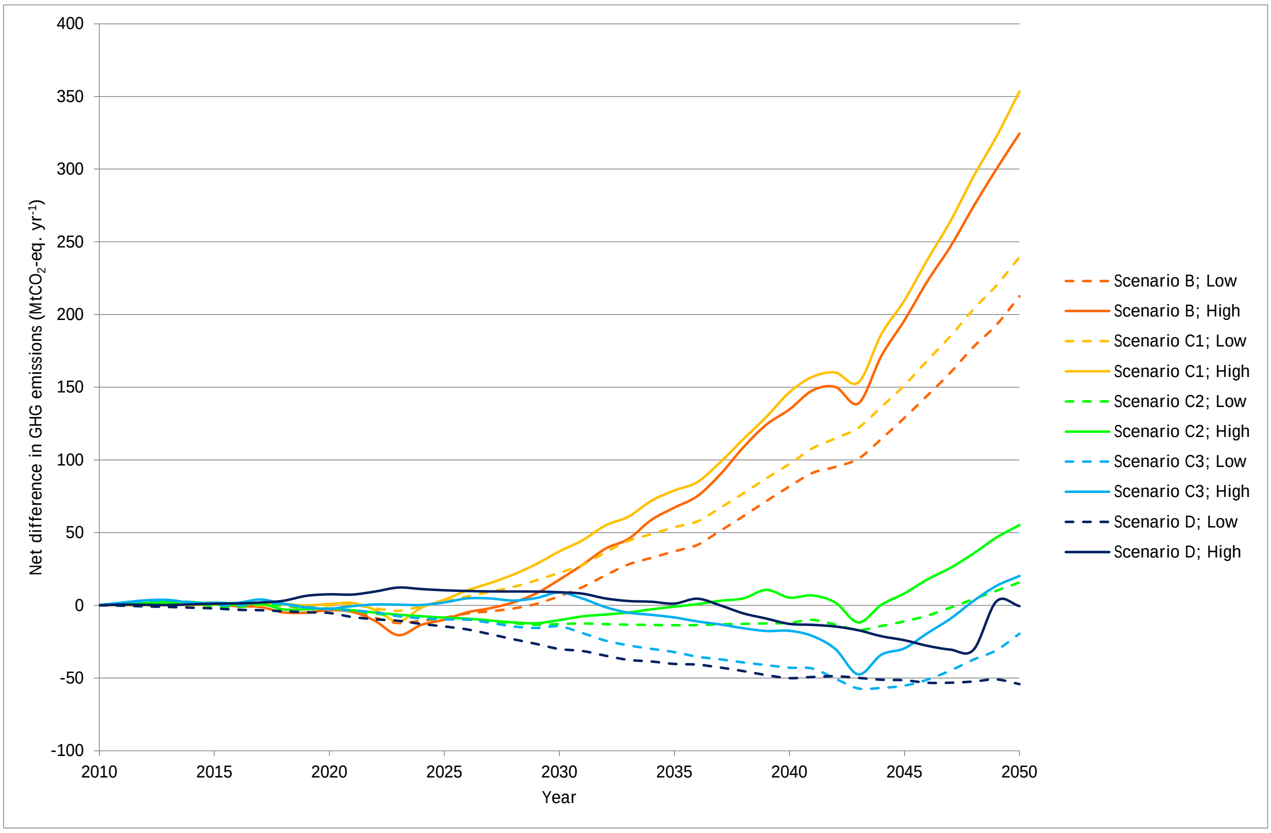

Figure 5.2. Range of net differences in GHG emissions as a result of forest bioenergy relative to Reference Scenario A.

In order to illustrate the range of results, for each of the four decarbonization scenarios, a 'high' and 'low' emissions situation was modelled. The main difference between these two is in the choice of fossil energy counterfactuals, natural gas in the 'high' case, coal in the 'low' case.

Figure 5.2 presents a lot of information in one graph and it is not always easy to follow the trajectories for individual scenarios. To assist with interpretation, Figures 5.3, 5.4 and 5.5 show snapshots of the results for different scenarios for each of the years 2030, 2040 and 2050 respectively.

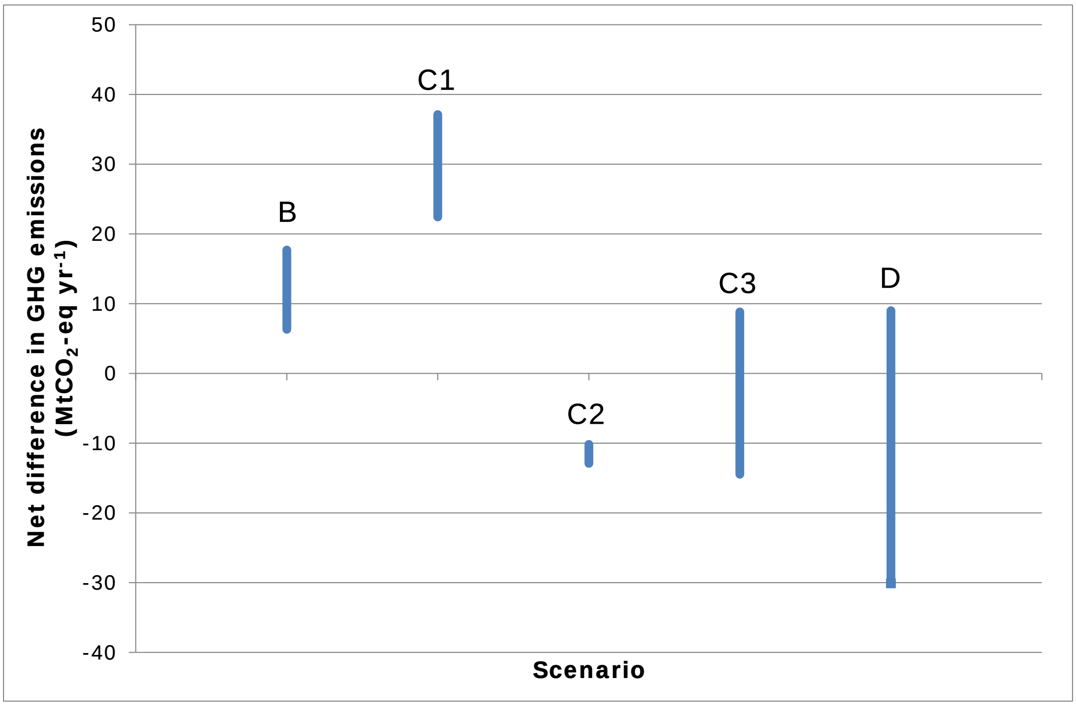

Figure 5.3. Range of net differences in GHG emissions in 2030 as a result of forest bioenergy relative to the Reference Scenario (A).

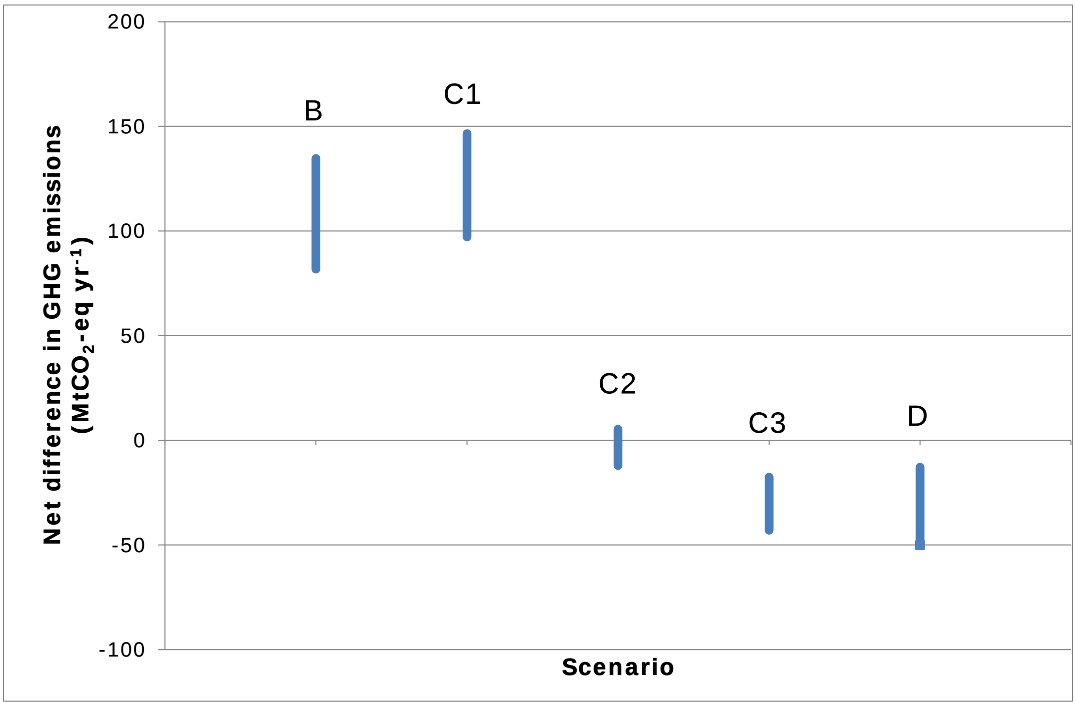

Figure 5.4. Range of net differences in GHG emissions in 2040 as a result of forest bioenergy relative to the Reference Scenario (A).

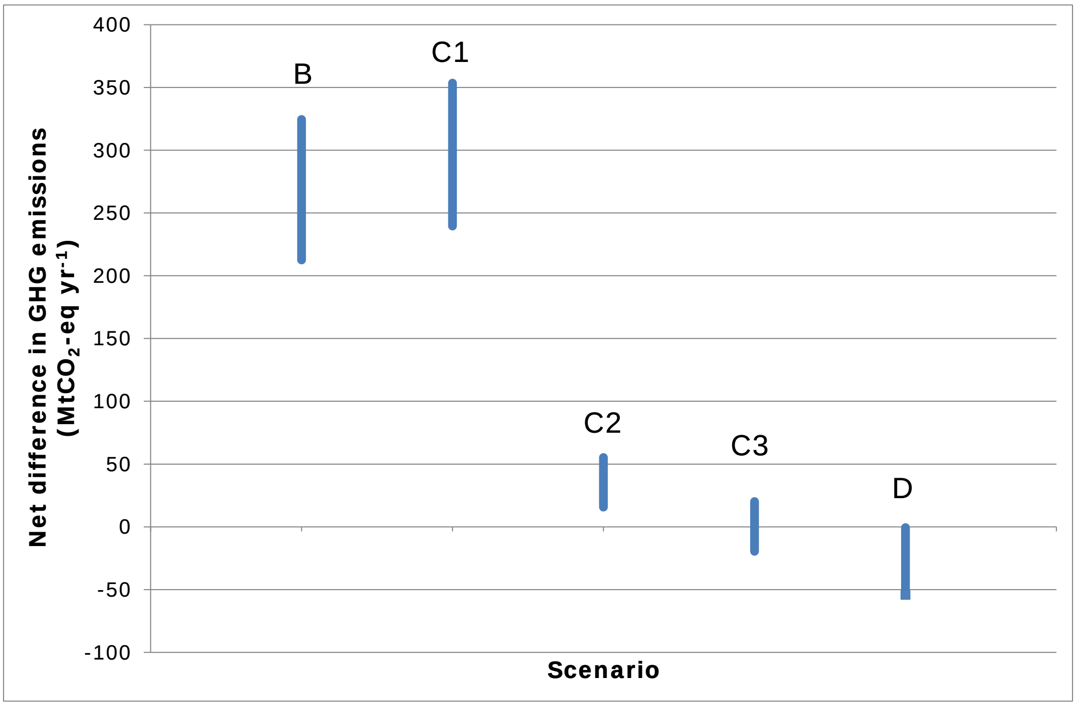

Figure 5.5. Range of net differences in GHG emissions in 2050 as a result of forest bioenergy relative to the Reference Scenario (A).

From Figures 5.2 to 5.5 it is possible to make certain observations about the impacts on GHG emissions as a result of forest bioenergy as represented in the decarbonisation scenarios:

- It can be seen that in the scenarios where bioenergy use is unconstrained, or comes largely from imported wood (Scenarios B and C1), GHG emissions as a result of forest bioenergy increase over time, compared to the Reference Scenario A, and are significantly greater by 2040.
- Scenario C2 (Carry on, domestic crops) does not display any substantial differences in terms of GHG emissions from forest bioenergy use compared to Reference Scenario A until after about 2040, when there is an increase.
- The scenario that emphasizes bioenergy supply from forests in the EU region (Scenario C3) delivers GHG reductions as a result of forest bioenergy in the near term that are comparable to those that are estimated for forest bioenergy in Scenario D, which represents a strategy of backing away from bioenergy. However, after 2040, by which time the level of forest bioenergy consumption represented in the Carry on scenarios has become very high, the net GHG emissions as a result of forest bioenergy start to rise relative to the Reference Scenario (and also Scenario D).
- Scenario D (Back off) also shows deepening GHG emissions reductions from forest bioenergy compared to Reference Scenario A over most of the period to 2050.

The results appear to suggest important differences in the GHG impacts of forest bioenergy supplied from forests in the EU region and forest bioenergy imported from other countries. However this is not a basis for drawing simplistic conclusions about the impacts of consuming domestically produced and imported forest bioenergy sources.

As explained in Section 4, notably in Section 4.2.2, the modelling of forest bioenergy supply from different geographical regions involved detailed assumptions about forest management and wood utilization, which varied significantly between regions.

Based on the results presented above, and description of scenarios in Section 4, notably in Section 4.2.2 and in Table 4.1, it may be tentatively concluded that, **with specific regard to forest bioenergy sources** (see definitions of practices in Box 1, Section 4.2.2):

- The scenario of unconstrained bioenergy use (B) and the scenario with higher imported wood (C1) achieve the lowest GHG reductions because they emphasize forest management and wood utilization practices involving additional harvesting and place less emphasis on the utilization of small/early thinnings, forest residues and industrial residues
- The scenario that emphasizes domestic forest bioenergy (C3) performs relatively well because it emphasizes forest management and wood utilization practices involving utilization of small/early thinnings, forest residues and industrial residues and places less emphasis on additional harvesting
- The scenario that backs away from bioenergy (D) also performs best in GHG reductions because the level of forest bioenergy production is lower than in the Reference Scenario, as a result of the de-prioritization of bioenergy consumption.

The implications of these conclusions are that (see definitions of practices in Box 1, Section 4.2.2):

- Bioenergy production involving additional harvesting, even if that involves co-production as part of additional harvesting, involves significant risks of high GHG emissions
- Bioenergy production involving utilization of small/early thinnings, forest residues and industrial residues involves low risks and should lead to low GHG emissions.

5.4. Cost and technical implications of scenarios

The main final report for the Bioimpact project included in Section 6.8 an assessment of the economic costs associated with the different scenarios. The assessment appeared to suggest that the scenario involving a backing away from bioenergy (D) involved greater costs than the scenarios involving increased consumption of bioenergy (B, C1, C2 and C3). The discussion of the cost results explained that this result was obtained because biomass energy sources were estimated to be relatively low cost. The assessment allowed for the existence of other low-cost, low-carbon energy options, including the deployment of solar and wind energy where appropriate. However, according to the assessment, when future consumption of bioenergy was constrained such as in Scenario D, the remaining low-cost energy options were not sufficient to meet future targets for renewable energy consumption and GHG emissions reduction. Hence, some higher-cost options needed to be included as part of actions taken to meet the targets. There was also some increased reliance on imported energy sources.

The Bioimpact project team made considerable efforts to compile the best possible cost estimate for different energy sources, including bioenergy and the team considers that the cost assessment was reasonably robust. However, this view is not shared by all stakeholders and it must be accepted that estimating the relative cost of energy sources up to 35 years into the future involves speculation. It must also be acknowledged that certain costs likely to be involved with more sophisticated deployment of certain bioenergy sources were not considered as part of the assessment (see Section 5.5) and that costs of wind and solar have fallen unexpectedly fast in recent years..

5.5. Measures to support forest bioenergy consumption with low GHG emissions

In addition to presenting the main project results, the final report of the Bioimpact project also considered results for scenarios involving the synergistic approach to forest management and wood utilization. The interpretation of these results was complex and has been contended by some stakeholders, hence, a simplified analysis and interpretation is presented here, limited to result for forest bioenergy produced from EU forests (this means the analysis excludes any contributions arising from forest biomass supplied to the EU through afforestation activities in Brazil, and as a result of limited changes in forestry activities in Canada and the USA, mainly involving more emphasis on co-production of wood for use as materials alongside bioenergy).

Compared to the main project results, **across all scenarios**, the results for the Synergistic approach modelled for EU forests indicate reductions in GHG emission could be achieved, amounting to about 40, 110 and 140 $MtCO_2\ yr^{-1}$ in 2020, 2030 and 2040 onwards, respectively. These reductions, achieved solely through activities involving wood production from EU forests, would:

- More than compensate for the net increases in GHG emissions estimated for forest bioenergy consumption, where these occur in the main project results for the scenarios emphasizing bioenergy supplied from agricultural or forest sources in the EU region (C2 and C3), giving net GHG savings
- Give deeper GHG savings for the scenario involving backing away from bioenergy consumption (D).

For the scenario emphasizing consumption of imported forest bioenergy sources (C1), the GHG emissions reductions estimated for the Synergistic approach would give overall net GHG savings until about 2040, after which the high levels of forest bioenergy consumption in the scenario would lead to a net increase in GHG emissions.

Taken superficially, the results for the Synergistic approach seem to suggest that forest biomass can be used as an energy source with low GHG emissions, if the types of activities represented under the Synergistic approach for EU forests can be promoted in the EU and possibly more widely, as part of bioenergy production. This view is reinforced when it is noted that not all possible activities that could be involved in producing biomass from forests with low carbon impacts were represented in the modelling for the Synergistic approach (an important example is the enhancement of forest growth rates as part of maintaining and restoring forest growing stock). However, such a simple conclusion could be viewed as seriously flawed. As already pointed out, the GHG emissions reductions estimated for the Synergistic approach are similar for all scenarios, including the scenario involving backing away from bioenergy consumption (D). This raises the question: couldn't activities such as represented in the Synergistic approach just be promoted anyway, without any association with increased bioenergy consumption, for example as part of measures aimed at climate change mitigation in the land use sector?

It is true that, in many (but not all) cases, relevant activities in the forest sector are not inevitably connected with bioenergy production and could be carried out regardless of any commitment to supplying forest biomass for use as an energy source. Notwithstanding, it remains the case that these activities are likely to require a framework to support their adoption, since this would be unlikely to occur as a result of simple commercial decisions about forest management. It follows that there is a choice to be made between:

- Not supporting such activities
- Supporting relevant activities through a suitable framework covering land use and forestry (i.e. not connected specifically with the consumption of forest biomass for energy or other purposes)
- Supporting relevant activities through a suitable framework covering the consumption of forest biomass (for energy and possibly for materials)
- Supporting relevant activities through an integrated approach to frameworks covering land use, forestry and the consumption of forest biomass for materials and energy.

It is the view of the Bioimpact project team that an important opportunity would be missed if an integrated approach were not to be taken to supporting climate change mitigation activities involving land use, forestry and forest biomass consumption, particularly if the consumption of forest biomass for energy is viewed as a potential problem. Furthermore, there is an existing strong interest in the EU to increase forest biomass production as part of the development of a low-carbon "bioeconomy", hence there is a natural opportunity to link such developments to support for low-carbon impact approaches to forest management and wood consumption. Supporting frameworks could be developed solely from the point of view of land use and forestry, but these may cost more if the existing impetus towards a bioeconomy is not harnessed. It should however be noted that while the EU has a relatively strong influence over energy policies, the forestry policies of individual Member States are largely a national competence and so the scope for EU directed action is limited, even within the EU.

Two important caveats must be attached to the previous points.

Firstly, forests in different EU Member States are very variable (e.g. in terms of tree species, growth rates, levels and types of management and risks of natural disturbances). As a consequence, opportunities for (and challenges to) the production of forest bioenergy with low carbon impacts occur unevenly across Member States. In principle, this could be addressed by managing efforts cooperatively at the scale of the EU and allowing for variations in the contributions made by individual Member States. Such an approach could be challenging to implement but could overcome potential barriers at national scale.

Secondly, the Bioimpact project did not include an assessment of any additional costs associated with the types of activities covered by the Synergistic approach. It may be speculated that the application of a mechanism to support these types of activities in conjunction with forest bioenergy supply would be likely to "even out" the relative performance of the scenarios involving increased bioenergy consumption (C1, C2 and C3) and the scenario involving backing away from bioenergy consumption (D), in terms of GHG impacts but also in terms of costs.

6. Implications for regulation of bioenergy

The key findings and conclusions of this project, as presented in Section 5, would appear to suggest two major policy options with regard to renewable energy and the potential contribution of bioenergy.

One option would involve de-prioritizing bioenergy in order to avoid potential risks associated with some bioenergy sources, whilst noting that this would be likely to require at least some of the following:

- The increased use of other renewable energy sources (particularly solar and wind power)
- More concerted efforts towards energy efficiency or demand-side response in the EU region across all sectors, but particularly in the residential and transport sectors

- Increased use of nuclear power (involving both current and assumed future technologies)
- Increased reliance on imports of natural gas, nuclear fuels and electricity into the EU region from elsewhere
- Some increased deployment of carbon capture and storage technologies.

The **alternative option** would be to carry on with supporting a contribution from bioenergy sources towards targets for renewable energy and GHG emissions reductions, whilst putting in place a policy framework capable of ensuring that bioenergy sources genuinely lead to significant near-term reductions in GHG emissions compared to fossil fuels.

If the bioenergy option were to be pursued, it is important to recognize that this study has identified that bioenergy, and forest bioenergy in particular, can be a potential contributor to increased GHG emissions. However, this is not inevitable if a framework is adopted to ensure only agricultural and forest biomass sources that deliver genuine emissions reductions are used for energy purposes.

6.1. General guidelines for bioenergy sources

Certain general guidelines for agricultural and forest bioenergy supply can be identified:

- Avoid serious risk of ILUC
- Keep levels of supply within sustainable yield capacity
- Limit negative impacts on carbon stocks of agricultural soils and forests (trees, litter and soils) and their capacity for future carbon sequestration
- In the case of forest bioenergy, avoid negative impacts on the potential supplies of wood for manufactured wood products, where these pathways have clearly lower-carbon impacts compared to using the wood for bioenergy.

In addition, for forest bioenergy sources, it is important to ensure that these sources provide genuine GHG emissions reductions within relatively short time scales (e.g. before 2050 and preferably sooner). Because of the complexity of forestry systems, their management and the many ways in which harvested wood is utilized, it is challenging to develop a simple guide to forest bioenergy sources that should ensure that GHG emissions reductions are achieved over timescales relevant to avoiding runaway climate change and supporting the temperature goals established by the Paris Agreement.

The final project report for the Bioimpact project included a proposed approach based on a decision tree (Section 2.4 and Appendix 1), for the assessment of forest bioenergy sources, in terms of the likelihood of achieving reductions in GHG emissions compared to fossil fuels, or risks of causing GHG emissions increases. This approach was welcomed by some stakeholders but considered too complicated by others. Below, an alternative approach is suggested, based on an extremely simplified decision tree (Figure 6.1) and a supporting table of criteria related to aspects of forest management and wood utilization for energy (Table 6.1).

The decision tree allows the assessor the option of first considering a set of criteria concerned with aspects of forest management associated with the harvesting of wood for energy purposes. These criteria are listed in part (a) of Table 6.1.

If the outcome of the assessment based on part (a) is immediately positive, a requirement to consider a second set of criteria (concerned with the utilization of specific wood feedstocks for energy) is significantly relaxed. (Specifically, it is then necessary to consider only two “mandatory” criteria related to wood feedstocks.)

In many situations it may be challenging for assessors to establish the nature of forest management involved in the supply of wood for utilization as energy (for example, there may be difficulties in tracing parcels of harvested wood back to the areas of forest that they originated from). In these circumstances, the assessor has the option of not referring to part (a) of Table 6.1 but instead proceeding directly to considering the full second set of criteria concerned with wood feedstocks. These criteria are listed in part (b) of Table 6.1.

Often, the outcome of the assessment based on forest management criteria in part (a) of Table 6.1 will require the assessor also to consider the full list of wood feedstock criteria in part (b).

The above approach could be relevant when evaluating other existing or proposed approaches to regulating bioenergy consumption in the EU. The examples of greatest current relevance in the context of this discussion are:

- The existing EU Renewable Energy Directive (RED)
- A “Proposal for a Directive of the European Parliament and the Council on the promotion of the use of energy from renewable sources (recast)”, otherwise referred to as the REDII proposal
- Of indirect relevance, but potentially high importance, the framework adopted for accounting for Forest Land in national GHG emissions inventories after 2020.

Table 6.1 also includes a comparison of the various provisions of the REDII proposal with the criteria derived from this project; this is discussed further in Section 6.2.

As with the decision tree presented in the original final project report, the designs of the decision tree and table of criteria presented here are provisional and likely to require further refinement.

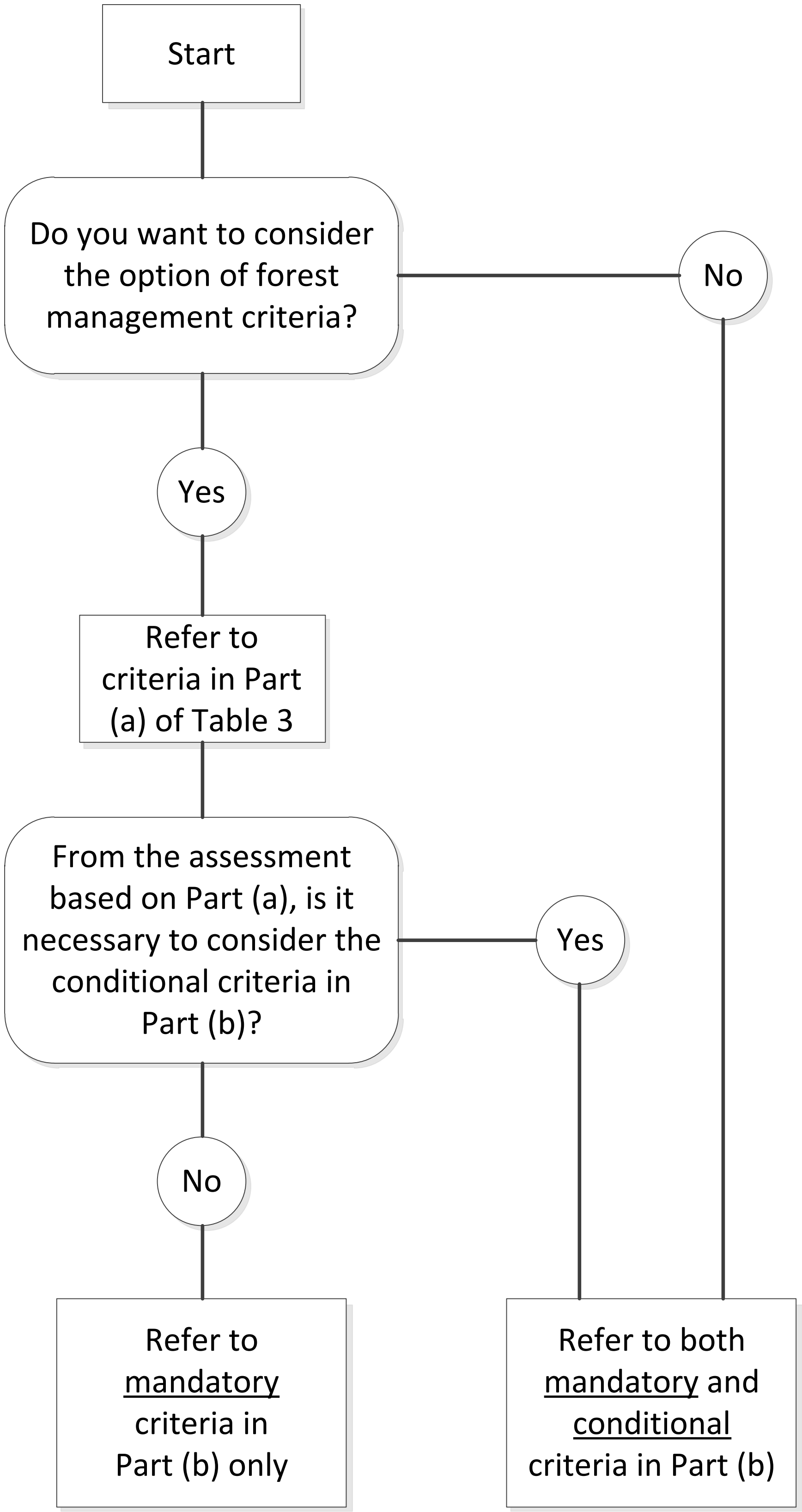

Figure 6.1 Decision flow diagram for application of criteria in Table 6.1.

Table 6.1 Tentative criteria for forest management and wood utilization aimed at bioenergy supply with low risks of increased GHG emissions compared to fossil fuels: Part (a) – Forest management

Criterion	Practice	Representation under proposed RED II
Deforestation	Disallow supplies of forest bioenergy that lead to deforestation.	Article 26 para 5 requires that "forest regeneration of harvested areas takes place" Article 26 para 3 addressing agricultural production requires that "biomass fuels [...] shall not be made from raw material obtained from land with high carbon stock, namely land that had one of the following statuses in January 2008 and no longer has that status: [...] continuously forested areas [...]; land spanning more than one hectare with trees [...] unless evidence is provided that [the calculated GHG savings would be sufficient]" (text in square brackets added for clarity).
Afforestation	Strongly favour supplies of forest bioenergy where these are explicitly associated with afforestation activities (see Sections 4.2.2 and 5.5). However, avoid afforestation activities: ● On soils with existing high organic carbon content ● That lead to high risks of indirect land-use change.	No specific proposals for promoting desirable activities other than general GHG emissions criteria (Article 26 para 7 (d)), see also discussion in Sections 6.2.1 and 6.2.2 See separate discussion of regulation of LULUCF (Section 6.3)

Table 6.1 Tentative criteria for forest management and wood utilization aimed at bioenergy supply with low risks of increased GHG emissions compared to fossil fuels: Part (a) – Forest management (continued)

Criterion	Practice	Representation under proposed REDII
Improvement of growing stock	Strongly favour supplies of forest bioenergy where these are explicitly associated with activities to conserve and enhance forest growing stock, carbon stocks and forest productivity (see Sections 4.2.2 and 5.5). There have been several previous discussions of the types of forest management involved in improving growing stock. Examples may be found in Schelhaas *et al.* (2006) and Sections 8.3 to 8.5 of Matthews *et al.* (2017)[9].	No specific proposals for promoting desirable activities other than general GHG emissions criteria (Article 26 para 7 (d)), however, positive impacts on carbon stocks not explicitly covered as no land-use change takes place, see Sections 6.2.1 and 6.2.2 See separate discussion of regulation of LULUCF (Section 6.3)
Growth rate	Disfavour forest bioenergy production from forest areas with low growth rates. Tentatively, low growth rate is defined as 2 m^3 ha^{-1} yr^{-1} or less. Possible exemptions in some cases, e.g. disease infested forest areas.	Not explicitly covered as no land-use change takes place, see Sections 6.2.1 and 6.2.2, however, Article 26 para 5 requires that “harvesting does not exceed the long-term production capacity of the forest” which would tend to disfavour harvesting in areas with low growth rates

[9] Schelhaas, M.J., Cienciala, E., Lindner, M., Nabuurs, G.J., and Meyer, J. (2006) *Survey of technical and management-based mitigation measures in forestry*. MEACAP WP4 D13. At: https://ieep.eu/publications/meacap-survey-of-technical-and-management-based-mitigation-measures-in-forestry;
Matthews, R.W., Mackie, E.D. and Sayce, M. (2017) *Natural Resources Wales Carbon Positive Project: greenhouse gas emissions and removals from woodlands on the NRW estate*. Final project report to Natural Resources Wales. Forest Research: Farnham (awaiting publication by NRW).

Table 6.1 Tentative criteria for forest management and wood utilization aimed at bioenergy supply with low risks of increased GHG emissions compared to fossil fuels: Part (a) – Forest management (continued)

Criterion	Practice	Representation under proposed RED II
Thinning and (clear)felling	If the level of supply of forest bioenergy from thinning and felling activities in forest areas is consistent with long-term historical levels, and with the principle of sustainable yield, then risks of issues with GHG emissions are low. If the level of forest bioenergy from thinning and felling activities in forest areas involves increased supply compared with long-term historical levels, then favour production from thinning over production from felling, with the aims of: ● Improving the quality of the remaining growing stock ● Minimising disturbance of litter and soil carbon. **If, and only if, the level of forest bioenergy from thinning and felling activities in forest areas involves increased supply compared with long-term historical levels, then it is necessary to consider the conditional criteria as well as the mandatory criteria regarding use of wood feedstocks for bioenergy in Part (b).**	Possible impacts on forest carbon stocks not explicitly covered as no land-use change takes place, see Sections 6.2.1 and 6.2.2 See separate discussion of regulation of LULUCF (Section 6.3)

Table 6.1 Tentative criteria for forest management and wood utilization aimed at bioenergy supply with low risks of increased GHG emissions compared to fossil fuels: Part (b) – Wood supply and feedstocks

Criterion (feedstock)	Practice	Representation under proposed REDII
Scale of forest bioenergy use: **Mandatory criterion**	Aim for levels of forest bioenergy use that are well within the long-term sustainable-yield capacity of the supplying forest areas. When setting levels for bioenergy use, take account of the consumption of biomass for other uses (i.e. materials) and levels of biomass consumption outside the EU region..	Article 26 para 5 requires that "harvesting does not exceed the long-term production capacity of the forest"
Stumps including roots: **Mandatory criterion**	Strongly disfavour supplies of forest bioenergy from stumps including roots.	No specific provisions in REDII. Likely negative impacts on forest carbon stocks not explicitly covered as no land-use change takes place, see Sections 6.2.1 and 6.2.2
Post-consumer waste wood: Conditional criterion	Strongly favour supplies of forest bioenergy from post-consumer waste wood. Particularly favour such sources where the waste wood would otherwise be burnt or put in landfill without energy recovery. Also favour use of waste wood at levels that do not compete with current levels of consumption of such feedstocks for material uses (e.g. wood-based panels).	Article 26 para 1 states "biomass fuels produced from waste and residues, other than agricultural, aquaculture, fisheries and forestry residues, need only fulfil the sustainability greenhouse gas emissions saving criteria" Provided that process and transport GHG emissions are small, this should encourage use of post-consumer waste where technical challenges, e.g. contamination, are not an issue
Industrial residues: Conditional criterion	Strongly favour supplies of forest bioenergy from industrial residues. Particularly favour such sources where the residues would otherwise be burnt as waste without energy recovery. Also favour use of industrial residues at levels that do not compete with current levels of consumption of such feedstocks for material uses (e.g. wood-based panels).	See above, industrial residues generated in the wood processing sector are explicitly excluded from the definition of forestry residues (Article 2) No explicit requirement to avoid feedstock competition with other products There is a possibility that some feedstock could be derived from unsustainable forestry activities

Table 6.1 Tentative criteria for forest management and wood utilization aimed at bioenergy supply with low risks of increased GHG emissions compared to fossil fuels: Part (b) – Wood supply and feedstocks (continued)

Criterion (feedstock)	Practice	Representation under proposed REDII
Forest residues: Conditional criterion	Strongly favour supplies of bioenergy from fast-decaying forest residues (i.e. apart from stumps including roots or other large residues) provided this avoids levels of extraction of forest residues that lead to high risks of degradation of site/soil quality (e.g. carbon stocks, nutrient status, water balance).	No specific provisions in the REDII Possible impacts on forest carbon stocks not explicitly covered as no land-use change takes place, see Sections 6.2.1 and 6.2.2
Salvage logging: Conditional criterion	Favour supplies of wood biomass from salvage logging where a simply calculated but robust estimate of GHG emissions meets a defined minimum threshold.	The use of specific forest biomass feedstocks is neither encouraged nor discouraged in the sustainability criteria Possible impacts on forest carbon stocks not explicitly covered as no land-use change takes place, see Sections 6.2.1 and 6.2.2
Whole tree stems: Conditional criterion	Restrict supplies of forest bioenergy from whole tree stems to small/early thinnings, with the aim of improving the quality of the remaining growing stock. Favour situations in which, otherwise, there would be limited incentives to thin and improve forest stands. Alternatively, favour supplies of wood biomass from small/early thinnings where a simply calculated but robust estimate of GHG emissions meets a defined minimum threshold.	No specific provisions in REDII. Possible impacts on forest carbon stocks as a result of increased thinning not explicitly covered as no land-use change takes place, see Sections 6.2.1 and 6.2.2

Table 6.1 Tentative criteria for forest management and wood utilization aimed at bioenergy supply with low risks of increased GHG emissions compared to fossil fuels: Part (b) – Wood supply and feedstocks (continued)

Criterion (feedstock)	Practice	Representation under proposed REDII
Small roundwood: Conditional criterion	Favour supplies of forest bioenergy from small roundwood at levels that do not compete with current levels of consumption of such feedstocks for material uses. Particularly favour such sources where the small roundwood would otherwise be burnt without energy recovery or sent to landfill.	No specific provisions in REDII. No explicit requirement to avoid feedstock competition with other products Where harvesting (thinning or felling) is increased, possible impacts on forest carbon stocks not explicitly covered as no land-use change takes place, see Sections 6.2.1 and 6.2.2
Sawn timber, especially suitable for construction uses: Conditional criterion	Strongly disfavour supplies of forest bioenergy from wood feedstocks suitable for use for sawn timber products.	No specific provisions in REDII.
Co-production: Conditional criterion	Strongly favour the supply of forest bioenergy as a by-product of wood harvesting for the supply of long-lived material wood products. However, it is very important to ensure that flanking measures are in place to ensure that other feedstock criteria above are met and to encourage the disposal of material wood products at end of life with energy recovery and/or in a way that ensures low GHG emissions.	No specific provisions in REDII. Where harvesting (thinning or felling) is increased, possible impacts on forest carbon stocks not explicitly covered as no land-use change takes place, see Sections 6.2.1 and 6.2.2

6.2. Biomass in the RED and proposed REDII

The EU Renewable Energy Directive (RED) is the principal current regulation addressing bioenergy consumption in the EU of relevance to this discussion. The stated aim of the RED is to establish "a common framework for the promotion of energy from renewable sources". It sets mandatory national targets for the overall share of energy from renewable sources in gross final consumption of energy and for the share of energy from renewable sources in transport. It lays down rules relating to statistical transfers between Member States, joint projects between Member States and with third countries, guarantees of origin, administrative procedures, information and training, and access to the electricity grid for energy from renewable sources. It establishes sustainability criteria for biofuels and bioliquids". It follows that the RED specifically aims to address the sustainability of consumption of "biofuels" (defined as "liquid or gaseous fuel for transport produced from biomass") and "bioliquids" (defined as "liquid fuel for energy purposes other than for transport, including electricity and heating and cooling, produced from biomass"). This includes setting minimum levels for life-cycle GHG savings (for processing and transport emissions but excluding ILUC and impacts on vegetation and soil carbon stocks and forgone carbon sequestration) to be achieved by biofuels and bioliquids and a methodology for their calculation. The sustainability of the utilization of solid biomass for heating, cooling and electricity is not within the scope of the current RED.

A set of proposals has been drafted to update the RED, and these are referred to as REDII. In REDII, Article 26 proposes sustainability and GHG emissions saving criteria for biofuels, bioliquids and also "biomass fuels", the latter defined as "gaseous and solid fuels produced from biomass". This would include setting GHG emissions savings (for processing and transport emissions but excluding methane emissions from stored biomass fuels, ILUC and impacts on vegetation and soil carbon stocks and forgone carbon sequestration) to be achieved through the use of solid biomass fuels for heating, cooling and electricity generation. Agricultural and forest biomass sources are explicitly included in the REDII proposals. However there is an exemption for all small and medium-sized plant: "Biomass fuels shall have to fulfil the sustainability and greenhouse gas emissions saving criteria [...] only if used in installations producing electricity, heating and cooling or fuels with a fuel capacity equal to or exceeding 20 MW in case of solid biomass fuels and with an electrical capacity equal to or exceeding 0.5 MW in case of gaseous biomass fuels", however "Member States may apply the sustainability and greenhouse gas emission saving criteria to installations with lower fuel capacity".

In order for energy from biomass sources to contribute to EU or member state renewable energy targets, compliance with renewable energy obligations or to be eligible for financial support, they would need to meet certain sustainability and GHG emissions criteria (for processing and transport emissions but excluding methane emissions from stored biomass fuels, ILUC and impacts on vegetation and soil carbon stocks and forgone carbon sequestration) and to comply with certain land use carbon accounting criteria. In the case of wastes and residues, other than agricultural or forestry residues, they would need only to meet the specified GHG emissions requirements.

6.2.1. REDII proposal and calculation of GHG impacts

Article 28 sets out how the GHG impact of biofuels, bioliquids and biomass fuels would be assessed, with the details given in Annex V (for biofuels and bioliquids) and Annex VI for biomass fuels. Article 28 specifies how actors would calculate GHG impact, either:

- Using default values, as provided in Annex VI Part A for biomass fuels; or
- By calculating explicitly, using the methodology set out for biomass fuels in Annex VI Part B.

The calculation in Annex VI Part B is essentially the same as specified in Annex V of the proposed REDII and in the existing RED for biofuels and bioliquids. The ultimate result of the calculation is the total GHG emissions attributed to a biomass fuel source, which is made up of a number of contributions. One of these contributions is defined as “the annualized emissions from carbon stock changes caused by land-use change”. If the calculated value of this contribution is zero or negative (which would imply no carbon stock change or a net carbon stock increase caused by land-use change), then it would be permitted to use the default values for estimating the total GHG emissions. The default values have been calculated based on an assumption of a zero value for the contribution arising from carbon stock changes.

By implication, the calculation of a non-zero value for carbon stock changes is only required in cases where biomass production involves land-use change. However, no definition is given for land-use change and it is not always clear under what circumstances land-use change would be considered to have taken place.

In circumstances where it is necessary to calculate a value for carbon stock changes, the methodology specified in the RED and proposed REDII involves a number of significant simplifications. Specifically:

- The calculation of carbon stock changes is deliberately simplified (involving assumed default values for initial and final carbon stocks) and is constrained to considering stock changes occurring over a maximum of 20 years
- The carbon stock changes are annualized over a standard 20 year period
- Where biomass produced for energy purposes is co-produced with biomass utilized for other purposes (e.g. sawn timber, wood based panels and/or paper), the annualized carbon stock change is allocated to the co-products on the basis of their biomass energy content

- The result of the above calculation steps for bioenergy sources may be adjusted by a "bonus" value, in situations where the biomass production is achieved by restoring "degraded land" according to certain conditions.

It should be apparent that the calculation methodology proposed in REDII is not directly comparable with that of this study, or with other CLCA studies. The methodology proposed in REDII uses a hybrid of attributional and consequential LCA approaches. This is particularly pertinent when considering how the proposed REDII methodology refers to counterfactuals and/or allocates GHG emissions between co-products. Reference to counterfactuals for products is only made for the fossil energy comparator to the bioenergy source(s). For other co-products, allocation is based on energy content. This methodology is fundamentally different to CLCA and will necessarily yield different results[10].

6.2.2. Implications of proposed calculation methodology

There are two potentially very significant implications of the methodology proposed for REDII as discussed in Section 6.1.1, for calculating the contribution of carbon stock changes towards GHG impacts of bioenergy sources:

1. Significant changes in land management may have taken place as part of the production of bioenergy, but it is possible there will be no deemed change in land use. Consequently the change in carbon stock is assumed to be zero, leading to no contribution from carbon stock changes to calculated GHG emissions;
2. Where land-use change is deemed to have taken place, and a calculation of carbon stock change is required, the methodology is simplified and consequently, frequently the result for an individual biomass fuel will differ from that derived from a CLCA.

It follows that it cannot be guaranteed that the calculation methodology proposed for REDII will always give results for GHG impacts of bioenergy sources that are consistent with an evaluation for policy purposes based on CLCA. Indeed, it should be clear from the preceding two points that there will be many cases where the proposed REDII methodology will give a very different result to that obtained from CLCA. For instance:

[10] The text of the REDII proposal (and also the original RED text) includes the statement, "Co-products from the production and use of fuels should be taken into account in the calculation of greenhouse gas emissions. The substitution method [i.e. reference to counterfactual products] is appropriate for the purposes of policy analysis, but not for the regulation of individual economic operators and individual consignments of transport fuels. In those cases the energy allocation method is the most appropriate method, as it is easy to apply, is predictable over time, minimizes counter-productive incentives and produces results that are generally comparable with those produced by the substitution method…". (Text in square brackets added for clarification.) However, no basis is given for these claims. In the experience of the Bioimpact project team, the "energy allocation method" and the "substitution method" can, and frequently do, give significantly different results for the GHG emissions impacts of bioenergy sources in conjunction with other co-products.

- Most obviously (due to point 1) bioenergy sources produced through the intensification of harvesting or extraction of biomass from agricultural or forest land, but with no change of land use considered to have taken place, will be estimated to have no GHG impacts arising from carbon stock changes associated with them. Hence, in many cases, the full GHG impacts of these bioenergy sources will not be counted.
- More generally, because of the simplification of calculations (point 2), the GHG savings achieved by bioenergy sources produced with associated carbon stock changes (losses or sequestration), and/or involving changes in the supply of non-energy co-products may be overestimated or underestimated, depending on the details of the management of agricultural or forest land and how the harvested biomass is being utilized.

If policy is developed using analysis based on one calculation methodology, and regulation is implemented using verification based on a different calculation methodology, then the regulation is unlikely to deliver the policy as intended.

This issue could be addressed by amending the regulatory calculation methodology to ensure better consistency with the intended policy outcomes. However, the need for practicality in regulatory mechanisms must also be acknowledged, a point stressed in the text of the RED and proposed REDII. To an extent, it may be possible to ameliorate significant inconsistencies in a regulatory methodology and desired outcomes by specifying further sustainability criteria, as proposed in Figure 6.1 and Table 6.1.

6.2.3. Other sustainability criteria in the proposed REDII

Post-consumer waste biomass

Post-consumer waste biomass (including post-consumer waste wood) is covered in the REDII proposals, implicitly through a provision in Article 26 which requires such sources only to meet criteria set for GHG emissions savings (as opposed to any other sustainability criteria, see below). However, for reasons explained near the start of Section 6.2, the GHG emissions saving criteria only apply to power, heating and cooling installations with a (solid) biomass fuel capacity of 20 MW or more. Where the 20 MW scale threshold is exceeded, demonstration of minimum GHG emissions reductions relative to a fossil fuel counterfactual (for heat, electricity or transport fuel) is required, and this increases over time. For electricity, heat and cooling it increases from 80% to 85% between 2021 and 2026 (based on the REDII calculation methodology – see above).

Agricultural biomass

Agricultural biomass is covered in the REDII proposals and there are a number of measures proposed in Article 26 to attempt to ensure sustainability and GHG emissions savings from its use. However, these only apply to power, heating and cooling installations with a (solid) biomass fuel capacity of 20 MW or more.

Where the 20 MW scale threshold is exceeded, demonstration of minimum GHG emissions reductions is required, similarly to post-consumer waste biomass.

In addition, land that had high biodiversity value on or after January 2008, including primary forest and highly biodiverse grassland, is precluded from the production of agricultural biomass fuels, as is land with high carbon stocks, including wetlands and forested areas and peatland.

There are also provisions to address crop based biofuels, by which the Commission has proposed a cap on the contribution of first-generation biofuels at 2017 levels, with a maximum contribution to the EU energy target of 7% in road and rail transport in 2020, reducing to 3.8% in 2030.

Forest biomass

Sustainability of biomass fuels produced from forests are also addressed in the REDII proposals, however again exemption for plants smaller than 20 MW (fuel capacity) applies to solid biomass fuels consumed for power generation, heating or cooling.

Various requirements for the land from which forest biomass is sourced, are proposed:

- Harvesting is legal and covered by a permit (precise details of implementation will vary depending on national regulatory frameworks)
- Forest regeneration of harvested areas takes place
- Areas of high conservation value, including wetlands and peatlands, are protected
- Impacts of forest harvesting on soil quality and biodiversity are minimized
- Harvesting does not exceed the long-term production capacity of the forest.

It is also required that the country in which the forest biomass is produced meets a number of commitments to manage and monitor GHG emissions and removals in the Land Use, Land-Use Change and Forestry (LULUCF) Sector, specifically:

- The country is a Party to, and has ratified, the Paris Agreement
- It has submitted a Nationally Determined Contribution (NDC) to the United Nations Framework Convention on Climate Change (UNFCCC), covering emissions and removals from agriculture, forestry and land use which ensures that either changes in carbon stock associated with biomass harvest are accounted towards the country's commitment to reduce or limit greenhouse gas emissions as specified in the NDC, or there are national or sub-national laws in place, in accordance with Article 5 of the Paris Agreement, applicable in the area of harvest, to conserve and enhance carbon stocks and sinks

- It has a national system in place for reporting greenhouse gas emissions and removals from land use including forestry and agriculture, which is in accordance with the requirements set out in decisions adopted under the UNFCCC and the Paris agreement
- Or, in cases where the above criteria are not fulfilled, that "management systems are in place at forest holding level to ensure that carbon stocks and sinks levels in the forest are maintained".

The role of national and international action on, and monitoring of, GHG emissions and carbon sequestration is an important topic and is discussed in Section 6.3.

6.2.4. Assessment of criteria in proposed REDII

Agricultural biomass

A lot of the discussion in Sections 6.2.1 to 6.2.3 is concerned with forest bioenergy sources. However, as noted in Section 6.2.2, a key concern for biomass produced through use or intensification of the management of agricultural land is the likelihood that, in cases where no land-use change will be involved, no account is taken under EU legislation of issues such as ILUC, impacts on vegetation or soil carbon stocks or forgone carbon sequestration. There are also concerns relating to soil fertility aspects (e.g. removal of straw from cropland as opposed to its incorporation into the soil). If such cases are not deemed to involve land-use change then the likelihood is that the GHG savings achieved by these bioenergy sources will be overestimated.

Forest biomass

As mentioned in Section 6.1, the final column of Table 6.1 (Section 6.1) presents a comparison of the various provisions of the REDII proposal with the criteria derived from this project. There is also a qualitative assessment in Table 6.1 of the extent to which the features of the proposed REDII would support the desired outcomes suggested by this project (or discourage the undesirable outcomes). In addition to giving cross reference to relevant draft articles of the proposed REDII, the entries in the final column of Table 6.1 are also colour-coded to indicate where provisions of the proposed REDII strongly support, weakly support or do not support the outcomes indicated for each criterion suggested by the findings of this project (see key in Table 6.2).

Table 6.2 Key to colour codes of qualitative assessment in Table 6.1

Colour code	Support for criterion
(green)	Strongly supports outcome indicated for criterion
(yellow)	Weakly supports outcome indicated for criterion
(orange)	Does not support outcome indicated for criterion

For the criteria in Table 6.1 addressing aspects of forest management:

- The worst practices (unsustainable harvesting, deforestation) are regulated against
- Forest management practices that could lead to significant GHG emissions savings are weakly supported or not supported
- Forest management practices that could involve variable risks with regard to GHG emissions are not addressed.

Most importantly, (although with a few exceptions), the criteria in Table 6.1 addressing aspects of the use of specific wood feedstocks are not addressed in the proposed REDII.

6.3. Relevance to bioenergy regulation of national and international action on LULUCF

As noted in the discussion of forest biomass in Section 6.2.3, the proposed REDII includes a sustainability criterion that a country supplying forest biomass for use as energy in the EU needs to meet a number of commitments to manage and monitor GHG emissions and CO_2 sequestration in the LULUCF sector. These include the supplying country or forest holding area having a system in place for managing forest carbon stocks and sequestration and/or reporting GHG emissions and CO_2 sequestration from land use including forestry and agriculture.

Two potential issues arise if the purpose of this provision in the sustainability criteria is to ensure the safeguarding of land-based carbon stocks, where land management is evolved to supply more biomass for use as energy.

First of all, the purpose of accounting for GHG emissions and CO_2 sequestration associated with the LULUCF sector is to ensure that countries participating in international agreements on climate action (such as the UNFCCC and the Paris agreement) account fully and transparently for emissions and/or sequestration in that sector, including any contribution from land management towards meeting national commitments to net GHG emissions reductions. The accounting system is intended to give incentives to these countries to pursue the management of land-based carbon stocks and sequestration in such a way as to avoid increasing net emissions and/or to enhance CO_2 sequestration. It follows that LULUCF accounting in this context operates at the scale of nations: it *does not* provide a framework of incentives for *individual actors* (e.g. the actual producers and consumers of biomass for use as energy or for other applications). Effectively, countries or groups of countries have to create a separate complementary framework to encourage individual actors to make the right choices when producing and consuming biomass, to ensure that biomass utilisation generally leads to net savings in GHG emissions, rather than increases. However, in the context of the EU, the relevant frameworks are the existing RED and proposed REDII and the potential issues with these have already been discussed above. At most, relying on

LULUCF accounting would ensure the impacts of biomass use on GHG emissions were registered (either by the country producing the biomass or by the consuming country); it would not explicitly support actions towards the desired outcome of GHG emissions savings.

The second potential issue concerns the specific approaches taken to accounting, i.e. the methods used to calculate accounted emissions increases or reductions associated with impacts of land management on land-based carbon stocks and sequestration. This subject could warrant an entire report in its own right but the essential points are outlined below.

Essentially the approach taken to accounting for emissions and CO_2 sequestration associated with the vegetation and soils of cropland and grassland is consistent with the approach used when accounting for burning fossil fuels. Taking the example of cropland in an individual country, the accounting approach involves the following steps:

- Calculate the total annual net emissions and sequestration associated with cropland in a historical base year or base period, say for a base year of 1990 or 2005 (call this the “base-year result”)
- Calculate the total annual net emissions and sequestration associated with cropland on average during an accounting period, say 2013 to 2020 or 2021 to 2025 (call this the “accounting-period result”)
- The accounted GHG emissions or sequestration are calculated as the difference between the accounting-period result and the base-year result.

In principle, this accounting approach for cropland and grassland should work, provided that:

- Changes over time in emissions and sequestration associated with cropland and grassland occur mainly as a result of the management of these lands (rather than for unrelated reasons, such as natural processes of carbon accumulation in soil)
- Systems for calculating and reporting emissions and removals associated with cropland and grassland are capable of registering the effects of the management of these lands. For example, if the removal of straw from cropland leads to net losses of carbon from the soil or a reduction in sequestration, the methods for calculating and reporting emissions and removals need to be sophisticated enough to enable these losses to be reflected in the reported results.

In practice, systems for calculating the emissions and removals of cropland and grassland can only fully reflect the effects of management if suitably advanced models of land management and land-based carbon dynamics are applied, or if comprehensive direct monitoring of cropland and grassland is carried out. National-scale monitoring systems are also needed to track how the management of land may be changing over time, for example as part of activities to increase production of biomass for use as energy. Currently, many countries do not have sufficiently developed monitoring and/or modelling systems to meet these requirements.

6.3.1. Forest biomass

A special approach is taken to accounting for emissions and CO_2 sequestration associated with forest land. The reason for this is the high likelihood of needing to separate out the influence of natural processes (e.g. age-related trends in tree growth) from the effects of management on net emissions and removals. In its purest form, the accounting approach involves the following steps:

- Where non-forest land has been actively converted to forest land or where deforestation has occurred in the recent past (e.g. within 20 years), a country needs to report the total annual emissions or sequestration associated with the land during the accounting period (say 2021 to 2025)
- For all other forest land, make a projection of the total annual net emissions or sequestration associated with the forest land during a future accounting period, say 2012 to 2025 (call this the "reference result")
- When constructing the above projection, assume that the ways in which forests are managed from the current time up until the end of the accounting period are not changed, when compared with recent historical patterns of forest management (e.g. levels of thinning in forests and rotations applied to forest stands)
- During the actual accounting period, calculate the total annual net emissions and sequestration associated with the forest land (call this the "accounting-period result")
- The accounted GHG emissions or sequestration are calculated as the difference between the accounting-period result and the reference result.

The assumption is made that the accounting-period result and the reference result should be the same or very similar, in the case when actual forest management has not changed or evolved from the current time up to and during the accounting period. Hence, if historical forest management practices in a country are continued during the accounting period, then the country does not need to declare a net debit (emission), neither can the country claim a net credit (sequestration) as a result of the management of existing forest land.

If activities occur in the country aimed at improving forest carbon stocks and sequestration, then the country should be able to claim a net credit (sequestration), equal to the difference between the accounting-period result and the reference result.

If activities occur in the country that lead to reductions in forest carbon stocks and rates of sequestration, then the country may need to declare a net debit (emission), equal to the difference between the accounting-period result and the reference result.

The above description captures the essential approach to accounting for emissions and removals associated with forest land. However, typically, the detailed accounting approaches for forest land agreed amongst countries as part of international climate action are more complicated than outlined above.

The accounting approach for forest land as outlined above is complex but in principle it should support efforts by countries to maintain or strengthen forest carbon stocks and sequestration, or to account for impacts on carbon stocks and sequestration as a result of changes in forest management, for example as a result of a significantly increased requirement for forest biomass utilized for energy. However, the practical issues raised with regard to accounting methods for agricultural land also apply here.

The accounting approach also relies heavily on an objective method for constructing the projection of emissions and removals from forest land forming the basis of the reference result. The method requires a clear understanding of what is involved in “existing” forest management practices within a country, and how these should be allowed for when making the projection. The EC Joint Research Centre has produced some preliminary guidance on this subject but it is not yet clear that a general consensus has been reached on the approach to be taken. This is important because, if countries take a wide interpretation of the approach to the estimation of the reference result, then there could be risks that significant net emissions arising from forest management (including for example from harvesting wood for bioenergy) may not be accounted for. It is particularly important that the future effects of relatively recent and potential future policies are not allowed for when defining the representation of forest management practices. For example, suppose that a country developed a policy to greatly increase the level of wood production from its forests, which would require associated changes to forest management. If the country were to claim that the consequent evolution of forest management was part of “current” practice, and then allow for this when calculating the reference result, the consequent impacts of the policy on emissions and removals associated with forest land would not be accounted for. It follows that it is particularly important for this accounting approach for forest land to be clearly defined, generally understood by countries and stakeholders, and for its application to be based on transparent data and assumptions about forest management.

7. Discussion

Inevitably, there are limits to the analysis, assessment and interpretation of the results of any particular study, to arrive at specific conclusions, depending on the question(s) asked. The analysis and assessment presented in this summary report and the original final project report, and the conclusions arrived at, most likely represent the full extent of the inferences that may be drawn from this project about the GHG emissions impacts associated with bioenergy use.

If a cautious position were to be taken, the project findings lead to the following tentative conclusion:

Unless appropriate policy measures are taken to support sustainable bioenergy supply (in terms of impacts on GHG emissions), particularly in the case of forest bioenergy supply, a significant increase in bioenergy use in the EU is likely to lead to a net increase, rather than decrease, in GHG emissions being contributed from bioenergy sources.

Whilst such a conclusion is reasonable based on the project findings, it should be clarified that, strictly, the results should not be interpreted to imply that the increased use of bioenergy in the EU must inevitably involve increased GHG emissions. Rather, the results strongly indicate that there are *significant risks* of increases in GHG emissions associated with greater bioenergy use, in particular forest bioenergy use, *unless* there are appropriate checks and balances on the supply and consumption of bioenergy sources with regard to associated GHG emissions. Hence, the corollary of this conclusion is that:

If specific measures are taken to ensure only sustainable bioenergy (in terms of impacts on GHG emissions) is incentivized, a net decrease, rather than increase, in GHG emissions is likely to be associated with bioenergy sources.

The view might be taken that whether one places emphasis on the tentative conclusion for bioenergy use or its corollary is analogous to asking whether a glass is half empty or half full, implying that this matter almost comes down to individual viewpoints. However, this view would be entirely incorrect, because the assessments in this project, including this summary, have indicated the outcomes that are likely to occur, in the absence or presence of suitable measures to ensure the supply of bioenergy (particularly forest bioenergy) with low associated GHG emissions. This suggests the need to address sustainability in the supply of bioenergy resources, as discussed in Section 6 of this report.

The validity of the conclusions reached about implications for regulation of bioenergy use and the assessment of the proposed REDII presented in Section 6 hinges on whether the findings of the Task 1 report and the final report for this project are sufficiently comprehensive and reliable. It must be acknowledged that, although a considerable body of research now exists on the GHG impacts of bioenergy sources, there are still some gaps in knowledge and areas where understanding still needs to be clarified. However, it is suggested that there is now enough scientific evidence to draw some conclusions on the management of risks with regard to the use of bioenergy sources and consequent impacts on GHG emissions. The authors of this report offer the general criteria set out in Section 6.1, and specifically for forest bioenergy sources in Table 6.1, as their best attempt to interpret current evidence and understanding.

Every effort has been made to keep the approach outlined in Section 6.1 as simple as possible. The approach may be viewed as complicated and problematic to implement in practice, for a number of reasons:

- It may prove to be very challenging for the final consumers of biomass sources to know and demonstrate clear connections to particular management activities on agricultural or forest land. This would be important for providing assurance that the production of certain bioenergy sources will deliver genuine emissions reductions compared to fossil fuels. However, for forest bioenergy sources, this is addressed to an extent in Table 6.1 (Section 6.1) by structuring the criteria and making some of them optional. It should be recalled that the designs of the decision tree and table of criteria presented in Section 6.1 are provisional. The criteria included in Table 6.1 do not necessarily represent a comprehensive or definitive list and there may be scope for further refinement.
- There appear to be difficulties in regulating forest bioenergy sources purely on the basis of wood feedstock types (which the structuring of the criteria in Table 6.1 attempts to address). It has proved difficult to arrive at widely understood definitions for certain feedstocks. Such definitions have been provided in Box 1 in Section 4.2.2, but some of these may still be regarded as ambiguous (e.g. “sawlog” and, through reference to this definition, “small roundwood”).
- Some of the proposed criteria still require a calculation methodology for GHG emissions impacts (and savings) associated with the use of different types of bioenergy but this has not been defined here. Section 6.1 discusses the possibility of requiring full GHG emissions assessments for bioenergy sources but this may place a very heavy burden on consumers/operators or prove impractical. Hence, it is likely that a simplified approach is still needed, for example involving the exclusion of high risk feedstocks, whilst supporting the desired policy outcomes identified by CLCA of policy options, such as undertaken in this project.
- Ideally, the findings of the quantitative assessment presented in the final project report and in this summary could be used to design and construct a refined or optimized scenario for biomass consumption from different sources, by determining building blocks based on picking the best aspects and avoiding the worst aspects of the scenarios modelled in this project. In addition, further CLCA could be undertaken at a more detailed scale to clarify further the variations in GHG impacts with respect to specific forest management practices, types of biomass feedstock and biomass energy value chains.

Undoubtedly, the developers of the original RED and the proposed REDII were very aware of issues and pitfalls such as those listed above, and particularly of the need for any proposal to be simple enough to be practical to implement. The question, as regards the REDII, is whether some balance can be found between the need for simplicity and practicality in regulation on the one hand, as addressed in the existing proposal for REDII, and the need for robustness (in terms of delivering GHG emissions reductions) on the other hand, as covered in the discussion in Section 6.1 of this report.