Programme Area: Bioenergy

Project: Carbon Accounting Evidence Collation

Title: Bioenergy Life Cycle Assessment Review Report – Attributional Studies Extension

Abstract:

The aims of this project on "Carbon Life Cycle Assessment Evidence Analysis" for the Energy Technologies Institute are to identify and review the existing evidence base, in terms of relevant life cycle assessments (LCAs) which calculate greenhouse gas (GHG) emissions associated with potentially major bioenergy value chains for the United Kingdom; to compile a compendium of the best and most reliable ranges of basic data used in such calculations; to develop suitable workbooks for consistent calculation of GHG emissions associated with these bioenergy value chains; and to produce results which can be compared and used to identify and prioritise key knowledge gaps.
This document is a supplementary report to the outcomes of deliverable 'D2 – Bioenergy Life Cycle Assessment Review Report" from Work Package 2 of this project which has the main objectives of analysing previous relevant LCA studies by providing a critique of the robustness of the evidence base based on both data and methodologies used; a measure of certainty behind the data reviewed; and details of the confidence the reviewer may have in interpreting the data.

Context:

The ETI appointed North Energy Associates (NEA) to lead a new Carbon Life Cycle Assessment (LCA) Evidence Analysis project in its Bioenergy Programme. LCAs are used to understand the greenhouse gas emissions associated with bioenergy from across the supply chain, from feedstock production to energy production. Several different methodologies can be used in LCAs and this ETI project assessed the strengths and weaknesses associated with applying these methodologies to bioenergy value chains. It also reviewed sources of data for LCAs and produced a compendium of the best and most reliable data across different UK-relevant bioenergy feedstocks and value chains. This compendium has formed the basis of a series of carbon balance calculations across a range of bioenergy value chains so that emissions from different feedstocks can be compared.

CARBON LIFE CYCLE ASSESSMENT EVIDENCE ANALYSIS: Deliverable D2B – Bioenergy Life Cycle Assessment Review Report – Attributional Studies Extension

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CARBON LIFE CYCLE ASSESSMENT EVIDENCE ANALYSIS: Deliverable D2B – Bioenergy Life Cycle Assessment Review Report - Attributional Studies Extension

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Executive Summary

1. This report is a supplementary report to 'Carbon Life Cycle Assessment Evidence Analysis: Deliverable D2 – Bioenergy Life Cycle Assessment Review Report' ("the main LCA review report") which was prepared for the Energy Technologies Institute (ETI) LLP in February 2017 as part of the 'Carbon Life Cycle Assessment Evidence Analysis' project.
2. The main LCA review report provided full reviews of 49 out of 147 studies that were selected as potentially relevant. This report provides full reviews of an additional 34 studies that formed part of the 147 potentially relevant studies but were not previously selected for full review because they were identified as adopting attributional LCA (ALCA) methodology instead of the consequential LCA (CLCA) methodology that was required by the defined LCA goal and scope of this project.
3. This report has been prepared in response to a specific request from the ETI; the additional full reviews of the 34 studies identified as adopting ALCA methodologies is solely due to this request and not to any change in the original goal and scope that applies to all other aspects of the project.
4. The 34 ALCA studies identified by the initial selection and screening process formed a sub-set of ALCA bioenergy studies likely to cover the scope of the project in terms of: biomass sources, being conventional forests (broadleaf, conifer and pine), plantation pine forests, short rotation forests (conifer and broadleaf), short rotation coppice (willow and poplar), miscanthus and wheat straw; geographical biomass provenance, being Canada, the USA and Europe; and specified conversion technologies.
5. Due to the nature of the screening process, coverage of the value chains relevant to this project is less assured for the selected ALCA studies than for the CLCA studies in the main review; no supplementary screening was carried out to identify ALCA studies that would have been excluded from detailed review for a reason other than adoption of ALCA methodology (such as provenance of biomass).
6. The main LCA review report incorporates sections on 'Setting the Context' and 'LCA Review Process'. These sections, though relevant, are not reproduced in this report, and hence it is recommended that this report should usually be read in conjunction with the main LCA review report.
7. The process adopted for the detailed review of the 34 ALCA studies is the same as that adopted for the reviews covered by the main LCA review report, with the results of each review being presented as succinct summaries detailing each study's purpose and goal, its methodology, its key assumptions, an assessment of its transparency, its conclusions and its stated headline results.
8. This report provides the results of each review as well as an assessment of the robustness of the evidence base provided by the studies (mainly in terms of coverage of value chains, transparency of calculations and methodologies adopted) and an examination of the differences and similarities between the studies.
9. The main findings from the review process were that, from the 34 reviewed ALCA studies, very few (11) of the potential (190) relevant whole bioenergy value chains were covered by 8 ALCA studies, and only 1 of these studies (a calculation tool with the potential to cover 3 of the specified value chains) had high transparency.
10. Taking into account the analysis of the reviewed ALCA studies, which demonstrates the extensive variations in the methodologies adopted and the physical parameters used for results reporting, it is apparent that there are limits to findings on confidence and critical data that can be derived from them for the evidence base for the specified bioenergy value chains in this project.

Glossary

Attributional Life Cycle Assessment	a life cycle assessment in which the environmental impacts under consideration are apportioned individually, by some specified means of allocation, between each of the multiple products and/or services from a product system.
Carbon Life Cycle Assessment	a life cycle assessment applied, specifically, to the evaluation of greenhouse gas emissions, generally, or, more specifically, on the prominent emissions of carbon dioxide, methane and nitrous oxide.
Collective Consequences	the environmental impacts of a group of products and/or services that are provided by a given product system which are treated in a combined manner rather than divided between them by means of allocation (see co-product/co-service allocation).
Consequential Life Cycle Assessment	a life cycle assessment in which the environmental impacts under consideration are determined collectively, by means of system expansion (see system expansion), to all of the multiple products and/or services from a product system so that their displacement effects are taken into account.
Co-product/co-service	a product or service that is provided in conjunction with other products or services; in such cases of multiple product or service provision, the principal product or service is usually designated as the main product or service whilst other products or services are often referred to as by-products and by-services.
Co-product or co-service allocation	means by which environmental impacts are divided between co-products and/or co-services.
Counterfactual	a product or service which has been replaced by the provision of a particular product or service.
Displacement Effects	the complete subsequent impacts caused when the provision of a product or service replaces an existing product or service.

Ex Ante Life Cycle Assessment	a life cycle assessment which quantifies the environmental impacts of a product system "before the event", or from its future implementation.
Ex Post Life Cycle Assessment	a life cycle assessment which quantifies environmental impact of a product system "after the event", or from its past implementation.
Functional Unit	the specified characteristic feature(s) of the product(s) and/or service(s) from a product system that are the subject of a life cycle assessment.
Goal of a Life Cycle Assessment	an elaboration of the purpose of a life cycle assessment covering its intended application and audience, the general nature of the environmental impact(s) under consideration, and the general nature, scale and system time horizon of the product system(s) under consideration.
Impact Time Horizon	the particular period of time over which product system impacts that have a cumulative effect on the environment are quantified in a life cycle assessment, specified in terms of the number of years, usually, after the point in time they originally arise.
Life Cycle Assessment	a technique for quantifying the impacts, usually but not exclusively on the natural environment, in its role as the source of resources and as a sink for emissions, associated with an activity, typically involved in the provision of a product or service, over a defined duration or life cycle which can encompass all or part of the acquisition and conversion of its raw materials, and, if relevant, its use and final disposal.
Methodology of a Life Cycle Assessment	all the specified procedures or rules of calculation applied to the quantification of environmental impacts by a life cycle assessment.

Purpose of a Life Cycle Assessment	a statement or question which a life cycle assessment seeks to address or answer and which encapsulates its goal and scope which provide necessary details (see goal and scope of a life cycle assessment).
Process Chain	an activity or series of activities that are directly involved in the provision of a chosen product or service and that are the subject of a life cycle assessment (see also value chain).
Product System	an activity or series of activities that are involved in the provision of specified product(s) and/or service(s).
Product System Scale	the physical size or magnitude of the product system(s) under consideration in a life cycle assessment study.
Scope of a Life Cycle Assessment	an elaboration of the purpose of a life cycle assessment covering the specific causes of the environmental impact(s) under consideration and the relevant impact time horizon(s), the specific composition, spatial system boundary and temporal system boundary of the product system(s) under consideration, the perspective on the environmental impact(s) of multiple products or services from the product system(s), the functional unit and the full metrics of the reported results.
Spatial System Boundary	an imaginary line drawn around and completely enclosing the part or whole of a product system that has been designated for investigation by a life cycle assessment without reference to any particular period of time (see also temporal system boundary).
Substitution Credit	the avoided environmental impact of a product or service which has been replaced by the provision of a particular co-product or co-service.
Sustainability	the ability of a product system to maintain its function(s) over its specified life cycle by avoiding natural resource depletion and without permanently impairing or significantly compromising the natural environment.

System Boundary	an imaginary line drawn around and completely enclosing a part or whole of a product system that has been designated for investigation so that all inputs and outputs which cross this line can be quantified by a life cycle assessment (see also spatial system boundary and temporal system boundary).
System Expansion	the procedure by which the system boundary is widened to include more activities that are related to the product system under investigation by a life cycle assessment.
System Time Horizon	the particular period of time over which a product system is investigated by a life cycle assessment (see temporal system boundary), specified in terms of the number of years, usually, from the past (see ex post) or into the future (see ex ante).
Temporal System Boundary	an imaginary line drawn around and completely enclosing the part or whole of a product system that has been designated for investigation by a life cycle assessment over a period of time specified by the system time horizon (see system time horizon).
Value Chain	an activity or series of activities that are directly involved in the provision of a chosen product or service and that are the subject of a life cycle assessment (see also process chain).

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Contents

1. INTRODUCTION

This project on "Carbon Life Cycle Assessment Evidence Analysis" for the Energy Technologies Institute (ETI) is being undertaken by North Energy Associates Ltd (NEA), Forest Research (FR) and the National Non-Food Crops Centre (NNFCC). The primary aims of this project are to identify and to review the existing evidence base, in terms of relevant life cycle assessment (LCA) studies which calculate greenhouse gas (GHG) emissions associated with potentially major bioenergy value chains for the United Kingdom (UK), and, from these and other suitable sources, to compile a compendium of the best and most reliable ranges of basic data used in such calculations. The secondary aims are to develop suitable workbooks for calculating, in a consistent manner, GHG emissions associated with these bioenergy value chains, and to produce results which can be compared and used to identify and prioritise key knowledge gaps.

The work programme for this project consists of the following 6 Work Packages (WPs):

- WP0; Project Management
- WP1; Goal and Scope Definition
- WP2; Bioenergy LCA Review and Data Collection
- WP3; Interim Workshop
- WP4; Carbon Balance Calculations, Analysis and Business Cases
- WP5; End of Project Review

The main report for WP2, 'Carbon Life Cycle Assessment Evidence Analysis: Deliverable D2 – Bioenergy Life Cycle Assessment Review Report' ("the main LCA review report") was delivered to the ETI in February 2017. This main LCA review report provided full reviews of 49 out of 147 studies that had been selected as potentially relevant. Subsequent to the delivery of the main LCA review report, the ETI requested an extension to the key project output, with the purpose of providing a review of the previously selected potentially relevant literature that relates to bioenergy LCA studies which adopt attributional LCA (ALCA) methodology. This additional review is intended to complement the review of bioenergy LCA studies, calculation tools, databases and reviews that adopt consequential LCA (CLCA) methodology as addressed in the main LCA review report.

The purpose of this report is to analyse the 34 bioenergy LCA studies identified in the main LCA review report as adopting ALCA methodology. The analysis includes a critique of the robustness of the evidence base as a whole and full reviews of the 34 ALCA studies. The reviews include succinct summaries for each study of:

- its purpose, goal and scope,
- the methodology adopted and other pertinent details,
- an assessment of transparency and accessibility,
- its key assumptions, and
- its conclusions and headline results.

The specification for the current review gave the reviewers the option to enter into correspondence with authors of the studies. No such correspondence was entered into, though there were informal internal discussions, as and when required, concerning studies for which current staff members of NEA, FR and NNFCC were co-authors.

In preparing the basis for the LCA study reviews in the main LCA review report, a concise summary of the background and context of bioenergy LCA studies was included, covering the types of questions that bioenergy LCA studies typically attempt to answer and the appropriate methodologies that they should use to do this, and highlighting some of the areas of bioenergy LCA studies where there are conflicting views as to the appropriate approach. The main LCA review report also includes descriptions of:

- the process of reviewing relevant LCA studies, as one part of the evidence base for this project, explained in terms of the selection and screening criteria adopted,
- an analysis of the basic statistics concerning the number of studies selected for screening, the screening process itself and the coverage of bioenergy value chains provided by the studies that, as a result of the screening process, were selected for full reviews,
- the Bioenergy LCA Database where basic information on the selected LCA studies is recorded, and
- The development of the Bioenergy LCA Data Compendium, as a means of recording critical and other data.

Details of the aspects of the main LCA review report given above are not reproduced here, though some of them are relevant to a comprehensive understanding of this report and, as such, it is recommended that this current report should usually be read in conjunction with the main LCA review report. For the benefit of readers without immediate access to the main LCA review report, its executive summary has been reproduced in Appendix A, and section 2.2.4.1, which describes the main differences between CLCA and ALCA, in Appendix B.

The contract amendment pertaining to this report is Contract Amendment Number 1, incorporating variation reference Var001, 'Bioenergy Life Cycle Assessment Review – Attributional LCA Extension', authorised on 13 May 2017.

2. LCA REVIEW ANALYSIS

2.1 Evidence Base – summary of basic statistics and robustness

The main LCA review report indicates that 147 studies were selected for screening, and that full reviews of 49 of these screened were carried out. Of the 98 studies that were not selected for full reviews, 34 studies were identified as adopting ALCA methodology instead of the CLCA methodology that was required by the defined LCA goal and scope of this project. These 34 bioenergy ALCA studies are the subject of this report.

The basic selection and review statistics are summarised in Table 1 which shows that all but one of the 34 selected ALCA studies were 'true' studies, with one being a calculation tool and none being databases or reviews of other studies.

Table 1 <u>Basic Analysis of the LCA studies</u>

Specification	Total Number	Number of LCA Studies	Number of Calculation Tools	Number of Databases	Number of Reviews
Selected for screening in the main LCA review:	147	130	4	2	11
Revised analysis of studies selected for screening in the main LCA review*:	147	129	5	2	11
Reviewed in the main LCA review:	49	44	4	1	0
ALCA studies reviewed in this report:	34	33	1	0	0

**Ref. No. 156, 'The UK Solid and Gaseous Biomass Carbon Calculator' was classified as a study rather than a calculation tool in the main LCA review report*

One of the most important features of the reviewed bioenergy LCA studies was their transparency, as the usefulness and robustness of the studies is, to a very great extent, determined by this particular attribute. As specified in the template for the full review summary sheet, transparency relates to the calculations performed in the LCA studies and was categorised as:

- "low transparency" indicating very little or no access to all the calculations, or no access to those calculations that make major contributions to total GHG emissions,

- "moderate transparency" indicating some access to those calculations that make major contributions to total GHG emissions, and

- "high transparency" indicating access to all calculations or access to all those calculations that make major contributions to total GHG emissions.

The emphasis on calculations is highly significant for both CLCA and ALCA studies as their general purpose is to quantify environmental and/or resource impacts. Hence, access to all or the most influential calculations, along with the assumptions on which they are based and the sources of data which they use, has a major role in determining the level of confidence that can be placed in their outcomes, in terms of their results, findings and recommendations. All the reviewed ALCA studies were qualified with respect to their adjudged transparency, taking into account supporting information where available, and subsequent statistics are summarised in Table 2.

Table 2 Transparency Statistics for Reviewed ALCA Studies, taking into account supporting information.

Number of Reviewed LCA Studies		
Low Transparency	Moderate Transparency	High Transparency
6	22	6

The use of proprietary LCA calculation software influenced the transparency rating, with some studies providing full transparency for elements of the calculations, but relying on proprietary software with limited transparency for other elements. Of the 34 studies, 9 studies (LCA Ref. Nos. 6, 36, 38, 45, 57, 69, 74, 120 and 142) utilised SimaPro software and one study (LCA Ref. No. 56) utilised GaBi software. None of these studies achieved a 'high transparency' rating, with 9 achieving 'moderate transparency' and one 'low transparency'.

14 of the 34 studies explicitly state that they utilise life cycle inventory data from the proprietary ecoinvent database (Ref. No. 41, reviewed in the main LCA review report). Ecoinvent is also used to provide inventory data to SimaPro software and, taking into account the 2 studies out the remaining 20 that utilise SimaPro, it can be seen that at least 16 of the 34 studies (47%) utilise data from ecoinvent.

Several studies also stated that they followed ecoinvent and/or IPCC guidelines for certain aspects of the calculations, but usually did not elaborate further; for example, only one study (LCA Ref. No. 156) indicated an IPCC tier level used.

For some studies, sufficient detail of calculation methodology was given to determine that 7 of the studies (LCA Ref. Nos. 27, 31, 66, 136, 143, 156 and 158) adopted CLCA methodology for some elements of the LCA calculation.

Similarly, by examining necessary details, it was possible to determine that 7 of the reviewed bioenergy LCA studies (21%) definitely include GHG emissions associated with plant construction and machinery manufacture and may possibly incorporate GHG emissions associated with plant and machinery maintenance (LCA Ref. Nos. 36, 45, 46, 80, 142, 143 and 149). Of the remaining 27 studies, some explicitly stated that emissions associated with plant and machinery manufacture and maintenance were not accounted for, though the majority either did not mention such contributions to GHG emissions, or did not give a clear indication of accounting treatment.

2.2 Coverage of Bioenergy Value Chains

The ALCA bioenergy studies should, in theory, never coincide with the goal and scope of this project, since such coincidence should lead to a CLCA study. Hence, the relevance of the ALCA studies is dependent only on the extent of their specific coverage of the bioenergy value chains covered by this project, or their significant parts (mainly biomass feedstock supply in the form of pellets and biomass feedstock conversion). This coverage is summarised for wood pellets supply from forests in Table 3; chip or pellets supply from energy crops in Table 4; and biomass feedstock conversion technologies in Table 5. It should be noted that wood chip, miscanthus bale and SRC billet production have been included in Table 4, even though the project scope specifies only pellets as the bioenergy feedstock for conversion processes; these have been included due to their relatively high incidence and because studies considered in this report are, in any case, outside of scope due to their use of ACLA methodology.

It should be noted that the studies were selected for review for the 'positive' reason that they were studies that had originally been selected for screening, but were then not selected for review because they adopted ALCA methodology. There was no further screening to excluded studies identified as ALCA studies that would have 'failed' the original screening process for another reason (such as geographical provenance of the biomass being out of scope). For this reason, a number of the studies do not concern a country/region that is in scope for the project. For example, 3 of the ALCA studies (LCA Ref. Nos. 69, 108 and 121) concern the production of pellets from forests in the Republic of Ireland, eastern Canada and Wisconsin in North East USA, respectively, all regions that are not included in the scope of the project.

The summary in Table 3 shows that there is almost complete coverage by the reviewed studies of the supply of wood pellets from forests chosen for this project, with only supply of pellets from conventional broadleaf forests in the Southern/South Eastern USA not covered.

The summary in Table 4 indicates that there are many gaps in the coverage by the reviewed studies of the supply of pellets from energy crops for this project, though when pellets, chips, SRC billets and miscanthus bales are considered, the coverage extends to all but three of the categories. It should be noted that wood pellet production from poplar and willow SRC in France and the Netherland is covered by neither the ALCA studies reviewed here nor the CLCA studies reviewed in the main LCA review report. However, wheat straw pellet production in the UK, which was not covered by any of the reviews in the main LCA review report, is covered (Ref. No. 56).

The summary in Table 5 also illustrates coverage by reviewed studies of all the specified biomass feedstock conversion technologies for this project with the exception of 'electricity generation (steam cycle) and district heat production' and 'electricity generation (CCGT) from gasification'. It should be noted that 'hydrogen and district heat production from the gasification of biomass feedstocks', the one conversion technology not covered by studies reviewed in the main LCA review report, is partially covered here (LCA Ref. No. 6); the coverage is only partial since hydrogen production is not included.

Table 3 Coverage of Wood Pellet Supply from Forests by Reviewed ALCA Studies

Country/ Countries	Region(s)	Forest Type	Reviewed LCA Study Ref. No.
Canada	Western	Conventional Forest (conifer)	5, 38
Canada	Not specified	Conventional Forest (conifer)	3, 31
Scandinavia and Baltic States	-	Conventional Forest (conifer)	80, 103, 106
United Kingdom	-	Conventional Forest (broadleaf)	80
		Conventional Forest (conifer)	80
United States of America	Southern/ South Eastern	Conventional Forest (broadleaf)	
		Conventional Forest (pine)	132
		Plantation Forest (pine)	74
	North Western	Conventional Forest (conifer)	80

Table 4 Coverage of Pellet (or other form, as specified) Supply from Energy Crops by Reviewed ALCA Studies

Country	Sources of Biomass Feedstock	Reviewed LCA Study Ref. No.
Belgium	Short Rotation Coppice (poplar and willow)	45 (chips), 46 (chips), 142 (chips),
France	Short Rotation Coppice (poplar and willow)	
Netherlands	Short Rotation Coppice (poplar and willow)	153 (chips)
Poland	Short Rotation Coppice (poplar and willow)	
United Kingdom	Miscanthus	143 (bales)
	Short Rotation Coppice (poplar and willow)	40 (chips), 131 (chips), 143 (billets)
	Short Rotation Forest (broadleaf)	
	Short Rotation Forest (conifer)	131 (chips)
	Wheat Straw (agricultural residue)	56, 57(not pellets), 59(not pellets)
United States of America, Southern and South Eastern Regions	Short Rotation Forest (broadleaf)	
	Short Rotation Forest (conifer)	154 (chips)

Table 5 Coverage of Biomass Feedstock Conversion Technologies by Reviewed ALCA Studies

Biomass Feedstock Conversion Technologies	Reviewed LCA Study Ref. No.
Small-scale Heat Only Production (boilers)	31, 40, 121, 136, 158
Medium-scale Heat Only Production (boilers)	31, 69, 136, 103
Medium-scale Combined Heat and Power Generation	45, 46, 69, 136, 158, 103
Large-scale Combined Heat and Power Generation	95, 106
Electricity Only Generation (steam cycle)	56, 74, 80, 108, 132, 136, 158
Electricity Generation (steam cycle) and District Heat Production	
Hydrogen Production from Gasification	6
Hydrogen and District Heat Production from Gasification	38 (though no hydrogen production)
Electricity Generation (combined cycle gas turbine) from Gasification	
Ethanol from Lignocellulosic Processing	57, 59, 66

One particular aspect of the coverage of biomass conversion technologies summarised in Table 5 is that some of the reviewed LCA studies do not address the biomass feedstocks specifically relevant to this project. Hence, in order to consider this aspect further, the coverage of reviewed LCA studies representing complete bioenergy value chains chosen for this project is summarised in Table 6. This shows that such coverage is considerably more restricted than implied by Tables 3 to 5, with only 11 full value chains covered across 8 LCA studies. The main reason for the relatively low number of complete value chains examples is that only one of the studies included in Table 4 covers the production of pellets.

Table 6 Coverage of Whole Bioenergy Value Chains Relevant to the Scope of this Project by Reviewed ALCA Studies

Biomass Feedstock Conversion	Reviewed LCA Study Ref. No.	Source of Biomass Feedstock
Small-scale Heat Only Production (boilers)	31	Western Canada conventional forest (conifer)
Medium-scale Heat Only Production (boilers)	31,103	Western Canada conventional forest (conifer)
Medium-scale CHP Generation	103	Scandinavia and the Baltic states conventional forest (conifer)
Large-scale CHP Generation	106	Scandinavia and the Baltic states conventional forest (conifer)
Electricity Only Generation (steam cycle)	56	UK Wheat Straw (agricultural residue)
	74	Southern USA plantation forest (pine)
	80,103	Scandinavia and the Baltic states conventional forest (conifer)
	80	UK conventional forest (conifer)
	80	UK conventional forest (broadleaf)
	132	Southern USA conventional forest (pine)
Electricity Generation (steam cycle) and District Heat Production	none	
Hydrogen Production from Gasification	none	
Hydrogen and District Heat Production from Gasification	38	Western Canada conventional forest (conifer)
Electricity Generation (combined cycle gas turbine) from Gasification	none	
Ethanol from Lignocellulosic Processing	none	

The transparency of those 8 reviewed ALCA studies which do cover specified full bioenergy value chains was investigated and the findings are presented in Table 7. This demonstrates that only one of the studies had high transparency, with 5 having moderate transparency and 2 having low transparency.

Table 7 Transparency of Reviewed ALCA Studies Representing Whole Bioenergy Value Chains Relevant to the Scope of this Project

Reviewed ALCA Study Ref. No.	Transparency
31	Low (limited access to the calculations)
38	Moderate (calculations that make major contributions to GHG emissions are shown)
56	Moderate (GaBi proprietary LCA calculation software used)
74	Moderate (SimaPro proprietary LCA calculation software used)
80	High (provided access to supporting user manual and workbooks)
103	Moderate (not all calculations are shown)
106	Moderate (life cycle inventory data are given, but limited calculations)
132	Low (limited details of LCA methodology and calculations)

2.3 Comparison of, and Confidence in, Results

Comparison of results is subject to many of the same issues as identified in the main LCA review report, the most relevant of which are which are re-iterated below.

As part of this exploration of the evidence base for the LCA of bioenergy value chains, it was instructive to examine the availability of headline results in the reviewed ALCA studies. There have been many attempts to perform meta-analyses of LCA studies to compare results, in the form of total GHG emissions, discern possible patterns or trends in results and even to produce ranges of results that are supposed to be representative of these chains, perhaps suggesting their variability or, indeed, uncertainty. The most fundamental causes of differences between LCA studies are differences in the purpose, goal and scope, and the subsequent calculation methodology adopted. Hence, in order to form any meaningful conclusions, such meta-analysis work needs to ensure that the LCA studies that are used share basic commonality of methodology, expressly in terms of the same LCA goal and scope. Since key aspects of the defined LCA goal and LCA scope have been applied in the selection and screening criteria of this review, it should provide a sound basis for any such presentation and possible comparison of headline results.

However, before these findings from the analysis of reviewed ALCA studies are provided, it is necessary to explain the practical constraints in accessing and considering headline results on a common basis. It will be appreciated that any LCA study will be conducted for its own stated or unstated purpose and that this is likely to influence what results are communicated and how they are presented, especially in terms of the functional unit. Sometimes relevant results are available in suitable units or in units that can be easily converted to those under consideration. However, it is often possible that a functional unit will have been chosen for entirely justifiable reasons which would require significant extra information, which might not be available in the original LCA study, or considerable analytical effort based on potentially questionable assumptions. For example, 3 of the reviewed ALCA studies were based on a functional unit which was 1 ha of land. In such instances, it can be difficult, if not virtually impossible, to convert headline results into, say, total GHG emissions per unit output of a given bioenergy value chain.

This is demonstrated in Table 8 which gives a (non-exhaustive) summary of the wide diversity of units used for results in the reviewed ALCA studies.

Table 8 Units Used for Results Reporting in Reviewed ALCA Studies

Output category	Units Used
Electricity Production	GHG/MJ_e delivered; GHG savings compared to average EU /MWh_e; GHG/kWh_e; GHG/kWh_e; GHG/kWh_e; GHG/kWh_e; GHG/kWh_e; GHG/MJ_e; GHG/MWh_e; t C released to atmosphere /GJ_e; GHG/MWh_e.
Heat Production	GHG difference between scenarios /GJ Heat at combustion equipment; GHG/kWh heat; GHG/MJ delivered residential heat; GHG/MJ_{th} delivered to district heating end-user; GHG/MWh delivered heat; GHG/MWh heat.
Biomass volume	GHG/m^3 felled fresh roundwood per year; GHG/m^3 harvested logs; GHG/m^3 wood chips.
Biomass energy content	GHG/GJ biomass at gate; GHG/GJ wood pellets.
Biomass mass	GHG/t wood pellets; GHG/t wood pellets; GHG/t wood pellets; t C in harvested wood; GHG/odt wood chips; GHG/odt miscanthus; GHG/odt pellets; GHG/odt wood chips.
Transport distance	GHG saved /passenger km; GHG/km flexible fuel vehicle; GHG/km small car driven.
Land area	Carbon offset Mg C/ha/a; GHG/15 year 1 ha stand of Salix SRC; GHG/ha.
Liquid fuel production	GHG/kg ethanol; GHG/MJ biofuel.
Other	Energy and quantity of inputs /kg hydrogen.

Whilst it is a comparatively simple procedure to convert some of the units to common units (for example, electricity and heat expressed in MWh and MJ), there are often further nuances that need to be taken into account, such as the point of measurement in the bioenergy value chain (for example, heat produced at combustion and heat delivered).

The variety of reporting units for quantity of biomass (mass, volume, bulk volume, mass of carbon content, energy content) often makes it difficult to equate reported results, even after close scrutiny of the studies; whilst results expressed in terms of common unit could theoretically be calculated for a number of studies, essential data required to enable such conversion (e.g. moisture content, calorific value, density, bulk density, percentage carbon content) are often not provided.

Furthermore, for ALCA studies, it is extremely important to take into account the basis of any allocation of GHG emissions between co-products as this can have a significant effect on the results (see Appendix B for an explanation of why allocation is often necessary for ALCA studies).

Any LCA should be carried out for a specified purpose, which can be articulated in the form of a specific question, or questions, that the study should address and that the results of the study should attempt to answer. The purpose of the LCA should be further elaborated by a clear statement of the goal and scope and the methodology adopted should follow on from the defined goal.

In the case of ALCA GHG emissions studies, the goals should include the accounting of GHG emissions to a particular product or service, and there should be clear explanations of why this is required (i.e. how it contributes towards fulfilment of an LCA's purpose) and, if it is necessary to allocate GHG emissions between co-products, a statement of the allocation procedure adopted (e.g. price or energy content) and a justification of this choice of allocation procedure.

The purpose of an LCA may require the adoption of a particular methodology which, in turn, specifies the adoption of a particular allocation basis (such as methodologies based on the methodology set out in the Renewable Energy Directive (RED) of the European Commission, which stipulates allocation by energy content). Hence, for LCA studies for which goals are clearly stated, the results for studies with the same, or very similar, goals, should be directly comparable, since similar methodologies and basis of allocation should have been adopted. Unfortunately, many studies do not adequately establish their goals or, in some cases, no goal is stated, which makes it extremely difficult to identify whether the results are comparable to any other studies.

The importance of choice of allocation procedure is well illustrated by bioenergy value chains that include CHP, since the chosen basis for allocating GHG emissions between electricity and heat can make a very significant difference to reported results; for a CHP unit with a power to heat output ratio of 0.7, allocation by energy content would result in 41% of the GHG emissions associated with provision of the fuel being allocated to electricity, whereas allocation by exergy might result in approximately 70% of emissions being allocated to electricity. Both allocation procedures are included amongst the reviewed ALCA studies: 2 studies (LCA Ref. Nos. 103 and 106) state that GHG emissions are allocated to CHP heat and power on the basis of energy content whereas 2 other studies (LCA Ref. Nos. 45 and 95) state that exergy is used as the basis for such allocation.

For LCAs where allocation is required, the choice of allocation basis is usually stated in the studies. The basis of allocation is usually determined by the stated purpose and goal of the LCA, when these have been clearly formulated. However, where the purpose and goal have been inadequately established, and in some other cases where good practice has not been followed, the allocation method is often stated with no supporting argument or reason, or a weak reason such as because it is 'easy to use' (LCA Ref. No. 103). The variety of allocation procedures adopted by the ALCA studies is demonstrated in Table 9.

Table 9 Allocation Procedures Adopted in Reviewed ALCA Studies

Allocation procedure	Number of studies
Allocation not required	8
Energy	4
Mass	4
Price	4
Exergy for CHP	2
Mass, price and (for CHP) energy	1
Price and (for CHP) energy.	1
Not stated	2
Energy and system expansion	1
Price and system expansion	1
Mass and price	1
Volume	1
Price (implied)	1
Price (residues with zero price, no emissions allocated)	1
Price and physical properties	1
Unclear allocation procedure	1

Due to the many different reporting units and allocation procedures used in the studies, the number of potentially comparable headline results that could be extracted from the reviewed LCA studies was somewhat limited.

The reviewed ALCA studies cover only 11 whole bioenergy value chains of relevance to this project, as demonstrated in Table 6. There are only 2 value chains covered by more than one study; medium-scale CHP generation using pellets from western Canada conventional forest (conifer) (LCA Ref. Nos. 31 and 103); and electricity only generation using pellets from Scandinavia and the Baltic states conventional forest (conifer) (LCA Ref. Nos. 80 and 103). A detailed review of the studies that include these two value chains reveals that LCA Ref. No. 103, although it covers 80 full bioenergy value chains including 3 within the scope of this project, only gives detailed numerical results for 4 bioenergy value chains, with results for the remainder being displayed as coloured circles on a graph with, seemingly, many circles not showing as overwritten by other circles. Only one of the 4 bioenergy value chains for which detailed results are given concerns conventional pellets, but the conversion technology for this chain is district heating which, on its own, is not a conversion technology within the scope of this project. Hence, although LCA Ref. No. 103 covers 3 whole bioenergy value chains of interest, it presents detailed results for none of these, so cannot be used for an accurate comparison of results. Since this is one of the two studies in each of the value chains where results comparison might have been possible, no whole bioenergy value chain results comparison is possible.

The example for LCA Ref. No. 103 above is illustrative of the problems encountered when attempting to extract numerical results from ALCA studies; it is fairly common for results to be presented in a confusing manner, or in the form of a graph rather than as precise numbers. However, even where precise results are available, comparisons would only be of use in the context of a full understanding of the assumptions, methodology, allocation basis, emissions factors, etc., used in the bioenergy ALCA studies.

There is significant variation in level of detailed LCA data provided for each stage in the bioenergy value chains covered by the studies, and this variation is one of the factors taken into account by the transparency rating (low, medium or high) given to each study. Whilst it is not within the scope of this review to extract and analyse data on individual stages of the bioenergy value chains, such detailed information, drawn from a variety of sources, is provided in the Data Compendium which complements this report, the main LCA review report and the Bioenergy LCA Database in establishing the evidence base required by this project.

Table 10 summarises the results and basis of GHG emission allocation for each of the studies identified as covering a whole bioenergy value chain.

Table 10 Results and Comments for Whole Bioenergy Value Chains Covered by Reviewed ALCA Studies

Biomass Conversion and Feedstock	Results and Comments
Small-scale Heat Only Production (boilers) using pellets from Western Canada conventional forest (conifer) (LCA Ref. No. 31)	'Comparative Life Cycle Analysis of Pellet, Natural Gas and Heavy Fuel Oil as Heat Energy Sources', LCA Ref. No. 31, gives a result of 32 kg CO_2eq/GJ of heat at combustion. The emissions allocation for pellets is carried out based on economic parameters, as deemed appropriate. The report states *'Emissions from burning…may vary depending on the type of equipment used (boilers vs. furnaces) and their capacities. However, such a detailed analysis was not possible due to lack of data.'* The combustion efficiency is based on ecoinvent data and the report highlights that this is 'old data' of moderate/low quality. The size of combustion equipment is not specified, hence this review has been included in both the 'small scale' and 'medium-scale' categories. The study highlights areas of uncertainty and the variability of data quality. Given that the combustion technology is not assessed, it is questionable as to whether this study truly covers the full bioenergy value chain.
Medium-scale Heat Only Production (boilers) using pellets from Western Canada conventional forest (conifer) (LCA Ref. Nos. 31 and 103).	LCA Ref. No. 31 is covered under 'Small-scale heat only' above, and gives a result of 32 kg CO_2eq/GJ of heat at combustion. 'Life Cycle Assessment of Norwegian Bioenergy Heat and Power Systems', LCA Ref. No. 103 (also covered in the main text of this report) covers 80 value chains, but gives detailed results for only 4 of these. From a graph given in the study, values for heat in the form of boiler steam or district heating heat appear to be approximately 50 g CO_2eq/kWh for pellets from 'energy wood'*,110 g CO_2eq/kWh for pellets from wood waste and 200 g CO_2eq/kWh for pellets from forest residues, stemwood and saw residues (equivalent to 14 kg CO_2eq/GJ, 31 kg CO_2eq/GJ and 56 kg CO_2eq/GJ respectively). These results are stated here on the assumption that the points on the graph for boiler heat have been overwritten by the points for CHP electricity. **Energy wood is not clearly defined, though it is inferred to consist of 'residual wood, softwood under bark, hardwood under bark'.*
Medium-scale CHP Generation using pellets from Scandinavia and the Baltic states conventional forest (conifer) (LCA Ref. No. 103)	LCA Ref. No. 103 is covered in the 'Medium-scale heat only' category above. For CHP, the study states that *'allocation is applied for the multi-output technology CHP…..Based on the energy content of heat and electricity, each energy unit (kWh) is assigned the same load.'* which appears to indicate that allocation is by energy, not exergy. The approximate results from the graph for electricity and heat appear to be the same as the results for 'medium-scale heat only' given above.
Large-scale CHP Generation using pellets from Scandinavia and the Baltic states conventional forest (conifer) (LCA Ref. No. 106)	'Life Cycle Assessment of Wood Pellet', LCA Ref. No. 106, gives examples of conversion technologies considered such as 'heat plants/CHP plants, with thermal output larger than 2MW'. It also indicates that GHG emissions are allocated equally to thermal output and electricity output (i.e. by energy, not exergy). However, the study does not give any results in terms of GHG emissions per unit heat generated or delivered. The only GHG emissions results that can be found are in a bar chart that shows a Global Warming Potential of approximately '14', though it fails to specify units.

Biomass Conversion and Feedstock	Results and Comments
Electricity Only Generation using pellets from wheat straw in the UK (LCA Ref. No. 56)	'Environmental Impacts of Future Bioenergy Pathways: the case of electricity from wheat straw bales and pellets', LCA Ref. No. 56. This study models a base case of a 50MWth input electricity only plant fuelled by pellets made from wheat straw with a conversion efficiency of 29%. Allocation of cultivation emissions between wheat grain and straw is by price. Electricity use in the pelleting mill is identified as the most significant contributor to GHG emissions. Results are given as between 26 and 36 g CO_2eq/MJe for the countries included in the study. The result for the UK is not given as a precise figure but is shown in a bar chart as approximately 34 g CO_2eq/MJe.
Electricity Only Generation using pellets from Southern USA plantation forest (pine) (LCA Ref. No. 74)	'How Certain are Greenhouse Gas Reductions from Bioenergy?', LCA Ref. No. 74. Results are 132 and 140 g CO_2eq/kWhe for pellets from forest residues and sawmill residue respectively. In common with most published LCAs concerning pellets, the results do not include methane emissions due to storage of the pellets - but it highlights the current uncertainty around, and the potential significant impact of, such emissions. Allocation is on the basis of price of supply of wood products in the USA.
Electricity Only Generation using pellets from Scandinavia and the Baltic states conventional forest (conifer) (LCA Ref. Nos. 80 and 103)	'Including UK and International Forestry in Biomass Environmental Assessment Tool ($BEAT_2$)', LCA Ref. No. 80. $BEAT_2$ is LCA Ref. No. 11 and is reviewed in the main LCA review report. This study describes the development of $BEAT_2$ to include sources of conifer and broadleaf forest biomass from: the UK; the Baltics, Scandinavia and Finland; boreal North America; and Boreal Eurasia. Allocation of GHG emissions associated with forest products is by price. Forest carbon stock changes are included. The study presents only illustrative results and these do not include results for pellets from Scandinavia and the Baltic States; however, such results would be available from use of the enhanced version of $BEAT_2$, as described by the study. Since $BEAT_2$ could be used to assess several whole bioenergy value chains based on the same assumptions, reference data and methodology, it appears to be a very useful tool for comparative assessment of the value chains. LCA Ref. No. 103 is covered in the 'Medium-scale heat only' category above. For electricity generation, using the graph given in the report, approximate values for electricity production appear to be 110 g CO_2eq/kWh for pellets from 'energy wood', 275 g CO_2eq/kWh for pellets from wood waste and 450 g CO_2eq/kWh for pellets from forest residues, stemwood and saw residues.
Electricity Only Generation using pellets from UK conventional forest (conifer) (LCA Ref. No. 80)	LCA Ref. No. 80 is covered in the 'Electricity only generation using pellets from Scandinavia and the Baltic States' category above. For the UK, illustrative results for electricity production from sustainably managed forests are given as '83 CO_2eq/MWh' (assumed to mean 83 kg CO_2eq/MWh) for pellets from coniferous roundwood.
Electricity Only Generation using pellets from UK conventional forest (broadleaf) (LCA Ref. No. 80)	LCA Ref. No. 80 is covered in the 'Electricity only generation using pellets from Scandinavia and the Baltic States' category above. For the UK, an illustrative result for electricity production from sustainably managed forests is given as 222 kg CO_2eq/MWh for pellets from broadleaf forests.

Biomass Conversion and Feedstock	Results and Comments
Electricity Only Generation using pellets from Southern USA conventional forest (pine) (LCA Ref. No. 132)	'Quantifying GWI of Wood Pellet Production in the Southern United States and its Subsequent Utilization for Electricity Production in The Netherlands/Florida', LCA Ref. No. 132. Electricity generation is modelled for 80 MW power stations in Florida and the Netherlands, both supplied with pellets from Florida. The results are 296.4 and 177.5 g CO2eq/kWh electricity generated for the Netherlands and Florida, respectively.
Hydrogen and District Heat Production from Gasification of pellets from Western Canada conventional forest (conifer) (LCA Ref. No. 38)	'Development of British Columbia Wood Pellet Life Cycle Inventory and its Utilization in the Evaluation of Domestic Pellet Applications', LCA Ref. No. 38. This study covers the production of heat for district heating through gasification of wood pellets in British Columbia. It does not, however, cover hydrogen production, so is not completely aligned with the bioenergy value chain specified by the scope of this project. No result for GHG emissions per unit heat produced is given (results focus more on emissions of non-GHG pollutants).

3. CONCLUSIONS

Only 11 whole bioenergy value chains within the scope of this project were covered by the reviewed bioenergy ALCAs. Of these 11 whole bioenergy value chains, only 2 were covered by more than 1 ALCA. Only 8 out of the 34 reviewed LCA provided this coverage, with a significant number of studies failing to provide whole bioenergy value chain coverage for the reason that the bioenergy input to the conversion processes was in the form of chips rather than pellets.

The transparency of the 8 ALCA studies covering whole bioenergy value chains in the scope of this project was limited, with only 1 of the studies judged to give high transparency and 2 of the studies judged to give low transparency.

It was found that headline results were reported in terms of a wide variety of units and that several different GHG emission allocation procedures were adopted by the studies, often without adequate justification. The choice of allocation procedure can have a very significant effect on the results, so results of studies adopting different allocation procedures cannot be meaningfully compared. Hence these two findings, on units and allocation procedures, illustrate the inherent difficulty of comparing the results of ALCA studies that have been carried out for different purposes and that have adopted different methodologies.

Overall, the review process generated limited quantitative data, though the detailed reviews of the studies given in Appendix F, together with the Bioenergy LCA Database (described in the main LCA review report) should assist a reader in identifying studies potentially relevant to particular research topics or value chains.

NORTH ENERGY

APPENDIX A: EXECUTIVE SUMMARY OF THE MAIN LCA REVIEW REPORT

Executive Summary

1. The aims of this project on "Carbon Life Cycle Assessment Evidence Analysis" for the Energy Technologies Institute are to identify and review the existing evidence base, in terms of relevant life cycle assessments (LCAs) which calculate greenhouse gas (GHG) emissions associated with potentially major bioenergy value chains for the United Kingdom; to compile a compendium of the best and most reliable ranges of basic data used in such calculations; to develop suitable workbooks for consistent calculation of GHG emissions associated with these bioenergy value chains; and to produce results which can be compared and used to identify and prioritise key knowledge gaps.

2. This report documents the outcomes of Work Package 2 of this project which has the main objectives of analysing previous relevant LCA studies by providing a critique of the robustness of the evidence base based on both data and methodologies used; a measure of certainty behind the data reviewed; and details of the confidence the reviewer may have in interpreting the data.

3. As a basis for this, a concise summary of the context of bioenergy LCA studies has been produced to cover the types of questions that, typically, they attempt to answer and the appropriate methodologies that they should use to do this, and to highlight some of the areas where there are conflicting views as to the appropriate approach.

4. In setting this context, the essential outcomes were that the most significant contributions to total GHG emissions for bioenergy value chains involving energy crops are direct and indirect land use changes, although there is no established consensus on modelling the latter; and, for forests, carbon stock changes simulated by suitable models, and the choice of counterfactuals for forest management and the use of timber for bioenergy or as wood products.

5. The process of reviewing relevant LCA studies, as one part of the evidence base, is explained in terms of the selection and screening criteria adopted; the Bioenergy LCA Database where basic information on the selected LCA studies is recorded; the details of the full reviews that have been conducted; and the findings that were drawn from the systematic analysis of these full reviews.

6. The main findings from the review process were that a quite large number (initially 161, subsequently confirmed as 147) of relevant LCA studies were selected, and, after screening, these were reduced to a somewhat smaller number (49) for full reviews. The chief reason why selected LCA studies did not pass screening was that they adopted attributional LCA methodology instead of CLCA methodology, as required by the defined LCA goal and scope of this project. From the 49 reviewed LCA studies, only some (55) of the potential (190) relevant whole bioenergy value chains (without carbon capture and storage) were covered by 8 LCA studies, most (7) with high transparency.

7. Taking into account the analysis of the reviewed LCA studies and the impacts of actual variability and modelling uncertainty, it is apparent that there are limits to findings on confidence and critical data that can be derived from them for the evidence base for specified bioenergy value chains in this project. Instead, it is explained that the Bioenergy LCA Data Compendium offers a more appropriate, fully transparent and crucially comprehensive means of providing this evidence base using both primary and statistical sources of relevant data for use in suitable bioenergy LCA workbooks that are being developed in Work Package 4.

APPENDIX B: ATTRIBUTIONAL AND CONSEQUENTIAL LCA

This appendix is a reproduction of Section 2.2.4.1, 'Attributional and Consequential Life Cycle Assessment' from the main report.

Partly due to the possibility of generating different results based on regulatory rules and in other LCA studies, a debate about methodologies began in the late 2000's. This led to differentiation between two methodologies referred to as "attributional LCA" (ALCA) and "consequential LCA" (CLCA). In particular, a paper from Ecometrica in the UK, stated that ALCA "provides information about the impacts of the processes used to produce (and consume and dispose of) a product, but does not consider indirect effects arising from the changes in the output of a product", whereas CLCA "provides information about the consequences of changes in the level of output (and consumption and disposal) of a product, including effects both inside and outside the life cycle of the product" (Ref. 1).

The main differences in the GHG emissions calculation methodologies of ALCA and CLCA can be summarised (Refs. 2 and 3). In particular, the ALCA methodology excludes GHG emissions from the construction of plant and the manufacture of machinery; possibly does not take into account counterfactuals or reference systems as alternatives to biomass feedstock land use or waste disposal; and applies co-product allocation, possibly based in economic value. The CLCA methodology includes GHG emissions from the construction of plant and the manufacture of machinery; does take into account land use or waste disposal reference systems; and adopts system expansion, "substitution credits" or counterfactuals for the treatment of co-products.

However, these and other specific details of calculation methodologies should really reflect differences in the stated purposes and defined goals and scopes of these different types of LCA study. The Ecometrica paper states that ALCA "provides information about the impacts of the processes used to produce (and consume and dispose of) a product but does not consider indirect effects from changes in the output of a product" in contrast to CLCA which "provides information about the consequences in the change in the level of output (and consumption and disposal) of a product, including effects both inside and outside the life cycle of the product" (Ref. 1). This leads to the suggestion that ALCA produces results for the average unit of product which are "useful for consumption-based carbon accounting" and, by possible extension, monitoring and regulation, whilst CLCA "models causal relationships originating from the decision to change the output of a product" which is relevant for policy-makers.

It can, however, be argued that both these calculation methodologies are capable of generating results for a process "as it is" or "as it might be" (Ref. 3). Instead, the key difference between ALCA and CLCA would seem to be the fundamentally different ways in which co-products are treated in calculations. In particular, ALCA attempts to partition or "attribute" GHG emissions between co-products whereas CLCA is intended to determine the GHG emissions "consequences" of all co-products by means of system expansion. It is in these ways that ALCA is particularly suited to the purposes and goals of monitoring and regulation because it assigns environmental impacts, such as GHG emissions, to a particular product or service, whilst CLCA is appropriate for the purpose and goals of policy analysis since it determines the overall outcomes for environmental impacts of providing a given product or service.

Over time, ALCA and CLCA have become shorthand terms for describing the application of LCA in regulation and policy analysis, respectively, especially with regard to biofuels and bioenergy. However, this characterisation is not entirely accurate, particularly when ALCA is used to describe the methodology of regulatory measures such as the EC's RED and FQD for biofuels and proposed sustainability criteria for bioenergy. This is because, as explained elsewhere, the application of LCA in these regulations involves the effectively hybridisation of methodology which combines elements of ALCA and CLCA (see, for example, Refs. 4, 5 and 6). Although the methodological details of these regulatory measures are set out in some detail, the actual meaning of subsequent results is unclear. This has led many to doubt the usefulness of results generated by the methodologies specified in the EC's RED, FQD and sustainability criteria.

In particular, it has been pointed out that the application of such methodologies does not enable the "real" GHG emissions associated with the production and use of biofuels and bioenergy to be quantified (see, for example, Refs. 4, 7, 8 and 9). Whilst correct, it could be argued that this was never the actual intention of these regulatory LCA methodologies. The problem is that the actual intention of the regulations is not specified in strict and explicit LCA terms by stating the LCA purpose and elaborating this by defining the LCA goal and scope, as required by ISO 14040 (Ref.10). If these fundamental principles of LCA had been followed then this would have resulted in specification of the correct methodology which is appropriate for the stated LCA purpose. Hence, it might be concluded that this represents a failure in the application of LCA principles rather than deficiencies with the LCA methodology.

At this point, it is probably useful to recap on the officially required features of the LCA goal and scope. ISO 14040 specifies that "the goal of an LCA study shall unambiguously state the intended application, the reasons for carrying out the study and the intended audience, i.e. to whom the results of the study are intended to be communicated" (Ref. 10). ISO 14040 also requires that the LCA scope should specify the functions of the product system(s) to provide and/or use and/or dispose of the given product or service under investigation; the functional unit which is used to express the essential nature, characteristics or purpose of a given product or service; the product system(s) to be studied; the product system(s) boundaries; and the co-product allocation procedures (Ref. 10).

With regard to these features, a product system is an activity or series of activities that are involved in the provision of specified product(s) and/or service(s). A system boundary is an imaginary line drawn around and completely enclosing a part or whole of a product system that has been designated for investigation so that all inputs and outputs which cross this line are quantified by the LCA study. Such system boundaries have both spatial and temporal dimensions, and, for completeness, both should be specified in the defined LCA scope. Co-product allocation determines how impacts, in general, or GHG emissions in particular are treated when multiple products and/or services are generated by the product system under consideration. Broadly speaking, co-product allocation consists of either partitioning impacts between co-products on some particular basis, or applying system expansion or the use of counterfactuals.

APPENDIX C: FINAL SCOPING LISTS FOR BIOENERGY VALUE CHAINS

Table C.1 Final Scoping List of Wood Pellet Supply from Forests

Country/ Countries	Region(s)	Forest Type	Sources of Biomass Feedstock
Canada	Western	Conventional Forest (conifer)	Harvest Residues Sawmill Co-products
Scandinavia and Baltic States	-	Conventional Forest (conifer)	Harvest Residues Sawmill Co-products Small Roundwood Complete Stemwood (early thinnings) Complete Stemwood (poor quality trees)
United Kingdom	-	Conventional Forest (broadleaf)	Sawmill Co-products Small Roundwood Complete Stemwood (thinnings)
		Conventional Forest (conifer)	Sawmill Co-products Small Roundwood Complete Stemwood (thinnings)
United States of America	Southern/ South Eastern	Conventional Forest (broadleaf)	Harvest Residues Sawmill Co-products Small Roundwood
		Conventional Forest (pine)	Sawmill Co-products Small Roundwood Complete Stemwood (early thinnings)
		Plantation Forest (pine)	Sawmill Co-products Small Roundwood Complete Stemwood (early thinnings)
	North Western	Conventional Forest (conifer)	Harvest Residues Sawmill Co-products

Table C.2 Final Scoping List of Pellet Supply from Energy Crops

Country	Sources of Biomass Feedstock
Belgium	Short Rotation Coppice (poplar and willow)
France	Short Rotation Coppice (poplar and willow)
Netherlands	Short Rotation Coppice (poplar and willow)
Poland	Short Rotation Coppice (poplar and willow)
United Kingdom	Miscanthus Short Rotation Coppice (poplar and willow) Short Rotation Forest (broadleaf) Short Rotation Forest (conifer) Wheat Straw (agricultural residue)
United States of America, Southern and South Eastern Regions	Short Rotation Forest (broadleaf) Short Rotation Forest (conifer)

Table C.3 Final Scoping List of Biomass Feedstock Conversion Technologies

Biomass Feedstock Conversion
Small-scale Heat Only Production (boilers)
Medium-scale Heat Only Production (boilers)
Medium-scale Combined Heat and Power Generation
Large-scale Combined Heat and Power Generation
Electricity Only Generation (steam cycle) with and without CCS
Electricity Generation (steam cycle) and District Heat Production with and without CCS
Hydrogen Production from Gasification with and without CCS
Hydrogen and District Heat Production from Gasification with and without CCS
Electricity Generation (combined cycle gas turbine) from Gasification with and without CCS
Ethanol from Lignocellulosic Processing

APPENDIX D: ALCA STUDIES SELECTED FOR REVIEW

Ref. No.	Title of Selected LCA Study	Reviewed in main LCA review report (Y = Yes, N = No)	Reason for Not Reviewing in Original Report	ALCA Study Reviewed in this Report (Y = Yes, N = No)
1	A Large and Persistent Carbon Sink in the World's Forests	N	Carbon stock change modelling only	
2	A Model of Carbon Capture and Sequestration with Demonstration of Global Warming Potential and Fossil Fuel Resource Efficiency	N	CO_2 storage options not in depleted offshore oil and gas fields, so considered not relevant to UK	
3	A Streamlined Life Cycle Analysis of Canadian Wood Pellets	N	Attributional LCA methodology	Y
4	An Assessment of Carbon Pools, Storage and Wood Products Market Substitution using Life-Cycle Analysis Results	N	Only considers carbon dynamics and CO_2 emissions	
5	An Environmental Impact Assessment of Exported Wood Pellets from Canada to Europe	N	Attributional LCA methodology; allocation by weight	Y
6	Assessing the Life-Cycle Performance of Hydrogen Production via Biofuel Reforming in Europe	N	Attributional LCA methodology; allocation by energy content	Y
7	Baseline Effects on Carbon Footprints of Biofuels: the case of wood	N	Only considers CO_2 emissions	
8	Bioenergy Driven Land Use Change Impacts on Soil Greenhouse Gas Regulation Under Short Rotation Forestry	N	Not an LCA study	
9	BIOGRACE II: harmonised greenhouse gas calculations for electricity, heating and cooling from biomass - version 3, Final Publishable Report, User Manual, Methodological Background Document, Calculation Rules and Additional Standard Values	Y		
10	Biomass Emissions and Counterfactual (BEAC) Model	Y		
11	Biomass Environmental Assessment Tool - version 2 ($BEAT_2$); and User Guide	Y		

Ref. No.	Title of Selected LCA Study	Reviewed in main LCA review report (Y = Yes, N = No)	Reason for Not Reviewing in Original Report	ALCA Study Reviewed in this Report (Y = Yes, N = No)
12	Biomass Power and Conventional Fossil Systems with and without CO2 Sequestration Comparing the Energy Balance, Greenhouse Gas Emissions and Economics	Y		
13	Biomass Supply and Carbon Accounting for Southeastern Forests	N	Carbon modelling only considers CO_2	
14	Biomass Yield and Energy Balance of a Short-Rotation Poplar Coppice with Multiple Clones on Degraded Land during 16 years	N	Climate impact not evaluated	
15	Boreal Forest Management and its Effect on Atmospheric CO_2	N	Appears to consider only CO_2 emissions	
16	Carbon Accounting of Forest Bioenergy: conclusions and recommendations from a critical literature review	N	Review of LCA studies	
17	Carbon and Energy Balances for a Range of Biofuels Options	Y		
18	Carbon Capture and Utilization: preliminary life cycle CO_2, energy and cost results of potential mineral carbonation	N	CO_2 storage options not in depleted offshore oil and gas fields, so considered not relevant to UK	
19	Carbon Capture, Storage and Utilisation Technologies: a critical analysis and comparison of their life cycle environmental impacts	N	Review of LCA studies	
20	Carbon Debt and Carbon Sequestration Parity in Forest Bioenergy Production	N	Not an LCA study, and CH_4 and N_2O may not be included	
21	Carbon Impacts of Biomass Consumed in the EU: quantitative assessment	Y		
22	Carbon Impacts of Using Biomass in Bioenergy and Other Sectors: energy crops	Y		
23	Carbon Impacts of Using Biomass in Bioenergy and Other Sectors: forests	Y		
24	Carbon in Wood Products and Product Substitution	N	Not an LCA study	

Ref. No.	Title of Selected LCA Study	Reviewed in main LCA review report (Y = Yes, N = No)	Reason for Not Reviewing in Original Report	ALCA Study Reviewed in this Report (Y = Yes, N = No)
25	Carbon Payback Period and Carbon Offset Parity Point of Wood Pellet Production in the Southeastern USA	N	Only considers carbon dynamics and CO_2 emissions	
26	Carbon Savings with Transatlantic Trade in Pellets: accounting for market-driven effects	Y		
27	Climate Change Mitigation Challenge for Wood Utilization - the case of Finland	N	Attributional LCA and only considers carbon dynamics and CO_2 emissions	Y
28	Climate Effects of Wood Used for Bioenergy	N	Not an LCA study; mainly addresses carbon stock timing	
29	CO_2 Emissions from Biomass Combustion for Bioenergy: atmospheric decay and contribution to global warming	N	Not an LCA study of a specific situation; mainly modelling	
30	Comparative Impact Assessment of CCS Portfolio: life cycle perspective	Y		
31	Comparative Life Cycle Analysis of Pellet, Natural Gas and Heavy Fuel Oil as Heat Energy Sources	N	Attributional LCA methodology; allocation by economic value	Y
32	Comparative Life Cycle Environmental Assessment of CCS Technologies	Y		
33	Comparing Soil Carbon of Short Rotation Poplar Plantations with Agricultural Crops and Woodlots in North Central United States	N	Country/region not in scope	
34	Comparison of Carbon Capture and Storage with Renewable Energy Technologies Regarding Structural, Economic, and Ecological Aspects in Germany	Y		
35	Counting the Cost of Carbon in Bioenergy Systems: sources of variation and hidden pitfalls when comparing life cycle assessments	N	Review of LCA studies	

Ref. No.	Title of Selected LCA Study	Reviewed in main LCA review report (Y = Yes, N = No)	Reason for Not Reviewing in Original Report	ALCA Study Reviewed in this Report (Y = Yes, N = No)
36	Cradle-to-Gate Life Cycle Assessment of Forest Operations in Europe: environmental and energy profiles	N	Attributional LCA methodology; allocation by economic value	Y
37	Development and Evaluation of Forest Growth - SRC a process-based model for short rotation coppice yield and spatial supply reveals poplar uses water more efficiently than willow	N	Climate impact not evaluated	
38	Development of British Columbia Wood Pellet Life Cycle Inventory and its Utilization in the Evaluation of Domestic Pellet Applications	N	Attributional LCA methodology; allocation by weight	Y
39	Development of Specific Rules for the Application of Life Cycle Assessment to Carbon Capture and Storage	N	Development of rules rather than an LCA study	
40	Dry Matter Losses and Methane Emissions During Wood Chip Storage: the impact on full life cycle greenhouse gas savings of short rotation coppice willow for heat	N	Attributional LCA methodology; allocation by economic value	Y
41	ecoinvent 3	Y		
42	Effects of Boreal Forest Management Practices on the Climate Impact of CO_2 emissions from Bioenergy	N	Only considers carbon dynamics and CO_2 emissions	
43	Efficacy of carbon and bioenergy markets in mitigating carbon emissions on reforested lands: A case study from Southern United States	N	Not consequential LCA methodology as counterfactuals not used	
44	ELUM: A spatial modelling tool to predict soil greenhouse gas changes from land conversion to bioenergy in the UK	N	Not an LCA study; rather a modelling study	
45	Energy and Climate Benefits of Bioelectricity from Low-Input Short Rotation Woody Crops on Agricultural Land over a Two-Year Rotation	N	Attributional LCA methodology	Y

Ref. No.	Title of Selected LCA Study	Reviewed in main LCA review report (Y = Yes, N = No)	Reason for Not Reviewing in Original Report	ALCA Study Reviewed in this Report (Y = Yes, N = No)
46	Energy and CO_2 Balances in Different Power Generation Routes Using Wood Fuel from Short Rotation Coppice	N	Attributional LCA methodology	Y
47	Energy and Greenhouse Gas Balance of the Use of Forest Residues for Bioenergy Production in the UK	N	Attributional LCA methodology	Y
48	Energy- and Greenhouse Gas-Based LCA of Biofuel and Bioenergy systems: key issues, ranges and recommendations	N	Not an LCA study; mainly concerning LCA methodology	
49	Energy- and Greenhouse Gas-based LCA of Biofuels and Bioenergy Systems - key issues, ranges and recommendations	N	Study is duplicate of No.48 - included in error	
50	Energy Budget and Greenhouse Gas Balance Evaluation of Sustainable Coppice Systems for Electricity Production	Y		
51	Environmental Assessment of Carbon Capture and Storage Deployment Scenarios in France	N	CO_2 storage options not in depleted offshore oil and gas fields, so considered not relevant to UK	
52	Environmental Assessment of German Electricity Generation from Coal-fired Power Plants with Amine-based Carbon Capture	N	CO_2 capture but not storage considered	
53	Environmental Evaluation of CCS using Life Cycle Assessment - a synthesis report	N	Not an LCA study; mainly concerning LCA methodology	
54	Environmental Evaluation of CCS Using Life Cycle Assessment (LCA)	N	Review of LCA studies	
55	Environmental Impacts of a German CCS Strategy	Y		
56	Environmental Impacts of Future Bioenergy Pathways: the case of electricity from wheat straw bales and pellets	N	Attributional LCA methodology	Y
57	Environmental Life Cycle Assessment of Bioethanol Production from Wheat Straw	N	Attributional LCA methodology; allocation by weight	Y

Ref. No.	Title of Selected LCA Study	Reviewed in main LCA review report (Y = Yes, N = No)	Reason for Not Reviewing in Original Report	ALCA Study Reviewed in this Report (Y = Yes, N = No)
58	Environmental Sustainability Analysis of UK Whole-Wheat Bioethanol and CHP Systems	Y		
59	Environmental Sustainability of Bioethanol Production from Wheat Straw in the UK	N	Attributional LCA methodology	Y
60	Establishment Phase Greenhouse Gas Emissions in Short Rotation Woody Biomass Plantations in the Northern Lake States, USA	N	Country/region not in scope	
61	European reference Life Cycle Database (ELCD) 3.2; and International Reference Life Cycle Data System (ILCD) Handbook: general guide for Life Cycle Assessment - provision and action steps	N	Mainly attributional LCA methodology	
62	Final Report on Technical Data, Costs, and Life Cycle Inventories of Advanced Fossil Power Generation Systems	Y		
63	Forest Bioenergy Climate Impact Can Be Improved by Allocating Forest Residue Removal	Y		
64	Forest Bioenergy or Forest Carbon? - assessing trade-offs in greenhouse gas mitigation with wood-based fuels	Y		
65	Full Chain Analysis and Comparison of Gas-fired Power Plants with CO_2 Capture and Storage with Clean Coal Alternatives	N	CO_2 storage options not in depleted offshore oil and gas fields, so considered not relevant to UK	
66	GHG Emissions Performance of Various Liquid Transportation Biofuels in Finland in Accordance with the EU Sustainability Criteria	N	Mix of attributional and consequential LCA methodologies	Y
67	Global Emissions Model for Integrated Systems (GEMIS) - version 4.94	Y		
68	Global Warming Potential Factors and Warming Payback Time as Climate Indicators of Forest Biomass Use	N	Only consider carbon dynamics and CO_2 emissions	

Ref. No.	Title of Selected LCA Study	Reviewed in main LCA review report (Y = Yes, N = No)	Reason for Not Reviewing in Original Report	ALCA Study Reviewed in this Report (Y = Yes, N = No)
69	Greenhouse Gas and Energy Based Life Cycle Analysis of Products from the Irish Wood Processing Industry	N	Attributional LCA methodology; allocation by weight	Y
70	Greenhouse Gas Balance of Native Forests in New South Wales, Australia	N	Country not in scope	
71	Greenhouse Gas Emissions from Four Bioenergy Crops in England and Wales: integrating spatial estimates of yield and soil carbon balance in life cycle analyses	Y		
72	Greenhouse Gas Performance of Heat and Electricity from Wood Pellet Value Chains – based on pellets for the Swedish market	Y		
73	Growth, Yield and Mineral Content of Miscanthus × Giganteus Grown as a Biofuel for 14 Successive Harvests	N	Not an LCA study	
74	How Certain are Greenhouse Gas Reductions from Bioenergy? - life cycle assessment and uncertainty analysis of wood pellet-to-electricity supply chains from forest residues	N	Attributional LCA methodology; allocation by economic value	Y
75	Hydrogen Production via Biomass Gasification - a lifecycle assessment approach	Y		
76	Identifying Potential Environmental Impacts of Large-Scale Deployment of Dedicated Bioenergy Crops in the UK	N	Review of LCA studies	
77	Impact Due to the Use of Combustible Fuels: life cycle viewpoint and relative radiative forcing commitment	N	Uses emission factors from papers to calculate a relative radiative forcing commitment	
78	Impacts of Intensive Management and Landscape Structure on Timber and Energy Wood Production and Net CO_2 Emissions from Energy Wood Use of Norway spruce	N	Only considers carbon dynamics and CO_2 emissions	

Ref. No.	Title of Selected LCA Study	Reviewed in main LCA review report (Y = Yes, N = No)	Reason for Not Reviewing in Original Report	ALCA Study Reviewed in this Report (Y = Yes, N = No)
79	Implications of Land-Use Change to Short Rotation Forestry in Great Britain for Soil and Biomass Carbon	N	Not an LCA study	
80	Including UK and International Forestry in Biomass Environmental Assessment Tool ($BEAT_2$)	N	Attributional LCA methodology; allocation by economic value	Y
81	Incorporating Uncertainty into a Life Cycle Assessment (LCA) Model of Short-Rotation Willow Biomass (Salix spp.) Crops	N	Country/region not in scope	
82	Indirect Carbon Dioxide Emissions from Producing Bioenergy from Forest Harvest Residues	Y		
83	Integrated Assessment of Carbon Capture and Storage (CCS) in the German Power Sector and Comparison with the Deployment of Renewable Energy	N	Review of LCA studies	
84	Is Woody Bioenergy Carbon Neutral? - a comparative assessment of emissions from consumption of woody bioenergy and fossil fuel	N	Country not in scope	
85	Land-Use Change to Bioenergy Production in Europe: implications for the greenhouse gas balance and soil carbon	N	Not an LCA study	
86	LCA of a Biorefinery Concept Producing Bioethanol, Bioenergy, and Chemicals from Switchgrass	Y		
87	Life Cycle Analysis of Pellet Burning Technologies	N	Only CO_2 and CH_4 are assessed	
88	Life Cycle Analysis of Short Rotation Coppice through the Example of Eucalyptus and Poplar for Bioenergy in France	N	Biomass feedstock not in scope; consequential LCA for Eucalyptus only	
89	Life Cycle Assessment (LCA) of an Integrated Biomass Gasification Combined Cycle (IBGCC) with CO_2 Removal	Y		

Ref. No.	Title of Selected LCA Study	Reviewed in main LCA review report (Y = Yes, N = No)	Reason for Not Reviewing in Original Report	ALCA Study Reviewed in this Report (Y = Yes, N = No)
90	Life Cycle Assessment of a Hypothetical Canadian Pre-combustion Carbon Dioxide Capture Process System	Y		
91	Life Cycle Assessment of a Pulverized Coal Power Plant with Post-combustion Capture, Transport and Storage of CO_2	Y		
92	Life Cycle Assessment of a Willow Bioenergy Cropping System	N	Country/region not in scope	
93	Life Cycle Assessment of Bioenergy Systems - state of the art and future challenges	N	Review of LCA studies	
94	Life Cycle Assessment of Biomass Chains: wood pellet from short rotation coppice using data measured on a real plant	Y		
95	Life Cycle Assessment of Biomass-Based Combined Heat and Power Plants	N	Attributional LCA methodology; allocation by economic value	Y
96	Life Cycle Assessment of Carbon Capture and Storage in Power Generation and Industry in Europe	N	CO_2 storage options not in depleted offshore oil and gas fields, so considered not relevant to UK	Y
97	Life Cycle Assessment of Carbon Dioxide Capture and Storage from Lignite Power Plants	Y		
98	Life Cycle Assessment of Electricity Production from Poplar Energy Crops Compared with Conventional Fossil Fuels	N	Country not in scope	
99	Life Cycle Assessment of Gas Power with CCS - a study showing the environmental benefits of system integration	Y		
100	Life Cycle Assessment of Membrane-Based Carbon Capture and Storage	N	CO_2 storage options not in depleted offshore oil and gas fields, so considered not relevant to UK	

Ref. No.	Title of Selected LCA Study	Reviewed in main LCA review report (Y = Yes, N = No)	Reason for Not Reviewing in Original Report	ALCA Study Reviewed in this Report (Y = Yes, N = No)
101	Life Cycle Assessment of Natural Gas Combined Cycle Power Plant with Post-combustion Carbon Capture, Transport and Storage	N	CO_2 storage options not in depleted offshore oil and gas fields, so considered not relevant to UK	
102	Life Cycle Assessment of New Willow Cultivars Grown as Feedstock for Integrated Biorefineries	Y		
103	Life Cycle Assessment of Norwegian Bioenergy Heat and Power Systems	N	Attributional LCA methodology; allocation by weight (biomass feedstocks) and energy content (energy outputs)	Y
104	Life Cycle Assessment of Selected Technologies for CO_2 Transport and Sequestration	Y		
105	Life Cycle Assessment of Wheat Straw as a Fuel Input for District Heat Production	Y		
106	Life Cycle Assessment of Wood Pellet - environmental measurements and assessment	N	Attributional LCA methodology; allocation by economic value	Y
107	Life Cycle Assessment Tool for Estimating Net CO_2 Exchange of Forest Production	N	Only considers carbon dynamics and CO_2 emissions	
108	Life Cycle Emissions and Cost of Producing Electricity from Coal, Natural Gas, and Wood Pellets in Ontario, Canada	N	Attributional LCA methodology	Y
109	Life Cycle Energy and Environmental Benefits of Generating Electricity from Willow Biomass	N	Country/region not in scope	
110	Life Cycle Environmental Impact Assessment of Biochar-Based Bioenergy Production and Utilization in Northwestern Ontario, Canada	Y		
111	Life Cycle Evaluation of Emerging Lignocellulosic Ethanol Conversion Technologies	Y		

Ref. No.	Title of Selected LCA Study	Reviewed in main LCA review report (Y = Yes, N = No)	Reason for Not Reviewing in Original Report	ALCA Study Reviewed in this Report (Y = Yes, N = No)
112	Life Cycle GHG Assessment of Fossil Fuel Power Plants with Carbon Capture and Storage	Y		
113	Life Cycle Impacts of Biomass Electricity in 2020: scenarios for assessing the greenhouse gas impacts and energy input requirements of using North American woody biomass for electricity generation in the UK	Y		
114	Life Cycle Impacts of Forest Management and Wood Utilization on Carbon Mitigation: knows and unknowns	Y		
115	Life Cycle Investigation of CO_2 Recovery and Sequestration	N	CO_2 storage options not in depleted offshore oil and gas fields, so considered not relevant to UK	
116	Life Cycle Modelling and Comparative Assessment of the Environmental Impacts of Oxy-fuel and Post-combustion CO_2 Capture, Transport and Injection Processes	N	CO_2 storage options not in depleted offshore oil and gas fields, so considered not relevant to UK	
117	Life Cycle Modelling of Fossil Fuel Power Generation with Post Combustion CO_2 Capture	N	CO_2 storage options not in depleted offshore oil and gas fields, so considered not relevant to UK	
118	Life-Cycle Assessment of Carbon Dioxide Capture for Enhanced Oil Recovery	N	Focus on enhanced oil recovery rather than CO_2 storage	
119	Life-Cycle Assessment of Straw Use in Bio-Ethanol Production: a case study based on biophysical modelling	N	Uses modelled data	
120	Life-Cycle Impacts of Forest Resource Activities in the Pacific Northwest and Southeast United States	N	Attributional LCA methodology	Y

Ref. No.	Title of Selected LCA Study	Reviewed in main LCA review report (Y = Yes, N = No)	Reason for Not Reviewing in Original Report	ALCA Study Reviewed in this Report (Y = Yes, N = No)
121	Life-Cycle Inventory of Wood Pellet Manufacturing and Utilization in Wisconsin	N	Attributional LCA methodology; allocation by weight	Y
122	Massachusetts Biomass Sustainability and Carbon Policy Study	N	Country/region not in scope	
123	Meta-Analysis of Greenhouse Gas Displacement Factors of Wood Product Substitution	N	Meta-analysis of other LCA studies	
124	Meta-Analysis of Life Cycle Assessment Studies on Electricity Generation with Carbon Capture and Storage	N	Review of LCA studies	
125	Modelling of Energy and Carbon Budgets of Wood Fuel Coppice Systems	N	Only considers CO_2 emissions	
126	Multi Criteria Evaluation of Wood Pellet Utilization in District Heating Systems	Y		
127	National and Global Greenhouse Gas Dynamics of Different Forest Management and Wood Use Scenarios: a model-based assessment	N	Country out of scope	
128	Potential Effects of Intensive Forestry on Biomass Production and Total Carbon Balance in North-Central Sweden	Y		
129	Production and Energetic Utilization of Wood from Short Rotation Coppice - a life cycle assessment	N	Country out of scope	
130	Projection of US Forest Sector Carbon Sequestration under US and Global Timber Market and Wood Energy Consumption Scenarios, 2010-2060	N	Only considers forest carbon stock changes	
131	Prospective Life Cycle Carbon Abatement for Pyrolysis Biochar Systems in the UK	N	Attributional LCA methodology	Y
132	Quantifying GWI of Wood Pellet Production in the Southern United States and its Subsequent Utilization for Electricity Production in The Netherlands/Florida	N	Attributional LCA methodology; allocation by economic value	Y

Ref. No.	Title of Selected LCA Study	Reviewed in main LCA review report (Y = Yes, N = No)	Reason for Not Reviewing in Original Report	ALCA Study Reviewed in this Report (Y = Yes, N = No)
133	Quantifying the Global Warming Potential of CO_2 Emissions from Wood Fuels	N	Only considers carbon dynamics and CO_2 emissions	
134	Regional Carbon Dioxide Implications of Forest Bioenergy Production	N	Only considers CO_2 emissions	
135	Renewable Energy from Willow Biomass Crops: life cycle energy, environmental and economic performance	N	Country/region not in scope	
136	Research to Support the Review of the Renewable Obligation Scotland and Impact of the Renewable Heat Incentive: part 2 - biomass thresholds for electricity, CHP and heat generation	N	Mix of attributional and consequential LCA methodologies	Y
137	Scottish Government Biomass Incentives Review: best use of wood fibre	Y		
138	Sequester or Substitute - consequences of increased production of wood based energy on the carbon balance in Finland	N	Only considers CO_2 emissions	
139	Short-Rotation Forestry of Birch, Maple, Poplar and Willow in Flanders (Belgium): I -biomass production after 4 years of tree growth	N	Not an LCA study	
140	Short-Rotation Woody Crop Systems, Atmospheric Carbon Dioxide and Carbon Management: a US case study	N	Only considers CO_2 emissions.	
141	Should Life Cycle Assessment be part of the Environmental Impact Assessment? Case Study: EIA of CO_2 capture and storage in Canada	N	Focuses on LCA methodology rather than being an LCA study	
142	Simulation of Environmental Impact Scores within the Life Cycle of Mixed Wood Chips from Alternative Short Rotation Coppice Systems in Flanders (Belgium)	N	Attributional LCA methodology	Y
143	Soil Organic Carbon Changes in the Cultivation of Energy Crops: implications for GHG balances and soil quality for use in LCA	N	Attributional LCA methodology	Y

Ref. No.	Title of Selected LCA Study	Reviewed in main LCA review report (Y = Yes, N = No)	Reason for Not Reviewing in Original Report	ALCA Study Reviewed in this Report (Y = Yes, N = No)
144	Sound Principles and Inconsistencies in the 2012 UK Bioenergy Strategy	N	Not an original LCA study	
145	Techno-Economic and Life Cycle Assessment on Lignocellulosic Biomass Thermochemical Conversion Technologies: a review	N	Review of LCA studies	
146	The Carbon Neutrality Assumption for Forest Bioenergy: a case study for Northwestern Ontario	N	Country/region out of scope and does not calculate GHG emissions but carbon neutrality and breakeven periods	
147	The Climate Effect of Increased Forest Bioenergy Use in Sweden: evaluation at different spatial and temporal scales	Y		
148	The Comparative Life Cycle Assessment of Power Generation from Lignocellulosic Biomass	Y		
149	The Economical and Environmental Performance of Miscanthus and Switchgrass Production and Supply Chains in a European Setting	N	Attributional LCA methodology	Y
150	The Effect of Assessment Scale and Metric Selection on the Greenhouse Gas Benefits of Woody Biomass	N	Only considers CO_2 emissions	
151	The Environmental and Economic Sustainability of Potential Bioethanol from Willow in the UK	Y		
152	The Influence of Organic and Inorganic Fertiliser Application Rates on UK Biomass Crop Sustainability	Y		
153	The Potential Contribution of a Short Rotation Willow Plantation to Mitigate Climate Change	N	Attributional LCA methodology; allocation by economic value	Y
154	The Potential for Short-Rotation Woody Crops to Reduce US CO_2 Emissions	N	Attributional LCA methodology	Y

Ref. No.	Title of Selected LCA Study	Reviewed in main LCA review report (Y = Yes, N = No)	Reason for Not Reviewing in Original Report	ALCA Study Reviewed in this Report (Y = Yes, N = No)
155	The Potential Role of Forest Management in Swedish Scenarios Towards Climate Neutrality by Mid Century	Y		
156	The UK Solid and Gaseous Biomass Carbon Calculator	N	Attributional LCA methodology	Y
157	Understanding the Carbon and Greenhouse Gas Balance of UK Forests	Y		
158	Using a Life Cycle Assessment Approach to Estimate the Net Greenhouse Gas Emissions of Bioenergy	N	Attributional LCA methodology; allocation by energy content	Y
159	Well-to-Wheels Analysis of Future Automotive Fuels and Powertrains in the European Context: Well-to-Tank Appendix 4 - version 4.0 description, results and pathway input data per pathway	Y		
160	Willow Short-Rotation Coppice in Multiple Land-Use Systems: evaluation of four combination options in the Dutch context	N	Climate impact not evaluated	
161	Yield and Spatial Supply of Bioenergy Poplar and Willow Short-Rotation Coppice in the UK	N	Climate impact not evaluated	

APPENDIX E: TEMPLATE FOR FULL LCA REVIEW SUMMARY SHEET

Instructions for the completion of a Review Summary Sheet are provided in *italics*.

Details of LCA Study/Calculation Tool/Database/Review: *Record the title, author(s), publishing details and DOI.*
Stated LCA Purpose, and Defined LCA Goal and Scope: *If explicitly documented, record any of these aspects. If not documented, record that they were missing and, if possible, indicate the likely implicit LCA purpose.*
Technological Coverage: *Provide a very brief summary of the types of technology covered, such as the source and nature of a biomass feedstock, its processing and final conversion depending on the bioenergy value chain(s) or other technologies relevant to the bioenergy value chain scoping list.*
Technological Assumptions: *Provide a very brief summary of any key assumptions made about the technology and its scale of application, such as a single biomass conversion plant with a quoted output or the national supply of biomass feedstock or subsequent bioenergy.*
Methodological Assumptions: *Provide a very brief summary of any stated assumptions about how LCA calculations were performed, especially the extent of spatial and temporal system boundaries; the inclusion or exclusion of GHG emissions associated with plant construction and machinery manufacture, and maintenance; and the values of any Global Warming Potentials applied in deriving total GHG emissions. For LCA studies involving forest biomass feedstocks, record whether (and, if possible, how, in very concise terms) net changes in biogenic carbon stocks are evaluated. For LCA studies involving energy crops, including short rotation forests, short rotation coppice and miscanthus, record whether (and, if possible, how, in very concise terms) indirect land use change was taken into account. For LCA studies involving wheat straw, record whether (and, if possible, how, in very concise terms) the counterfactual to its removal for fuel use was evaluated.*
Overview of Transparency: *Specify the transparency of all the calculations performed, in which:* • *“low transparency” indicates very little or no access to all the calculations, or no access to those calculations that make major contributions to total GHG emissions,* • *“moderate transparency” indicates some access to those calculations that make major contributions to total GHG emissions, and* • *“high transparency” indicates access to all calculations or access to all those calculations that make major contributions to total GHG emissions.*
Reviewer: *Name of person recording this information*
Headline Results: *Any prominent results from the LCA study in their original units (with output explained, if necessary).*

APPENDIX F: FULL LCA REVIEW SUMMARY SHEETS

Note: the indicated reviewers undertook the initial reviews of the studies; all reviews were subsequently edited/amended to varying degrees by Jeremy Rix (NEA), including in response to comments on the initial draft report by ETI's external reviewers.

Ref. No. 03: Details of LCA Study/Calculation Tool/Database/Review: A Streamlined Life Cycle Analysis of Canadian Wood Pellets by Francesca Magelli and Tony Bi, University of British Columbia, Vancouver, BC, Canada. DOI: not available.
Stated LCA Purpose, and Defined LCA Goal and Scope: 1-Gate-to-Gate LCA analysis of wood pellet production (wet sawdust input, pellets output) in Canada using different fuels for heating - sawdust (wet/dry), wood pellets, coal, gas. 2-A cradle-to-tank LCA analysis for producing and transporting wood pellets from Canada to Europe.
Technological Coverage: The study is in the form of a series of presentation slides, giving limited detail. Feedstock: sawdust/chopped biomass 1- Gate to Gate LCA: biomass drying, grinding, pelleting. 2- Cradle-to-tank LCA: Harvesting, collection, transport by truck and rail, biomass drying (lumber mill residues), grinding, pelleting, handling and transport by vessel to Europe.
Technological Assumptions: Feedstock Drying by: wet sawdust, dry sawdust, pellets, coal or gas.
Methodological Assumptions: Functional Unit: 1 tonne of wood pellets. Energy consumptions based on mathematical modelling and field data. Emission inventories: Emission factors taken from US Emission US--EPAEPA--AP42 database and literature. Impact assessment: environmental impacts (GHGs, ozone depletion, smog, acid rain), health impacts, total cost. Not clear if carbon change, construction, machinery is included.
Overview of Transparency: low – no calculations or process details shown.
Reviewer: Maha Elsayed
Headline Results: Gate to Gate LCA results (approximate values read off a bar chart) per tonne of pellets: Primary Energy MJ/tonne: 3,500 (using pellet as fuel), 3,900 (using wet sawdust as fuel), 3,800 (using dry sawdust as fuel), 3,600 (using coal as fuel), 3,050 (using natural gas as fuel) (values estimated from bar chart on slide number 14). GWP kg CO_2eq/tonne: 50 (using pellet as fuel), 50 (using wet sawdust as fuel), 50 (using dry sawdust as fuel), 300 (using coal as fuel), 240 (using natural gas as fuel) (values estimated from bar chart on slide number 15). Gate to Tank LCA (per tonne of pellets, data from slide number 28): Energy GJ/tonne: Using sawdust as a fuel: Harvest 2.09, transport to pelleting plant 0.07, production 3.78, transport to Europe 2.85, Total 8.80. Using natural gas as fuel: Harvest 2.09, transport to pelleting plant 0.07, production 2.97, transport to Europe 2.85, Total 7.99. GWP kg CO_2eq/tonne: Using sawdust as a fuel: Harvest 24.3, transport to pelleting plant 7.0, production 48.0, transport to Europe 445.2, Total 524.4. Using natural gas as fuel: Harvest 24.3, transport to pelleting plant 7.0, production 238.8, transport to Europe 445.2, Total 715.3. Results do not include biogenic emissions of CO_2.

Ref. No. 05: Details of LCA Study/Calculation Tool/Database/Review: An Environmental Impact Assessment of Exported Wood Pellets from Canada to Europe by F. Magelli, K. Boucher, H. T. Bib, S. Melin and A. Bonoli, Elsevier, Biomass and Bioenergy 33 (2009) 434-441, **DOI**: 10.1016/j.biombioe.2008.08.016.
Stated LCA Purpose, and Defined LCA Goal and Scope: ***Purpose:*** to achieve improvement in pellet production and transportation to reduce environmental impacts. Analysis of the net benefits of exporting wood pellets from Canada to Europe with the consideration of environmental impacts associated with the production and transportation of wood pellets. ***Goal:*** LCA of fuel consumption and air emissions associated with the wood pellet production in British Columbia and export to Sweden. ***Scope:*** System boundary - tree harvesting, transport by truck, pellet production, shipping of wood pellets by train to port and by ocean vessel from Vancouver to Stockholm in Sweden.
Technological Coverage: Feedstock: Wood residues and sawdust from sawmills processing wood from natural forests in British Columbia. Processes considered: harvesting (felling trees, skidding trees to landing area, processing trees to logs (debarking, topping, bucking, de-limbing and cutting to length), woodchip drying, size reduction (grinding) and densification (pelleting).
Technological Assumptions: 5 tonnes/hr pellet plant. the pellet production site selected for analysis is located in Prince George in British Columbia, where most pellet plants are situated in close proximity.
Methodological Assumptions: Functional Unit: 1 tonne of wood pellets. Distance from the forest to the lumber mill: an average of 110 km. Wood residues (shavings and sawdust) are transported by trucks for an average distance of about 27 km to the pellet plant. The wood pellets are transported from the plant to the Vancouver port by train, over an average distance of 750 km. The wood pellets are then loaded onto ocean vessels and shipped from North America to Europe over about 15,500 km. Energy required for a truck to transport 1 tonne of goods over 1 km is 1,590 kJ on average, assuming an average payload of 20 tonnes. The amount of fuel consumed by freight train is calculated to be 6.07 litres per 1,000 revenue tonne-km (RTK) transported, with RTK defined as "the total weight (in tonnes) of revenue commodities handled multiplied by the distance (in km) transported, excluding the tonne-km involved in the movement of railway materials or any other non-revenue movement". The average fuel consumption for ocean vessels is estimated to be 0.0037kg fuel/tonne-km. No biogenic carbon stocks are evaluated. The emissions and energy consumptions associated with tree harvesting in British Columbia are taken from a paper from S.M. Sambo, which reported an energy consumption of 273 MJ/m^3 of harvested wood, assuming that all the energy comes from diesel fuel. The emissions associated with the harvesting are estimated using the emission factors from US EPA's AP-42 database. The energy consumption and emissions are partitioned between the lumber and the sawdust based on their weight ratios. Average weight of a truck with both payload and fuel is around 30,000 kg. At the pellet plant woodchips at 50-60% MC are dried to 10%. For every tonne of wood pellets to be produced 1.56 tonnes of raw material are needed. For drying of wood chips 2 scenarios are considered: using wet sawdust or natural gas as fuels. Energy used to produce 1 tonne wood pellets is around 3.8 GJ using wet sawdust as the fuel for drying, and around 3 GJ when natural gas is used for drying. Higher Heating Value of (HHV) of wood pellet of 18.5 GJ/tonne is used. Total energy consumption and environmental impacts on global warming, acid rain formation, smog formation and human health are evaluated. The life cycle analysis software GHGenius is used to estimate the fuel consumption from a heavy-duty diesel (HDV) engine. GWP indices based on the 2001 IPCC reports are used. No plant construction or machinery are included.
Overview of Transparency: high
Reviewer: Maha Elsayed
Headline Results: For each tonne of wood pellets sold in Europe, net energy consumed: Using sawdust for drying: 7.2 GJ/tonne of which 3.5 GJ/ tonne are from fossil fuel sources. Using natural gas for drying: 6.43 GJ/tonne (fossil fuel sources component not given). **GWP:**532 kg CO_2eq/tonne for sawdust as fuel and 723 kg CO_2eq/tonne for natural gas as fuel. Results do not include biogenic emissions of CO_2.

Ref. No. 06: Details of LCA Study/Calculation Tool/Database/Review: Assessing the Life-Cycle Performance of Hydrogen Production via Biofuel Reforming in Europe by Ana Susmozas, Diego Iribarren, Javier Dufour, Resources 2015, 4, 398-411, DOI: 10.3390/resources4020398.
Stated LCA Purpose, and Defined LCA Goal and Scope: **Purpose**: decision-making processes oriented towards sustainability. **Goal**: cradle-to-gate life-cycle (environmental and energy) performance of biohydrogen produced in Europe via steam reforming of glycerol (GSR-H2) and bio-oil (BSR-H2). **Scope**: 1) Glycerol as a by-product from the production of biodiesel via the transesterification of rapeseed (RS) oil in Europe. 2) Bio-oil from the fast pyrolysis of short-rotation poplar biomass cultivated in Europe.
Technological Coverage: 1) Rapeseed feedstock. Process: oil production and transportation, biodiesel (and glycerol) production, bio-glycerol steam reforming, water gas shift (WGS) process, and hydrogen purification through pressure swing adsorption (PSA). 2) Poplar biomass feedstock (50% moisture). Processes: bio-oil production and transportation, bio-oil steam reforming, WGS process, and hydrogen purification through PSA.
Technological Assumptions: Processing plants are simulated in Aspen Plus® to provide inventory data for the life cycle assessment
Methodological Assumptions: The functional unit (FU) used is 1kg of hydrogen produced. Capital goods were excluded from the study. It is not clear if indirect land use change or cultivation of rapeseed or poplar are taken into account. For the glycerol system allocation of emissions is based on the relative energy content of biodiesel (allocation factor: 0.9575) and bio-glycerol (allocation factor: 0.0425). For the bio-oil system, no allocation approach was applied since only hydrogen is produced. Some of the produced char in the bio-oil system is burnt to provide the heat required by the pyrolysis reactor and the biomass dryer. The environmental impact potentials evaluated using SimaPro 8 included abiotic depletion, global warming, ozone layer depletion, photochemical oxidant formation, land competition, acidification and eutrophication. Furthermore, the cumulative (total and non-renewable) energy demand (CED) is calculated. GWP was evaluated using the 100-year characterisation factors defined by the IPCC 5th Assessment Report (2013). Inventory data from ecoinvent database was used. Lower heating value of hydrogen: 119.96 MJ/kg
Overview of Transparency: Low. No detailed calculation is shown.
Reviewer: Maha Elsayed
Headline Results: **CED_t** (total cumulative energy demand) indicators per kg hydrogen: Glycerol system 344.67 MJ (63.05% renewable), Bio-oil system 466.31 MJ (80.84% renewable). **GWP** per kg hydrogen: Glycerol system: 12.65 kg CO_2eq/kg, Bio-oil system: 3.79 kg CO_2eq/kg. Calculations include absorption and emissions of biogenic CO_2, with the headline results above including the net change in atmospheric CO_2.

Ref. No. 27: **Details of LCA Study/Calculation Tool/Database/Review:** Climate Change Mitigation Challenge for Wood Utilization - the case of Finland, S. Soimakallio, L. Saikku, L. Valsta and K. Pingoud, Environmental Science and Technology, Vol. 50, pp. 5127 - 5134, 2016, DOI: 10.1021/acs.est.6b00122.
Stated LCA Purpose, and Defined LCA Goal and Scope: To comprehensively examine the net carbon emissions associated with wood utilisation in Finland and "to comprehensively consider the sensitivity of the results to the parameter uncertainties."
Technological Coverage: Domestic and imported wood from forests and recycled wood used for energy, paper, board and sawn wood products compared with fossil fuel, plastic, fossil boards, concrete and steel.
Technological Assumptions: Assesses the extended life cycle carbon emissions and considers the substitution for other products (fossil fuel, plastics, fossil boards, concrete and steel) for various wood utilization scenarios over 100 years from 2010 onward for Finland. The scenarios are based on various but constant wood utilization reflecting current and anticipated mix of wood utilization activities.
Methodological Assumptions: This LCA study considers the carbon flows of the wood utilization system in Finland in 2010. Direct and embodied carbon emissions are taken into account including the forest carbon sink as well as the avoided carbon emissions from displacement of alternative materials and energy by harvested wood products. The temporal scope of wood utilization scenarios is 100 years (from 2010). Substance flow analysis (SFA) is used to track and quantify the direct carbon flows in the system. The functional unit is harvested wood (t C). The reference system is no harvesting of forest over the studied 100-year time horizon. To quantify the forest carbon sink impacts, the relative carbon (RC) indicator introduced by Pingoud et al over a 100-year time horizon (RC100) is used. The life cycle carbon emissions of a wood utilization system are compared with alternative materials and energy, serving an equivalent (comparable) function with harvested wood products. Allocation is by expansion of systems boundaries using "substitution credits" from material and energy use of wood when possible. The uncertainty and sensitivity of the results to the input parameter are assessed using Monte Carlo simulation. MS Excel software and its add-in @Risk application are used to model the scenarios and to carry out the calculations.
Overview of Transparency: Moderate transparency, supporting information available.
Reviewer: Anna Evans
Headline Results: The annual direct carbon emissions due to wood utilization in Finland in 2010 were −3.6 Mt C. Net carbon sequestration in biomass exceeded direct carbon emissions from wood utilization and fossil fuel combustion in industrial and energy wood processing. This was the case even though fairly large amounts of wood were imported from abroad and more than 90% of the carbon in the harvested wood was released into the atmosphere. However, annualised carbon emissions over a lifetime of 100 years, calculated using mean values, came, to +15.1 Mt C per year. The 18.6 Mt carbon difference between annual direct and annualized life cycle flows consisted of three factors: the fossil carbon emissions embodied in fossil fuels, paper production additives, and imported wood increased the carbon flow to the atmosphere by 1.2 Mt C; imported pulp involved embodied biogenic carbon emissions (0.3 Mt C) and finally most significantly, when accounting for life cycle carbon flows, continuous wood harvesting over the studied 100-year time horizon resulted in lower forest carbon stock compared to the land-use reference system with no wood harvesting. Further extension of the system boundary to include the avoided emissions from substitution of alternative materials and energy products significantly reduced the net carbon emissions related to the wood utilization in Finland compared to the life cycle flows. However, the net carbon emissions remained positive over the studied 100-year time horizon, although reduced to 2.7 Mt C yr−1. This was because the substitution credits (−12.4 Mt C yr−1) were not large enough to compensate the combined emissions from the reduction in forest carbon sink (11.1 Mt C yr−1), fossil fuel inputs (3.5 Mt C yr−1) and other embodied emissions (1.5 Mt C yr−1). The sensitivity analysis of the stochastic simulations indicated that the uncertainty of the results is mainly due to the parameter "reduction in the forest carbon sink per the carbon content of wood harvested (RC100)". The authors conclude that it is exceptionally unlikely that the wood utilization in Finland provides significant unit reductions in net carbon emissions within the upcoming 100 years, with the reduction in forest carbon stocks a very significant impact. They state that this presents a major challenge for forest management practices and wood utilization activities in responding to ambitious climate change mitigation targets, but they do not give any recommendations for future forest management policy or techniques.

Ref. No. 31: Details of LCA Study/Calculation Tool/Database/Review: Comparative Life Cycle Analysis of Pellet, Natural Gas and Heavy Fuel Oil as Heat Energy Sources, Lal Mahalle, FP Innovations, Vancouver, Canada - Project No. 301006317, DOI: not available.
Stated LCA Purpose, and Defined LCA Goal and Scope: The purpose of the study is to educate clients and business partners of Groupe Savoie in Europe and to investigate options for improving the environmental performance of their pellet manufacturing process. The study's goals are to create a gate-to-gate life cycle inventory (LCI) for pellet manufacturing and, using this LCI and data from other sources, to develop a full life cycle impact assessment that allows them to compare and contrast the life cycle environmental performance of pellets manufactured at their plant in St Quentin, New Brunswick, Canada with natural gas and heavy fuel oil as heat energy sources in Europe. A cradle to gate life cycle impact assessment for the pellet plant as well as a cradle-to-grave assessment for the whole heat generation process is carried out. The scope includes all upstream and downstream processes associated with the three energy systems. The functional unit is defined as the generation of 1 GJ of heat energy at the combustion equipment.
Technological Coverage: Sustainable Canadian forest wood residues, sawdust and bark. Processes included are harvesting, sawmill operation, drying and pellet manufacturing and combustion for heat in boilers or furnaces.
Technological Assumptions: Considers a pellet plant belonging to Groupe Savoie in St Quentin, New Brunswick, Canada. The pellets are then exported to Europe and combusted in boilers. The efficiency, size and type of boiler are not specified.
Methodological Assumptions: Primary data are used for the assessment of harvesting, sawmilling and pellet manufacture operations. The source of the primary data is not stated explicitly, though an assumption that it is from Group Savoie's own operations appears reasonable. Secondary data from the ecoinvent database were used for pellet combustion in furnaces and natural gas and heavy fuel oil combustion systems. Allocation to the different wood fractions was by economic allocation. Secondary data from ecoinvent are used for combustion in furnaces, natural gas and heavy fuels. Allocation to the different fractions from oil refining is by physical properties. Carbon uptake and biogenic carbon is not included. The US Environmental Protection Agency's tool for the reduction and assessment of chemical and other environmental impacts (TRACI) was used to carry out the assessment complemented with Cumulative Energy Demand (CED) to calculate primary energy consumption by fuel sources. Allocation is by economic value for pellet production. Greenhouse gas (GHG) emissions, ozone depletion and primary energy are evaluated. Plant manufacturing and building impacts are not included. Land use change is considered to be zero as the forests are sustainably managed. Uncertainty is considered and sensitivity analysis carried out.
Overview of Transparency: Low transparency, limited access to the calculations.
Reviewer: Anna Evans
Headline Results: 32kg CO_2eq/GJ heat at combustion equipment. Pellets have a lower environmental impact than natural gas and fuel oil for ozone depletion and global warming. Pellets reduce greenhouse gas emissions by 39 and 69kg per functional unit on a full life cycle basis. Electricity use is the most prominent hotspot in the manufacture of the pellets. Shipping to Europe is responsible for more than 50% of the fossil energy use. Calculations include uptake of CO_2 in forests and emissions of biogenic CO_2 during combustion, with the headline results above including the net change in atmospheric biogenic CO_2.

Ref. No. 36: Details of LCA Study/Calculation Tool/Database/Review: Cradle-to-Gate Life Cycle Assessment of Forest Operations in Europe: environmental and energy profiles. S. González-García, M. T. Moreira, A. C. Dias and B. Mola-Yudego, Journal of Cleaner Production 66 (2014) 188e198 DOI: 10.1016/j.jclepro.2013.11.067.
Stated LCA Purpose, and Defined LCA Goal and Scope: Purpose was to give an overview of European current forest practises with industrial application performed nowadays as well as to orientate forest based industries towards the use of alternative wood biomass resources. The goal was to analyse and compare the environmental profiles associated with the production of wood biomass from five representative tree species: willow (Salix sp.), poplar (Populous sp.), maritime pine (Pinus pinaster), Douglas-fir (Pseudotsuga menziesii) and spruce (Picea abies). Different industrial uses (wood and energy) in several European countries (Sweden, Germany, France, Portugal and Italy) were considered for each of these species. The scope was cradle to grave from extraction of raw materials through management operations up to the loading of wood on to trucks (system boundary) including production of machinery and inputs (fossil fuels, herbicides etc.). The environmental impacts considered were GWP, photochemical oxidant formation, eutrophication and acidification as well as fossil and nuclear cumulative energy demand analysis (CED). The functional unit was 1 m^3 of felled fresh roundwood per year (m^3/year).
Technological Coverage: 12 different management scenarios were compared (across the following species: Willow in Sweden (2), Poplar in Italy (2), Maritime pine in France and Portugal (4), Douglas-fir in Germany and France (3), Spruce in Sweden (1)). Each scenario covered: 1) site preparation, including herbicide application, weeding and stool elimination 2) stand establishment and tending: including planting including mechanical weed control, and 3) logging operations up to loading on to trucks.
Technological Assumptions: Information on foreground processes was taken directly from forest plantations from interviews with workers. French scenario information was built according to expert advice and literature as opposed to forest workers. Background process (machinery and implements production, fertiliser production etc.) information was taken from ecoinvent and adapted to the specific characteristics of each forest. Inventory data for seedling production taken from Aldentun (2002).
Methodological Assumptions: LCA was conducted using characterisation factors reported by the Centre of Environmental Science of Leiden University - CML Method v 2.04. An energy analysis was also performed based on the cumulative non-renewable fossil and nuclear energy demand (CED) calculated according to Hischier et al. (2009) as an additional indicator. SimaPro 7.3.2 was used for computational implementation of all the inventories. Activities related to construction and maintenance of infrastructure (road and firebreak) were excluded in willow, spruce and poplar scenarios (due to lack to information) however the authors state that their understanding is that the contribution is likely to be negligible in any case. All cradle to grave scenarios considered single output systems: thus, all wood biomass harvested (including pruning and thinning) was managed as a unique product and differences were not considered between wood biomass from operations such as pruning and thinning as all biomass can be used in industrial applications. Harvesting residues such as small branches, leaves and stumps were excluded under the assumption that this residual biomass remains in the stand, to improve soil quality. Diffuse emissions derived from application of organic and mineral fertilisers were calculated according to literature. Assumption that wood biomass production systems are in steady state with respect to carbon stocks and management operations; availability of nutrients and water, land use and soil organic carbon (SOC) stocks remained unchanged. Uptake of CO_2 from atmosphere is assumed equal to the CO_2 released during combustion.
Overview of Transparency: moderate transparency
Reviewer: Paula McNamee
Headline Results: GWP (kg CO_2eq/m^3 felled fresh roundwood) Highest = 2.69 (Swedish more intensively managed Willow), Lowest = 0.05 (Germany Douglas Fir) Results do not include biogenic emissions of CO_2.

Ref. No. 38: Details of LCA Study/Calculation Tool/Database/Review: Development of British Columbia Wood Pellet Life Cycle Inventory and its Utilization in the Evaluation of Domestic Pellet Applications by A. A. Pa, The University of British Columbia, Canada, 2008 (Master's Thesis), DOI: not available.
Stated LCA Purpose, and Defined LCA Goal and Scope: The first objective of the study was to "establish a LCI (Life Cycle Inventory) database for BC (British Columbia) wood pellets using data that are specific to BC whenever possible". The second objective was "to use the in-house BC wood pellet LCI database to evaluate possible domestic applications of these pellets". The aim of the studies was to provide insights of the pros and cons of these applications, demonstrate the potential for wood pellets to reduce GHG emissions and suggest the amount of incentive that may be required for consumers to switch to wood pellets.
Technological Coverage: Harvesting wood from forests, waste wood, wood processing, sawmill operations, pelletising, transport, port operation and combustion in district heating systems or domestic heating.
Technological Assumptions: The LCI database for pellet production was based as far as possible on average data for BC pellet production. Four scenarios for the replacement of natural gas in the existing district heating facility at the University of British Columbia (UBC) by wood pellet gasification were investigated. These were wood waste (50% forest residue from harvesting operations and 50% sawmill and planer mill residue) and wood pellet gasification systems with and without electrostatic precipitator (ESP) for particulate matter (PM) removal and selective catalytic reduction (SCR) unit for NO_X control. The annual operation is based on the amount of heat generated annually (974 TJ) for the UBC district heating facility. A further case study looks into replacing firewood for BC residential heating with wood pellets.
Methodological Assumptions: An in-house LCI database for BC wood pellets is used to compare the performance of BC pellets exported to Rotterdam and BC pellets staying within BC. The functional unit is 1 tonne of wood pellets. Two domestic applications of BC wood pellets: replacing natural gas combustion in UBC district heating facility with wood waste or wood pellet gasification, and replacing firewood in BC residential heating with wood pellets. The functional unit is impacts per unit of energy produced. Impacts considered include energy penalty, human health, ecosystem quality and climate change. The life cycle impact assessment (LCIA) is carried out in SimaPro (IMPACT 2002+). Emissions and impacts associated with land usage and infrastructure are not included. Only air emissions are taken into account; soil and water emissions are not. Allocation is by dry mass. The system boundary includes: harvesting wood from forests, transport by truck, sawmill operations, pellet production, transport by train, port operation, ocean transport and where relevant, combustion in domestic and district heating systems. Primary energy requirement for different types of energy and fuels are obtained from Ecoinvent database. Emissions considered are CO_2, CH_4, NO_2, CO, NMVOC, NO_X, SO_X and PM. The global warming factors listed in IMPACT 2002+ are mostly based on the IPCC 2001 report's 500-year time horizon values. Data are collected from published literature, reports, including government documents, and industrial survey distributed and collected with the help of the Wood Pellet Association of Canada.
Overview of Transparency: Moderate transparency; calculations that make major contributions to total GHG emissions are shown.
Reviewer: Anna Evans
Headline Results: For exported pellets, marine transportation contributes approximately 50% to non-biogenic CO_2 emissions and CH_4 emissions, and 18% to N_2O emissions (CO_2eq figures are not given). Harvesting has the second largest contribution. Pelletisation contributes around 80% to biogenic and 30% to PM emissions. The high biogenic and PM emissions are linked to the use of wood residue as an energy source within the pellet plants. Life cycle GHG emissions for pellets exported to Europe are 15.9 KgCO_2eq/GJ, approximately twice the emissions of pellets used in BC but still significantly lower than emissions due to fossil fuels (which range from 99.1 to 56.6 kg CO_2eq/GJ). For locally used pellets, the harvesting stage remains the hot-spot for non-biogenic emissions while pelletisation is the main source of biogenic emissions. For pellet gasification, emissions reductions of 85% for non-biogenic CO_2 and 77% for CH_4 emissions resulted when the district heating boiler was switched from natural gas to woody biomass gasification. The equivalent figures for wood waste gasification are reductions of 82% for non-biogenic CO_2 and 61% for CH_4. Wood waste gasification resulted in an increase in biogenic CO_2 emissions of 29% compared to pellet gasification. PM emissions increase very significantly for all gasification scenarios, reaching approximately 130 and 77-fold for wood waste and wood pellets, respectively, compared to natural gas. Switching from logs to pellet combustion in domestic appliances results in a 30% increase in non-biogenic and a 42% decrease in biogenic CO_2 emissions and a 38% reduction in overall CO_2 emissions. The reduction in non-biogenic emissions is largely due to high combustion efficiency/fuel quality and the increase in non-biogenic emissions is mainly due to the extra processing required for pellet production compared to chopping for firewood. Switching from logs to pellets resulted in emissions reductions of 92% for CH_4, 72% for N_2O, 95% for PM and between 27% and 98% for all other major pollutants. Results are reported with and without inclusion of biogenic emissions of CO_2 due to use of biomass in the pellet production process, but they do not include biogenic CO_2 intake by forests or emissions during final combustion.

Ref. No. 40: Details of LCA Study/Calculation Tool/Database/Review: Dry Matter Losses and Methane Emissions During Wood Chip Storage: the impact on full life cycle greenhouse gas savings of short rotation coppice willow for heat by C. Whittaker, W. Macalpine, N. E. Yate and I. Shield, Bioenergy Resources, 9, 2016, 820–835, DOI: 10.1007/s12155-016-9728-0.
Stated LCA Purpose, and Defined LCA Goal and Scope: The goal of the study is to evaluate the GHG emissions that arise from the use of short rotation coppice (SRC) willow chips for heating and to test the sensitivity of the overall GHG emission savings to dry matter (DM) losses during the wood chip storage phase, and the extent to which such DM losses are in the form of methane. The scope of the study includes cutting production, main crop site establishment, agronomy, harvesting, delivery to storage, outside storage, transportation and combustion. The system boundaries of the study include cuttings, diesel fuel consumption, fertiliser application and pesticide use and considered carbon sequestration under the crop due to direct land use change. The functional unit is 1 GWh delivered heat from SRC chips. (Sensitivity analysis accounts for impact of DM loss (1, 10 and 20%) and methane from storage (1, 2 and 3% of carbon))
Technological Coverage: The study covered cutting propagation of SRC, SRC cultivation, storage, transport to consumer and combustion in a specialised burner that is 90% efficient.
Technological Assumptions: SRC yields based on empirical yield model predicting yield of 9 odt/ha. The study states that approximately 3,000 ha of SRC are currently grown for bioenergy in England (2016). Assume crop harvested has 50% moisture with assumed bulk density of 240 kg/m^3. Fertiliser assumed to be met by pig slurry from a local source (10km). Wood chips are assumed to dry from 50% to 30% during storage phase. The Milne equation and Phyllis (ECN) databases are used to predict the LHV of fuel. Wood chips are combusted in specialised burner that is 90% efficient. Ash disposal is assumed to incur negligible environmental impacts.
Methodological Assumptions: Performed using MS-Excel based model and LCA performed according to ISO 14040. Direct and indirect N_2O emissions expected to be the same as arable crops (derived from experimental data), and calculated using various default emission rate data from IPCC Guidelines for National Inventories (for which the authors acknowledge that there is a high degree of uncertainty associated with these default values). Includes carbon sequestration under the crop due to direct land use change from arable land to willow, and uses Hillier et al. who deduced that following characterisation: C_{input} = 8:01 (0.5 + 0.5 (1−e$^{-0.23Yield}$)) where C input is the total carbon sequestered (t C/ha) over the lifetime of the crop with a specified average yield. Indirect land use change is not examined. Manure used as fertiliser is assumed to be a waste product therefore is not allocated upstream GHG emissions. Milne equation and Phyllis (ECN) database used to predict LHV of fuel. GWP for the refrigeration of cuttings is included, where the GWP of the refrigerant is given as 1,725 kg CO_2eq/kg (R410A). Emissions factor of 0.005 kg/GJ biomass for CH_4 and N_2O. Emission factors for diesel fuel and other fossil fuels are derived from current GHG reporting emission factors
Overview of Transparency: Moderate to high
Reviewer: Paula McNamee
Headline Results: Base case GHG Life cycle emissions of 27.3 kg CO_2eq/MWh of heat generated from SRC Willow (a saving of 95% when compared to natural gas at 516 kg CO_2eq/MWh) assuming no DM loss and excluding carbon sequestration. The inclusion of carbon sequestration, assuming 29 t CO_2 eq./ha are sequestered under the crop over the 23-year lifetime, gives net negative GHG emission of −10.0 kg CO_2eq/MWh. The authors estimate that 1, 10 and 20% losses of DM during storage cause 1, 6 and 11 % increases in GHG emissions per MWh due to the reduction in biomass mass (i.e. assuming none of the DM is lost in the form of methane). The LHV energy content of the biomass is increased by the drying process (due to the increase in LHV), but a DM loss of approximately 4% will negate this increase. Sensitivity to the loss of carbon in the form of methane is very significant; releases of 1, 2 or 3 % of the carbon within the biomass in the form of methane increase the life cycle GHG emissions by 206, 413 and 618 %, respectively. A release of approximately 9% of the carbon in the biomass in the form of methane would result in GHG emissions savings of zero (compared to natural gas generated heat). The authors conclude that DM losses in the form of methane have the potential to severely compromise GHG savings from woody supply chains. Due to the lack of research data regarding the level of such methane production, the authors recommended that further research is performed to examine the evolution of methane within wood chip stacks and to test whether this can be avoided by alternative methods of storage. Biogenic CO_2 uptake by SRC and emissions during combustion are not accounted for (other than biogenic CO_2 uptake sequestered).

Ref. No. 45: **Details of LCA Study/Calculation Tool/Database/Review:** Energy and Climate Benefits of Bioelectricity from Low-Input Short Rotation Woody Crops on Agricultural Land over a Two-Year Rotation by S. N. Djomo, O. El Kasmioui, T. De Groote, L. S. Broeckx, M. S. Verlinden, G. Berhongaray, R. Fichot, D. Zona, S. Y. Dillen, J. S. King, I. A. Janssens and R. Ceulemans, Applied Energy, 2013, 111, pp 862-870, DOI: 10.1016/j.apenergy.2013.05.017.
Stated LCA Purpose, and Defined LCA Goal and Scope: Goal of the study (not explicitly defined) is to report and document quantitative primary data, on the land requirement, energy yield and greenhouse gas (GHG) emissions associated with the production of chips from short rotation woody crops (SRWCs) on former agricultural land and to compare GHG emissions of electricity generation using such chips with EU non-renewable grid mix electricity generation. Scope of study covers field growth to end use (direct combustion and gasification followed by combustion) including embedded processing and transport emissions. Emissions from direct land use change (dLUC) were also considered, but emissions from indirect land use change (iLUC) were not. The functional unit is 1 kWh_e.
Technological Coverage: 18.4ha of conventionally managed agricultural land was converted to an 'industrial-size' SRCW plantation (of various poplar and willow genotypes), with no use of fertilizer, for the specific purpose of this study in Lochristi, Belgium. Data were collected over a 2-year period (2010-2012) covering the period from establishment (April 2010) to first harvest (2012). Soil organic carbon (SOC) was measured prior to land preparation for SRCW establishment and again just before first harvesting. GHG flux measurements (for CO_2, CH_4 and N_2O) were carried out on-site from June 2010 to December 2011 using the eddy covariance method. Primary data collection covered inputs to land preparation (including agrichemicals use), planting, weeding and harvesting. Transport to power plant, preparation and direct combustion or gasification/combustion to produce electricity and heat were modelled (based on 'two existing CHP plants'). GHG emissions associated with capital equipment were assessed. The system boundary of the reference system EU non-renewable grid mix electricity generation included the extraction, transport, refining, storage, and conversion of non-renewable fuels to electricity.
Technological Assumptions: Two existing CHP plants were modelled for electricity generation from SRWC chips, with 30% moisture content (MC) assumed: (i) a gasification plant which gasified 35.5 kton/year of chips to produce 40.2 GWh_e/year at 27.5% efficiency (ii) a combustion plant that burned 31.3 kton/year to produce 25.9 GWh_e/year at 22% efficiency. Chip drying is not mentioned in the study (though this may have been included in the process stage named 'biomass preparation').
Methodological Assumptions: Detailed management input data for all SRCW activities was inventoried (e.g. a book keeping method to measure amount of diesel and lubricant consumed to carry out each activity and data on lifespan, weight, implements and tractors used and operation time for each farming activity). It was assumed that soil carbon content of the converted agricultural land was at a constant level, so there was no carbon sequestration foregone due to dLUC. Environmental impacts were based on the Impact 2002 + method and were limited only to land requirement, energy balance and GHG emissions of the bioelectricity production. LCA modelling was performed in SimaPro 7.1. Data collected was normalised to functional unit 1 kWhe. SimaPro 7.1 results were exported to an Excel spreadsheet where energy balance and GHG emissions calculations were performed. Emissions from dLUC were considered,however emissions from iLUC were not considered. GHG emissions were allocated to heat and electricity (from CHP plant) on an exergy basis. Combustion (biogenic) CO_2 emissions were not accounted for. Emissions factors taken from the ecoinvent database.
Overview of Transparency: moderate – some good primary data, but limited details of calculations
Reviewer: Paula McNamee
Headline Results: GHG emission of electricity generation from SRWC chips (including dLUC) in a biomass-fired power station: Direct combustion: 'about 272g CO_2e/kWh_e', gasification/combustion: '~256g CO_2e/kWh_e'. dLUC contributes 89% of these emissions. These results represent reductions compared to the EU non-renewable grid mix electricity of 52% and 54% respectively. The authors note that the SRWC plantation was established on agricultural land that contained depleted SOC pools due to repeated tillage, giving a relatively low reduction in SOC compared to some other studies. They also note that annual the SOC reduction rate will decrease and then reverse over the lifetime of the plantation and that the relatively low yield obtained would be likely to increase as the plantation becomes well established. Conversion of agricultural land to an SRWC plantation resulted in a loss of SOC of 27.8 ± 9.6 t CO_2e/ ha in the top 15 cm of soil over the two-year period. The authors discuss the results of the GHG flux measurements, noting that soil N_2O emissions were higher than expected. It is however, unclear how the results of flux measurements were used in the calculation of GHG results. Biogenic CO_2 uptake by SRWC and emissions during combustion are not accounted for (other than biogenic CO_2 uptake sequestered as SOC).

Ref. No. 46: **Details of LCA Study/Calculation Tool/Database/Review:** Energy and CO_2 Balances in Different Power Generation Routes Using Wood Fuel from Short Rotation Coppice by X. Dubuisson and I. Sintzoff, Biomass and Bioenergy, 1998, 15 (4-5), pp 379-390 DOI: 10.1016/S0961-9534(98)00044-0.
Stated LCA Purpose, and Defined LCA Goal and Scope: Not explicitly documented. The goal (from objectives) of this study was to evaluate the energy performances, carbon balances and reduction of carbon emissions of generating power from short rotation coppice, taking into consideration the whole energy production system. The scope of the study covers the cultivation of SRC (from ground preparation till harvest, as well as wood fuel storage and transport) under three scenarios: low, medium and high intensification of mechanisation and inputs defined according to the standards of three typical farms in Belgium (for 25 years). The SRC was used to produce bioenergy to energy using three conversion technologies: local electricity generation by gasification, cogeneration of heat and power by gasification, and wood and coal cofiring in a classical power plant.
Technological Coverage: Three conversion technologies are considered in this study: local electricity generation by: 1) gasification (Small-scale down draft gasifier and diesel gas engine), generating peak electricity for 1,500 hours per year; 2) cogeneration of heat and power by gasification (small scale downdraft gasifier and CHP gas engine) producing base power for 4,500 hours a year; and 3) wood and coal cofiring in a classical power plant (classical pf coal plant) producing base power for 4,265 hours a year.
Technological Assumptions: For gasification (small-scale down draft gasifier and diesel gas engine): wood chips dried to 10% moisture using recycled exhaust gases. For cogeneration of heat and power by gasification (small scale downdraft gasifier and CHP gas engine): gas engine that allows burning of wood gases without any fossil fuel addition. Heat losses from the engine are recovered to produce hot water (<100˚C). The residual heat losses are used to dry wood chips till their moisture content is <20%. This system is only suitable where there is a local demand for heat. For wood and coal cofiring in a classical power plant (classical pf coal plant): wood fuel must be pre-treated in dried wood fines of 1±3 mm.
Methodological Assumptions: A classical energy analysis was applied as described by Boustead and Hancock. Energy and carbon costs of fossil fuels inputs were chosen consistent with European average supply, taking into account crude oil extraction, ocean or pipe-line transport, refining and distribution. Energy costs embodied in materials (fertilisers, buildings) and machinery were compiled from the literature only, taking into account the indirect energy costs incurred by the construction of the conversion plant. Other indirect energy costs such as water supply, limestone consumption, human transport, etc. were considered negligible. Land use change not considered
Overview of Transparency: moderate transparency
Reviewer: Paula McNamee
Headline Results: Final carbon emissions: For gasification: 7.2 +/- 0.6kg C/GJ delivered For cogeneration: 2.9 +/- 0.3kg C/GJ delivered For cofiring: 12.0 +/- 0.4kg C/GJ delivered Note that results are given in terms of C, not CO_2. Greenhouse gases other than CO_2 are not accounted for. The authors do not make clear whether the final carbon emission results given above are calculated with reference to electricity delivered or electricity+heat delivered. However, elsewhere in the paper they calculate the energy efficiency of the processes with reference to ‘useable energy output’. Results do not include uptake or emissions of biogenic CO_2.

Ref. No. 47: **Details of LCA Study/Calculation Tool/Database/Review:** Energy and Greenhouse Gas Balance of the Use of Forest Residues for Bioenergy Production in the UK by C. Whittaker, N. Mortimer, R. Murphy and R. Matthews Biomass and Bioenergy, 2011, 35(11), pp 29-45. DOI: 10.1016/j.biombioe.2011.07.001.
Stated LCA Purpose, and Defined LCA Goal and Scope: Does not state that it is an LCA. The goal of this study (not explicitly defined) is to assess the direct and indirect primary energy requirements (MJ) and GHG emissions for harvesting whole trees, roundwood and stem tips & branches for 8 different tree species growing in the UK. The scope is cradle to forest gate covering site establishment, forest road construction, harvesting and forwarding and chipping for Corsican Pine (CP), Douglas Fir (DF), Japanese Larch (JL), Lodgepole Pine (LP), Norway Spruce (NS), Scots Pine (SP) and Sitka Spruce (SS). The functional unit is MJ or kg GHG per oven dried tonne (ODT) of wood chips.
Technological Coverage: Construction of forest road (overlay road construction), harvesting of trees using bundle harvester and roadside chipping.
Technological Assumptions: It is assumed that each biomass type is stored at the roadside to allow for natural drying from 50% to about 30% moisture content. A lower heating value of 12.1 GJ/t (or 3.4 MWh/t) is assumed, based on the Milne equation, using average compositional data (ultimate and proximate analysis data) for coniferous wood available from the Phyllis (ECN) database. Roadside chipper has total working life of 3,000 hours.
Methodological Assumptions: BEATv2 is used to calculate avoided GHG emissions from displaced fossil fuels and Energy requirements and GHG emissions for forest management supplies (such as agrochemicals, etc.). Value of Global Warming Potentials of each GHG are based on the latest (at time of writing) IPCC guidelines for global warming potential for carbon dioxide (1), methane (25) and nitrous oxide (298). An MS Excel based 'Forest LCA tool' was developed. Two allocation procedures are examined: allocation by mass and by price. The energy requirements and GHG emissions for the establishment, road construction and road maintenance events are allocated between each co-product removed from the site. The economic value of saw logs, pulpwood and biomass are based on a ratio of 4:2:1. Harvesting, processing and transportation events are allocated specifically to each co-product. Site establishment and road construction events are allocated between biomass and roundwood according to the extractable yield. Material left on the site is not accounted for. It is assumed that the site is not at risk of soil erosion.
Overview of Transparency: moderate transparency
Reviewer: Paula McNamee
Headline Results: A total of 9,100 kg CO_2eq/km road built is emitted in the construction and maintenance of forest roads. GHG emissions per ODT of wood chips: Whole tree thinnings: 96.43 kg CO_2eq Roundwood: 91.07 kg CO_2eq Brash bales: 63.95 kg CO_2eq Average forest harvesting residues: 91.27 kg CO_2eq Results do not include forest uptake of biogenic CO_2.

NORTH ENERGY

Ref. No.56: Details of LCA Study/Calculation Tool/Database/Review: Environmental Impacts of Future Bioenergy Pathways: the case of electricity from wheat straw bales and pellets by J. Giuntoli, A. K. Boulamanti, S. Corrado, M. Motegh, A. Agostini and D. Baxter, Global Change Bioenergy, 5 (5),497-512 (2013) DOI: 10.1111/gcbb.12012.
Stated LCA Purpose, and Defined LCA Goal and Scope: The purpose of the LCA is to produce a full life cycle assessment of the electricity produced from the combustion of straw bales and straw pellets and aims to fill gaps in the literature on the environmental impacts of straw pellet combustion, the emissions and end use. The goal is to assess the life cycle impacts of wheat straw bales and pellets combusted in a 50MW straw-fired power plant (to produce electricity) and determine the greenhouse gas savings against existing coal plants and the EU grid average with an aim of filling the gaps in the literature on the environmental impacts of straw pellet combustion, the emissions and end use. The scope includes the cultivation data for wheat grains and straw in five different European countries, the production of straw pellets (for pellets chain only), and their utilisation in a medium scale electricity plant (50MW) (cradle to grave). The functional unit is 1 MJ electricity. Environmental impact categories include: global warming, eutrophication, acidification, particulate matter and photochemical oxidants. Results are compared with coal generation and EU electricity grid average.
Technological Coverage: Cultivation of winter wheat in Germany, UK Spain, Poland and the Netherlands. The production of pellets (drying, size reduction, pelleting, cooling, and screening). Combustion in an industrial furnace (50MWth input).
Technological Assumptions: Cultivation of wheat and grain modelled using average and specific data to wheat cultivation. The straw used for energy in this study is part of the surplus fraction (after straw left on field to restore nutrients, maintain soil carbon, and protect soil for erosion) and therefore does not affect other markets or soil productivity. Effect of straw removal from field on P and K concentrations was considered irrelevant. Losses considered during storage (3%) and pellet mill (1%). Truck transport of bales to pellet mill assumed to be diesel Euro 4 type flatbed truck. Assumed no drying of feedstock is required before pelleting. Industrial furnace capacity is taken as 50MWth input (requiring 100kt of straw annually) with efficiency of 29%. Electrical power taken from grid. Combustion emissions data taken from Danish emissions inventory for a 25MWe CHP plant (assumed to be comparable with the plant in this study).
Methodological Assumptions: Performed according to ISO14040 and 14044 standards and using Gabi5 software. Data (for inventory) taken from literature, emissions inventories, and state of the art technologies for straw conversion relevant to Europe and supplemented, where required, with data from sources such as ecoinvent 2.2 and Gabi Professional. Machinery and infrastructure emissions systematically ignored. Does not consider any emissions due to direct or indirect land-use change (but does consider the additional nitrogen that must be applied for the removal of straw from the field). In this study, the allocation of emissions to wheat and grain cannot be decoupled by system expansion, therefore dataset used economic allocation. (The price of straw was assigned based on the cost of straw baling and on the amount of mineral fertilizer which could be substituted with the straw in the case where straw was left on the field). Several sensitivity analyses are performed changing e.g. efficiency of plant, drying of straw before pelleting.
Overview of Transparency: moderate
Reviewer: Paula McNamee
Headline Results: GHG emissions: Straw bales: 16-26g CO_2eq/MJ_e Straw pellets: 26-36g CO_2eq/MJ_e. Results do not include uptake or emissions of biogenic CO_2.

Ref. No. 57: **Details of LCA Study/Calculation Tool/Database/Review:** Environmental Life Cycle Assessment of Bioethanol Production from Wheat Straw by A. Li Borrion, M. C. McManus and G. P. Hammond, Biomass and Bioenergy, 2012, 47, pp 9-19, DOI: 10.1016/j.biombioe.2012.10.017.
Stated LCA Purpose, and Defined LCA Goal and Scope: The goal of the study is to quantify the environmental impacts of the bioethanol from wheat straw conversion processes and compare ethanol blend fuels with conventional petrol. The scope of the study includes the life cycle of ethanol use from a well to wheel perspective, including wheat straw production, ethanol conversion and transport to a blending refinery, ethanol blending with petrol and storage and, burning of fuel in a small passenger car. The study considers blends of 15% (by volume) ethanol with petrol (E15) and 85% with petrol (E85) used in a small passenger car and results are compared with 100% fossil petrol driven car. The impact categories analysed include global warming, ozone depletion, photochemical oxidant formation, acidification, freshwater eutrophication, marine eutrophication, terrestrial ecotoxicity, freshwater ecotoxicity, marine ecotoxicity, water depletion, and fossil depletion. The functional unit is the amount of fuel required to drive 1 km distance by a small passenger car (well-to-wheel). A second functional unit, 1kg of ethanol produced from wheat straw, is also used in this study to further assess the contribution of environmental burdens from the ethanol conversion process (well-to-gate).
Technological Coverage: Technological coverage includes the ethanol conversion process which includes washing and shredding, pre-hydrolysis and conditioning (sulphuric acid and steam), hydrolysis and co-fermentation (with cellulase), ethanol recovery (distillation and dehydration), waste water treatment. Chemical and enzyme production is also covered. The fuel distribution stage includes ethanol (and petrol) storage and blending and final fuel is in a small passenger car.
Technological Assumptions: The wheat straw is considered generic straw from the European region. The conversion of the wheat straw to ethanol is based on the laboratory data on wheat straw from the research programme and the National Renewable Energy Laboratory (NREL) large scale simulation process. The process is assumed to have 8,406 hours of operation time, which is equal to an annual production scale of 757,152 tons of wheat straw on a dry basis. Material flows and energy flows are collected from the report; equipment information and chemicals are collected through manufacture websites, estimation and life cycle inventory databases, predominantly ecoinvent. Bioethanol is used to fuel passenger cars at a specific consumption of 2.45 MJ/km. The study does not include any specific differences regarding vehicular emissions at different blend rates.
Methodological Assumptions: The software package SimaPro (version 7.2) is used to build the inventory and undertake the impact assessment analysis. Ecoinvent database is primarily used in this study. In the case of different data available in different databases, preference is given to ecoinvent library. The life cycle impact assessment was conducted using ReCiPe Midpoint methodology. Only classification and characterization are applied; weighting and normalisation are not considered in this study paper. Allocation was by mass.
Overview of Transparency: moderate
Reviewer: Paula McNamee
Headline Results: GWPs: E15 = 287.13g CO_2eq/km driven E85 = 88.10g CO_2eq/km driven Petrol (comparator) = 330.09g CO_2eq/km driven Results do not include uptake or emissions of biogenic CO_2.

Ref. No. 59: **Details of LCA Study/Calculation Tool/Database/Review:** Environmental Sustainability of Bioethanol Production from Wheat Straw in the UK by L. Wang, J. Littlewood and R. J. Murphy, Renewable and Sustainable Energy Reviews, 2013, 28, pp 715-725, DOI: 10.1016/j.rser.2013.08.031.
Stated LCA Purpose, and Defined LCA Goal and Scope: The goal of the study (not explicitly stated) was to evaluate the environmental impact of wheat straw ethanol using varying pre-treatment technologies and compared with the environmental impact of petrol. The scope of the study was well to wheel: from wheat cultivation, harvesting and straw collection through to bioethanol production from straw and end use in a flexible fuel vehicle (FFV). The functional unit is 1km driven in a flexible fuel vehicle (FFV). The results are compared with a petrol life-cycle which includes the petrol production, distribution and its end use. The environmental impacts covered are global warming potential (100-year horizon), abiotic resource depletion, acidic potential, eutrophication, ozone layer depletion, photochemical-oxidants, ecotoxicity.
Technological Coverage: Feedstock is wheat straw from UK grown wheat. Wheat straw is subject to 1 of 5 pre-treatment steps: 1) steam explosion without catalyst, 2) steam explosion with acid catalyst, 3) dilute acid, 4) liquid hot water, and 5) wet oxidation before saccharification and fermentation to ethanol. The solid fraction of distillation is used to generate power, the steam of which is recycled to a waste water treatment that processes the liquid fraction (not ethanol) of distillation. The ethanol is used in FFV at a blend of 100% (E100).
Technological Assumptions: Estimated annual wheat straw yield of between 8-10 million tonnes in the UK. The process design configuration was developed based on the NREL corn stover-to-bioethanol model. The plant is designed to process 2,000 dry metric tonnes of wheat straw per day.
Methodological Assumptions: Inventory data for enzyme production were collected via questionnaires. Mass and energy balance data bioethanol production process were obtained from computer models (AspenPlus™) using data derived from literature reviews as the model inputs. The process design configuration was developed based on the NREL corn stover-to-bioethanol model. Inventories for other input production such as wheat straw, petrol, chemicals, fertilisers and energy and for infrastructure was from ecoinvent database v2.2. Inventories for output such as emission factors for agricultural field emission, fuel combustion in road transport and field operation were derived from the IPCC approach set out in IPCC Guidelines for national greenhouse gas inventories and 2009 EMEP-EEA Guidebook. The authors give no further details regarding the IPCC guidelines adopted. The inventory data for low sulphur petrol production and combustion were adopted from ecoinvent v2.2 research reports. In the baseline scenario, environmental burdens associated with wheat cultivation were allocated between wheat grain and wheat straw based on their economic values while burdens associated with additional fertiliser use and soil carbon change were assigned to wheat straw only in the sensitivity analysis scenario. In addition, 'system expansion' was applied on surplus electricity which is credited with avoided emissions from generation of an equivalent amount of the average UK National Grid electricity.
Overview of Transparency: moderate
Reviewer: Paula McNamee
Headline Results: GWP_{100} kg CO_2eq/FU (where FU = 1km driven in a FFV) for each pre-treatment process: Steam Explosion without catalyst = 0.134 Steam Explosion with Acid Catalyst = 0.212 Dilute Acid = 0.264 Liquid Hot Water = 0.156 Wet Oxidation = 0.166 The GWP emissions comparator for petrol is not stated in figures, though can be estimated from Figure 5 in the study as approximately 90% of the figure for Dilute Acid giving ~ 0.238 Results do not include uptake or emissions of biogenic CO_2.

Ref. No. 66: Details of LCA Study/Calculation Tool/Database/Review: GHG Emissions Performance of Various Liquid Transportation Biofuels in Finland in Accordance with the EU Sustainability Criteria by K. Koponen, S. Soimakallio, E. Tsupari, R. Thun and R. Antikainen, Applied Energy, Vol. 102, pp. 440 - 448, 2013, DOI: 10.1016/j.apenergy.2012.07.023.
Stated LCA Purpose, and Defined LCA Goal and Scope: The aim was "to determine whether it is possible to conclude that a biofuel chain passes (or does not pass) the Renewable Energy Directive (RED) greenhouse gas (GHG) emission-saving limit when the uncertainties and sensitivities related to the calculation parameters are taken into account". No further definition of LCA goal or scope.
Technological Coverage: A review of LCA methodology with examples including ethanol production using enzymatic hydrolysis and fermentation of straw, ethanol production from barley and reed canary grass, and Fischer-Tropsch diesel production from forest residues and stumps.
Technological Assumptions: Production of biofuels for sale in the European Union.
Methodological Assumptions: The thesis examines the validity of using the European Union Renewable Energy Directive (EU RED) methodology to determine the GHG impact of biofuels. For compliance with the RED, total emissions from biofuels are the sum of emissions from the extraction or cultivation of raw materials; annualised emissions from carbon stock changes caused by direct land-use change; emissions from biofuel processing; emissions from transportation and distribution; emission savings from soil carbon accumulation via improved agricultural management; emission savings from carbon capture and storage or replacement; and emission savings from excess electricity from cogeneration. Emissions from manufacturing and maintenance of machinery and equipment are excluded. The fixation of carbon dioxide during the growth of the biomass is considered to be equal to the carbon dioxide released on combustion. The total emissions are compared to the total life cycle emissions of a fossil fuel comparator, given by the RED as 83.8g CO_2eq/MJ for transportation fuels (gasoline and diesel). The average emission intensity of electricity for the relevant region should be used to determine the impact of the electricity used in the production of the biofuel. Allocation of emissions between the products, co and by-products is in proportion to their energy content (Lower Heating Value) except for electricity where system expansion is used. The functional unit is one MJ of fuel (end product), and the greenhouse gas emissions are expressed as g CO_2eq/MJ
Overview of Transparency: Moderate to good transparency: important assumptions and calculations are explained and supplementary information is available.
Reviewer: Anna Evans
Headline Results: The author concludes that the results of the study show that the current RED GHG assessment method cannot alone guarantee the climate change mitigation benefits due to biofuel use. Literature reviews showed up methodological differences and considerable variation in results compared to the RED. It is considered using the RED methodology may result in an over-estimate of the GHG savings. Major sources of uncertainties and sensitivities are nitrous oxide emissions from soil and nitrogen fertiliser, emissions from process heat production and soil carbon stock changes in biomass production (RED methodology does not include uptake, sequestration or emissions of biogenic CO_2).

Ref. No. 69: Details of LCA Study/Calculation Tool/Database/Review: Greenhouse Gas and Energy Based Life Cycle Analysis of Products from the Irish Wood Processing Industry by F. Murphy, G. Devlin and K. McDonnell, Journal of Cleaner Production Vol 92, pp. 134 - 141, 1 April 2015, DOI: 10.1016/j.jclepro.2015.01.001.
Stated LCA Purpose, and Defined LCA Goal and Scope: This research endeavours to expand existing knowledge of the environmental impacts of biomass supply chains in Ireland by widening the analysis to incorporate the wood processing supply stage. The study determines and analyses energy and material inputs in the production of several timber products; sawnwood, wood based panel boards (WBP), wood chip and wood pellets, with an analysis of the resulting greenhouse gas emissions. The study represents a 'cradle-to-gate' life cycle assessment (LCA) and the system boundary includes all processes from raw material production to the finished product at the factory gate.
Technological Coverage: Irish forestry producing roundwood, sawdust, wood chip and bark and wood pellets for combustion in combined heat and power plant. Processes include forest operations, sawmill operations, pellet production, and medium density fibre board (MDF) and oriented strand board (OSB) manufacturing.
Technological Assumptions: Production in Ireland
Methodological Assumptions: The system boundary includes all processes from raw material production to the finished product at the factory gate. The analysis does not consider the embodied carbon in any of the wood products produced. The functional unit for wood chip and wood pellet production is '1 oven-dried tonne (odt) of product at the factory gate'. However, to allow comparison with other energy sources, results are also expressed per gigajoule (GJ) of energy contained in the biomass. The data inventory compiled for this LCA study consists mainly of data specific to Irish conditions and includes primary data. Simapro7.3 and ecoinvent 2007 are used for the modelling and calculations. Allocation between products is by mass. Direct and indirect emissions are included. Neither embedded carbon or forest carbon stock changes are considered.
Overview of Transparency: Moderate transparency as details of the calculations are not given but are modelled in SimaPro.
Reviewer: Anna Evans
Headline Results: Forest operations and timber transportation make an important contribution to overall emissions in sawnwood and wood chip production chains. Electricity usage from the national grid is the major cause of GHG emissions in wood processing, including sawnwood, wood chip, wood pellet and OSB production. GHG emissions can be considerably reduced in sawmilling and wood pellet production by the integration of CHP plants with sawmills and pellet plants. Synthetic resin utilisation in wood based panel board manufacture has a considerable GHG emissions impact, accounting for a large proportion of emissions in both MDF and OSB manufacture. Wood energy products compare favourably with other sources of biomass and with fossil fuels. The study does not include consideration of uptake or emissions of biogenic CO_2.

Ref. No. 74: Details of LCA Study/Calculation Tool/Database/Review: How Certain are Greenhouse Gas Reductions from Bioenergy? - life cycle assessment and uncertainty analysis of wood pellet-to-electricity supply chains from forest residues by M. Rőder, C. Whittaker and P. Thornley, Biomass and Bioenergy (2015) Volume 79, 50-63, DOI: 10.1016/j.biombioe.2015.03.030.
Stated LCA Purpose, and Defined LCA Goal and Scope: The LCA purpose was to examine the significance of key sources of GHG uncertainty in the wood pellet supply chain from forest residues and saw mills. The LCA goal was to investigate emissions uncertainties of selected forest residue supply chains (forest residues and sawmill residues) to evaluate possible impacts and identify supply chain steps that require close attention to ensure real GHG reductions and to compare results with coal-fired electricity generation. The LCA scope covers the supply chain of existing pathways for large-scale electricity production in the UK from biomass (Cradle to grave). For forest residues scenarios, the system boundary covers forest production, harvest, pelleting, international transport to conversion to electricity. For sawmill residues, the system boundary includes forest production, harvest, pelleting, international transport and conversion to electricity. The functional unit was 1kWh of electricity generated in the UK. Impact assessment covered the evaluation of GHG emissions from electricity generation in CO_2 equivalents accounting for CO_2, N_2O and CH_4 with a 100-year time horizon.
Technological Coverage: Forest is made of mixed loblolly pine (Pinus taeda) and shortleaf pine (Pinus echinate) which makes up 25% of the forest area and 59% of the net volume of growing stock in the south-east USA. (established by land preparation, planting as seedlings, growing period of 45 years yield class 9 and harvested by clear cut. Forest residues are left to dry outside for 12 weeks followed by chipping, pelleting in a pellet mill using a common pelleting procedure and (following transport) combustion in a large-scale 670MW dedicated biomass boiler to generate electricity in the UK. Sawmill residues are derived from logs, pelleted in mill and (following transport) combusted in a large-scale 670MW dedicated biomass boiler to generate electricity in the UK.
Technological Assumptions: During natural (outdoor) drying lasting 10-12 weeks, the moisture content of residues drops from 50 to 30%. Drying during pelleting used biomass (base case). Assume CV of wood pellets with 10% MC is 16.5 MJ/kg. Estimated that 0.537kg of wood pellets required to produce 1kWh of electricity. Combustion takes place in dedicated 670MW biomass boiler with a load factor of 80% and an efficiency of 40%.
Methodological Assumptions: LCA conducted in accordance with ISO 14040:2006 and 14044:2006. Carbon stocks, carbon debt and payback did not significantly impact the parameters explored in this study and so variants were neglected in the analysis. MS Excel was used to build LCA model- combined with SimaPro 8.0.1 using the ecoinvent database (2009) and the CML 2001 baseline method (Version 2.04) for mid-point assessment. Emissions for the conversion process for generating electricity was calculated using BEAT2. Supply chain data taken from large-scale electricity generation industrial stakeholders. Emissions factors taken from Defra, ecoinvent, VTT and Edwards. Direct emissions from soil were calculated according to ecoinvent and IPCC guidelines for national greenhouse gas inventories, considering nitrous oxide emissions as intermediate product from denitrification through soil microorganisms, as well as indirect N2O emissions from leakage and volatilisation. Production of residues was within system boundaries (i.e. not considered a waste which may not be assigned GHG emissions) with price allocation chosen as an appropriate method. Price and allocation was provided by AEBIOM. All transport emissions included an empty return journey. Nitrous oxide emissions from storage not considered as likely to be negligible. CH_4 release during feedstock storage (considered as lost C in the supply chain) and sawmill storage.
Overview of Transparency: moderate
Reviewer: Paula McNamee
Headline Results: Base Case GHG emissions for generating electricity: 132 g/kWh from forest residues pellets 140 g/kWh from sawmill residue pellets Transport contributes most to life-cycle emissions (39% for forest; 31% for sawmill) followed by processing activities (31% and 29% respectively). Uptake and emissions of biogenic CO_2 are not included in the results.

Ref. No. 80: Details of LCA Study/Calculation Tool/Database/Review: Including UK and International Forestry in Biomass Environmental Assessment Tool (BEAT2) by J. Bates, R. Matthews and N. Mortimer, Environment Agency, Report-SCR090022/R1, Bristol, United Kingdom, July 2011, DOI: not available.
Stated LCA Purpose, and Defined LCA Goal and Scope: The stated purpose of the study is to (a) identify a representative range of forest types and management profiles for inclusion in Biomass Environmental Assessment Tool ($BEAT_2$); (b) develop a method for estimating the changes in forest carbon and GHG emissions from forestry options; (c) incorporate these data into a set of three MS Excel workbooks representing the combustion of forestry products to produce electricity and modify ($BEAT_2$) to include these options; and (d) generate illustrative results for forestry profiles to allow the effect of different management regimes and other factors on GHG emissions to be assessed.
Technological Coverage: Wood from United Kingdom, Fennoscandia and Baltic States sustainably-managed broadleaf and conifer forests; boreal Eurasia and North America conifer forests; United Kingdom neglected forests with thinning and no felling, and clear felling; and old growth boreal Eurasia and North America forest with clear felling used for electricity generation by combustion of roundwood, wood chips and wood pellets in a dedicated biomass plant.
Technological Assumptions: UK electricity generation based on combustion in dedicated biomass power plants.
Methodological Assumptions: An attributional LCA methodology which uses prices to allocate net carbon stock changes in forests and GHG emissions associated with forest management and harvesting between different wood products. The change in forest carbon associated with each profile is modelled using Forest Research's CSORT model. CSORT is a forest carbon accounting tool which models changes in the carbon in trees, litter and soil on the basis of tree species composition, growth rate and management regime. CSORT is also used to provide estimates of fuels and materials used during operations to establish and regenerate the forest and harvest and to extract products from the forests. Direct and indirect emissions of carbon dioxide, methane and nitrous oxide are included as well as GHG emissions associated with plant construction, machinery manufacture and maintenance. Allocation is on the basis of price.
Overview of Transparency: High. The report, if read alone, is of moderate transparency as it only provides very brief details of the LCA method. However, when considered together with the user manual and Excel workbooks the transparency is high as all the details of the calculations are given.
Reviewer: Anna Evans
Headline Results: Illustrative results include '83 CO_2eq/MWh_e', (assumed to mean 83kg) for wood pellets from roundwood. The main results are presented in the form of percentage savings relative to average EU emissions for electricity of 713 kg CO_2eq/MWh. Electricity produced from wood chips and roundwood (timber) from sustainably managed forests in the UK and abroad, and from UK neglected forests regenerated through thinning but no felling, offers substantive savings (60 to over 100 per cent). If electricity is produced from pellets from sustainably managed forests in the UK and abroad, and from UK neglected forests regenerated through thinning but no felling, then savings are considerably reduced (38–88 per cent). These savings are based on using fossil fuel to dry the wood prior to pelletisation and would be higher if wood fuel is used to dry the wood. Emissions from forests where wood is extracted by clear felling (old growth forests in Boreal Eurasia and Boreal North America, and UK neglected forests regenerated by clear felling) have very high emissions and offer no savings when evaluated over the short term (20-year time horizon). However, by 100 years, when the forests have regenerated, savings are just over 60 per cent. Results include biogenic carbon stock change in forests.

Ref. No. 95: Details of LCA Study/Calculation Tool/Database/Review: Life Cycle Assessment of Biomass-Based Combined Heat and Power Plants by Geoffrey Guest, Ryan M. Bright, Francesco Cherubini, Ottar Michelsen and Anders Hammer Strømman, Journal of Industrial Ecology, 15(6), December 2011, **DOI**: 10.1111/j.1530-9290.2011.00375.x.
Stated LCA Purpose, and Defined LCA Goal and Scope: **Purpose**: Policy makers and sustainability-reducing GHG emissions, doubling Norway's use of renewable energy by 2020. **Goal**: attributional LCA to assess the environmental impacts of 3 CHP sizes through gasification of forest residues. **Scope:** environmental impacts of a hypothetical case of one micro, one small, and one medium scale CHP plant fueled by forest residues in the mid-Norway region.
Technological Coverage: Biomass feedstock: 1) residues from thinning and harvesting from Scandinavian soft wood forestry, and 2) sawmill residues (chips, sawdust) from local sawmills. Harvesting, logging, bundling, chipping, sawmill operations Conversion: CHP - electricity and district heating.
Technological Assumptions: A comparison of micro (≥1MW), small (1-20 MW), and medium (20-100 MW) CHP units. The study focuses on a regional perspective situated in Middle-Norway's Nord- and Sør-Trøndelag counties.
Methodological Assumptions: Two functional units are used: 1 (MJ) of electricity and 1 MJ of district heating, delivered to the end user. Distances for transporting wood residues from the forest was assumed as 115, 39, 29 km. The average distance for transporting sawmill residues was calculated to be 110 kilometres. For the micro and small-scale CHP systems, down-draft gasification was chosen, and for the medium scale, integrated gasification combined cycle technology was assumed. Exergy allocation between electricity and heat was considered. The exergy-based fraction of environmental impacts attributed to electricity, E_{el}, for the medium, small, and micro scale was calculated to be 0.78, 0.72, and 0.69, respectively. The environmental impacts from the manufacturing and construction of the energy distribution network (i.e. district heating network and electricity grid infrastructure) and those indirectly attributed to the energy distribution due to operational energy losses on the rest of the system upstream are accounted for. Impacts categories: GWP, Ozone, acidification, Eutrophication, human, water and marine toxicity potential are calculated. The midpoint CML 2 Baseline 2000 impact assessment method (CML 2001) is used to assess the impacts. All operational emissions data for the three CHPs are taken from the GEMIS 4.5 database. ecoinvent v2 (2010) database is used for the majority of the foreground processes. All processes considered to be occurring locally (within Norway) have been modified under the assumption that Norwegian-produced electricity and fossil oil are used as inputs. The process is considered as carbon neutral; stock changes due to land-use change (LUC) or indirect land-use change (iLUC) are not considered in the study.
Overview of Transparency: Low as no values are given for GWP contributors and all impacts are aggregated.
Reviewer: Maha Elsayed
Headline Results: GWP range for the CHP systems: 2.4 to 2.8 g CO_2eq/MJ of thermal district heating and 8.8 to 10.5 g CO_2eq/MJ of electricity to the end user. Uptake and emissions of biogenic CO_2 are included in the results.

Ref. No. 103: Details of LCA Study/Calculation Tool/Database/Review: Life Cycle Assessment of Norwegian Bioenergy Heat and Power Systems by Anne-Marit Melbye, Norwegian University of Science and Technology, Department of Energy and Process Engineering, Masters Thesis, 2012, DOI: not available.
Stated LCA Purpose, and Defined LCA Goal and Scope: The aim is to assess and compare the environmental impacts of six bioenergy value chains in Norway. The study is intended for policy makers and development to reduce GHG emissions as Norway intends to double its use of bioenergy for heat and power by 2020. Life cycle inventories are constructed for a set of six feedstocks, seven treatment options, ten energy conversion options and three energy distribution choices. 2 scenarios are considered: present Norwegian bioenergy technologies & future technologies (2020).
Technological Coverage: Feedstock: Norway Spruce and Pine (stemwood, energy wood, forest residues), sawmill residues, paper and cardboard (P&C) waste, wood waste chips, pellets (imported from Canada) and torrefied pellets. Harvest operations: transport and energy distribution are considered. Pre-treatment options assessed: chipping, pelletising, integrated torrefaction and pelletising. Conversion options assessed: CHP, district heating, thermal power generation and steam production.
Technological Assumptions: 50MW plant for all conversion options, assumed to refer to input power.
Methodological Assumptions: The functional unit is 1 kWh electricity or heat delivered. Energy allocation is applied for CHP output and mass allocation is applied for stemwood and forest residue harvest. Economic allocation is applied between saw residues and sawn timber. Both biogenic CO_2 emissions from the biomass systems and GHG emissions from biomass storage and decay are included, with methane emissions assumed to arise from wood chip storage (but not from pellet storage). Forest carbon stock changes are accounted for. Surface albedo effects are considered for stemwood and forest residues. Impact Assessment: GWP, terrestrial acidification potential (AP), particulate matter formation potential (PMFP) and freshwater ecotoxicity potential (ETP) were all investigated. A 100-year period for climate change and terrestrial acidification is considered. The rotation periods used are: 100 years for final stemwood and forest residues harvest and 20 years for thinning wood. To calculate the cumulative climate impact from a biomass based combustion system, global warming potential indexes are used, GWP_{bio}. Matlab is used to perform foreground and LCA calculations and the ecoinvent database is used for modelling. The harvesting inventories for energy wood harvest are based on the ecoinvent processes. Also, infrastructure for drying, pelleting and torrefaction processes is included using ecoinvent modelling. Other infrastructure considered includes construction and maintenance of the electricity distribution network.
Overview of Transparency: Moderate. No access to GHG calculations. Only some calculations are shown. Conversion processes are discussed in detail.
Reviewer: Maha Elsayed
Headline Results: 2 graphs show GWP [g CO_2eq/kWh], including biogenic CO_2 emissions and forest carbon stock changes, for the different energy technologies and combusted materials (with or with no surface albedo effects). Results are given for pellets (and torrefied pellets, referred to as 'TOP') made from wood waste, energy wood, forest residues and saw residues. The presentation of the results is confusing, with overlapping circles on the graphs and the discussion of results giving ranges rather than precise figures for each option. The GWP for all systems ranges from 50 -514g CO_2eq/kwh (with no surface albedo effects). The thermal power plant has a GWP from 111-514g CO_2eq/kWh, The district heating plant has GWP ranging from 54-240g CO_2eq/kWh. The CHP plant shows a GWP between 52-231g CO_2eq/kWh for heat and The steam producing boiler and CHP plant with electricity demand GWP: 50-230g CO_2eq/kWh and 50-229 g CO_2eq/kWh respectively.

Ref. No. 106: Details of LCA Study/Calculation Tool/Database/Review: Life Cycle Assessment of Wood Pellet. MSC Thesis - Environmental Measurements and Assessment by Siyu Chen, Chalmers University of Technology, Göteborg, Sweden, 2009, DOI: not available.
Stated LCA Purpose, and Defined LCA Goal and Scope: To investigate the environmental impacts of producing wood pellets, and the contribution of wood pellets to global warming. The results of the study will be used to help communicate with future customers for better environmental management. **Goal**: To assess the environmental impacts of producing wood pellets and investigate the contribution to these environmental impacts of the different process stages. **Scope**: wood production, sawmill operation, pellet production, combustion, waste disposal. **Impacts:** global warming, acidification, eutrophication, toxicity and resources depletion (fossil fuels, minerals).
Technological Coverage. Feedstock: roundwood - sawdust of Norway spruce and/or Scots pine. Processes included: silviculture, sawmill operation, pellet production (drying, grinding, pelleting, cooling, screening, storing, packaging). Final conversion system: combustion, combined heat and power (CHP).
Technological Assumptions: A Neova pellet plant located in Vaggeryd is taken as a reference plant. Annual production of wood pellets from the plant is 90,000 tons (the author uses 'ton', though it may be reasonable to assume that this refers to a metric tonne, since the study concerns Europe and metric units are used for other parameters) using 585,000 m^3 sawdust as raw material. Pellet combustion boilers: Large-scale heat plants/CHP plants, with thermal output ≥ 2MW, Medium scale: thermal output 50 kW - 2 MW.
Methodological Assumptions: Functional unit: 1GJ energy of wood pellets. System Boundary: Cradle to grave – wood production to ash disposal. Allocation is done by economic values of sawmill products: timber, pulpwood, sawmill, bark and wood chips. Allocation between heat and electricity in a CHP is treated equally, which means the environmental load caused by producing 1 kWh of heat is equal to 1 kWh produced electrical power. No inclusion of GHG associated with plant construction and machinery and no changes in biogenic carbon stocks are evaluated. Data for silviculture processes in Sweden is collected from the CPM LCA database (run by Chalmers University). GEMIS 4.5 is used to simulate the combustion of wood pellets in household stoves. Data for the pellet plant production process and up- and downstream processes is from Neova. Secondary sources of data are used such as literature data, journal papers, published LCA reports, LCA databases etc. *Assumptions*: only fresh sawdust is used to produce pellets. Bark is used for drying in the pellet plant. Energy content of wood pellets: 17.3 MJ/kg. Transportation distances: 80 km to sawmill, 100 km to pellet plant. Environmental impacts evaluated: Global warming: CO_2; CH_4; N_2O. Acidification: SO_2, NO_x. Eutrophication: NO_x. Photo-oxidant formation: CO, NO_2, SO_2, CH_4. Resources depletion: Oil, Natural gas, Hard coal, Fossil energy, Iron, Copper, Lead, Bauxite, Uranium. Global warming potential values taken were from IPCC 2003, being 1 for CO_2, 23 for CH_4 and 296 for N_2O for a 100 year time horizon.
Overview of Transparency: moderate
Reviewer: Maha Elsayed
Headlines Results: Results for energy use by the process stages are presented in bar chart form, resolved to electricity, fossil fuel and renewable fuel (Figure 4.4), with pellet production identified in the text as the process stage with the greatest specific energy use (172 MJ/GJ wood pellets). GWP (total and for individual process stages) is shown in one of the small bar charts in Figure 5.1. From the chart total GWP is approximately 14, though no mention is made of the units. Table 4.12 presents 'Environmental load over the entire life cycle of wood pellet', with the text indicating that the figures given in the table are per functional unit. The figures for energy use are: Fossil fuel: 251 MJ, electricity: 22.5 kWh and biofuel: 176MJ. The figures for GWP are: CO_2: 13,936g, N_2O: 1.3g and CH_4: 3.4g. Uptake and emissions of biogenic CO_2 are not considered.

Ref. No. 108: Details of LCA Study/Calculation Tool/Database/Review: Life Cycle Emissions and Cost of Producing Electricity from Coal, Natural Gas, and Wood Pellets in Ontario, Canada by Y. Zhang, J. McKechnie, D. Cormier, R. Lyng, W. Mabee, A. Ogino and H. L. MacLean, Environmental Science & Technology, 2010, 44 (1), pp 538–544, DOI: 10.1021/es902555a.
Stated LCA Purpose, and Defined LCA Goal and Scope: **Purpose**: Policy making and sustainability for GHGs mitigation to reduce global greenhouse gas (GHG) emissions. **Goal**: life cycle (LC) GHG emissions and costs of 100% wood pellet firing and cofiring with coal in two coal-fired generating stations (GS) in Ontario, Canada for electricity generation. **Scope:** System boundary: Harvesting, forest renewal, forest road construction, transportation to pellet facility, pellet production, pellet cofiring and 100% pellet firing for electricity production.
Technological Coverage: Biofibre for pellet production is supplied by forest management units (Roundwood and hardwood) in the Great Lakes St. Lawrence (GLSL) forest region of Ontario. The pellet production activities include biofibre harvesting, forest renewal, forest road construction, biofibre transportation to a pellet facility, pelletisation, and pellet delivery to Nanticoke and Atikokan generating stations.
Technological Assumptions: Data on electricity and biofibre consumption during pelletisation were provided by a northeastern U.S. pellet producer with pellet capacity of 12 ODT/hr. Pellets fired at 10%, 20% and 100% rates in 2 electricity coal generating stations: - Nanticoke located on Lake Erie, has eight 490MWe (net) wall-fired natural circulation pulverized coal boilers. Capacity of 250 MWe when operating with pellets only. - Atikokan in north-western Ontario, has one 215 MWe (net) boiler.
Methodological Assumptions: The functional unit is 1 kWh of electricity produced. Biomass combustion is assumed to be carbon-neutral and no change in biogenic carbon stock is considered. Material and energy inputs needed for equipment manufacture, facility construction, and labour are not included in the study. The forest stands are assumed to provide biofibre for both pellets (35%) and traditional products. Therefore only 35% of the total inputs required for forest operations are allocated to pellets. The investigation includes GHG and criteria air pollutant emissions (NO_X, SO_X) which are compared with current coal and natural gas combined cycle (NGCC) facilities. The data obtained from the pellet producer were utilised, with two modifications [to drying energy use and the use of the Ontario grid for grid-based electricity]. For Nanticoke and Atikokan at 20% cofiring rates, efficiencies are 34.7% and 32.7%, respectively. Atikokan's capacity, when operating with pellets, is expected to be close to that when operating with coal. The heat rate degradation at Atikokan is estimated to be 5% for 100% pellet operation compared to coal-only, resulting in an efficiency of 31.4%. The capacity of Nanticoke's unit when operating with pellets is anticipated to be 50% of its capacity when operating with coal, resulting in an efficiency of 31.8%. No measurements have been made of CH_4 and N_2O emissions for 100% pellet firing at the GS, so data from references are used to estimate these emissions. Test data for 100% pellet firing at Atikokan are utilized for estimating SO_X and NO_X emissions for both plants. Life cycle cost models are developed to estimate the cost of electricity generated from coal, pellet, and NGCC system's capital cost (including financing), fixed operating and maintenance (O/M), non-fuel variable operation, maintenance and fuel costs are considered.
Overview of Transparency: low - no detailed calculations are shown.
Reviewer: Maha Elsayed
Headline Results: GHG emissions (non-biogenic) for the two GSs, in g CO_2eq/kWh (including emissions from the coal combustion and non-biogenic emissions associated with biomass production), are given in bar chart form in Figure 1 in the study. Approximate readings off the bar chart give: Nantikoke: 1,000 (all coal), 900 (10% co-firing rate), 840 (20% co-firing), 100 (100% biomass). Atikokan: 1,200 (all coal), 1,090 (10% co-firing rate), 1,000 (20% co-firing), 100 (100% biomass). The accuracy of the results given above for 100% biomass firing is low, due to the scale of the bar chart. Text in the study states: "Reductions at Nanticoke and Atikokan are 91% and 92%, respectively, compared to the reference coal pathways" – which would result in 100% biomass results of approximately 90 and 96 g CO_2eq/kWh for Nantikoke and Atikokan respectively. Uptake and emissions of biogenic CO_2 are not included in these headline results.

Ref. No. 120: Details of LCA Study/Calculation Tool/Database/Review: Life-Cycle Impacts of Forest Resource Activities in the Pacific Northwest and Southeast United States by L. R. Johnson, B. Lippke, J. D. Marshall and J. Comnick, Wood and Fibre Science, 2005, 37, pp 30-46, DOI: not available.
Stated LCA Purpose, and Defined LCA Goal and Scope: The goal of the study is to conduct a broad life-cycle analysis into forest resource activities conducted in South-eastern US and the Pacific Northwest (PNW) to determine emissions associated with wood production. The scope of the study is the establishment and maintenance of forest (thinning and fertilisation) through to the harvest of merchantable logs from the stand for three forest management scenarios in both South-eastern US and the PNW. The functional unit is 1 m^3 harvested log. A full emissions analysis is included (covering GHGs and pollutants).
Technological Coverage: Coverage includes planting, fertilisation, felling, grounding skidding trees to landing, processing of trees to logs and loading of logs on to trucks in two regions in the United States: South-Eastern US and PNW.
Technological Assumptions: For each region, three combinations of management intensity and site productivity were allocated to acreages corresponding to the U.S. Forest Service RPA allocation and then merged into a single estimate of yield and the corresponding harvesting impacts. (Southeast low, medium and high are 37, 58 and 5% respectively; Northwest low, medium and high were 42, 46, and 12%). Vegetation growth for the scenarios was simulated through established growth and yield vegetation simulators developed for each respective region. Factors (including the fertilizer used in seedling growth and the electrical energy required to operate forest nursery pumps and to keep seedlings cool for planting) involved in growth of the seedlings were modelled as input to the system, but were not considered to be within the system boundary. Volumes of logs destined for pulp and paper manufacture were treated as co-products of the forest resource module. Seedlings in both regions were assumed to be planted by hand.
Methodological Assumptions: Environmental impacts were assessed using into the SimaPro 5.09 to generate emission factors, and to analyse the relative contribution of the various site preparation and harvesting processes to emissions. The assessment method selected for the modules analysed in the comprehensive CORRIM analysis was Eco-indicator 99 (E)/Europe EI 99 E/E. Cost, production, and emission factors associated with site preparation and forest stand establishment were developed from information in existing studies and were integrated with information on subsequent stand treatments and final harvesting to develop overall factors associated with the log delivered to a lumber mill, plywood plant, or oriented strand board (OSB) mill. Emission factors for fertilizers used in seedling development and in forest management were derived from existing database factors within the FAL database. In the Southeast, carbon estimates were developed through the NUTREM2 model developed and used in the region. In the Northwest, carbon budgets were constructed from tree lists describing standard inventory data for individual trees, e.g., species, diameter, and crown ratio.
Overview of Transparency: moderate
Reviewer: Paula McNamee
Headline Results: Results are presented in terms of emissions to produce logs loaded onto trucks (Table 6 in the report). Emissions of CO_2, CO_2(fossil), CO_2(non-fossil), methane and N_2O are included. However, the figures for CO_2 are ambiguous as the sum of fossil and non-fossil CO_2 does not equal the figure given for 'CO_2'. The figures given for CO_2(fossil) are as follows: CO_2(fossil) emissions from SE base case: 9.25 kg/m^3 harvested log CO_2(fossil) emissions from SE alternate: 9.71 kg/m^3 harvested log CO_2(fossil) emissions from PNW base case: 8.02 kg/m^3 harvested log CO_2(fossil) emissions from PNW alternative case: 8.12 kg/m^3 harvested log The 'alternative' cases represent more intensive forest management scenarios for both regions. Uptake of biogenic CO_2 not included in these headline results.

Ref. No. 121: Details of LCA Study/Calculation Tool/Database/Review: Life-Cycle Inventory of Wood Pellet Manufacturing and Utilization in Wisconsin by John F. Katers, Adam J. Snippen and Maureen E. Puettmann, Forest Products Journal (Vol. 62, No. 4) pp289-295, DOI: not available.
Stated LCA Purpose, and Defined LCA Goal and Scope: ***Purpose:*** Addressing Policy makers and business developers to meet renewable energy mandates in the US. **LCA Goal:** The study summarizes environmental impacts (GWP) of ''premium'' wood pellet manufacturing and use through a cradle-to grave life-cycle inventory. A cradle-to-gate LCI for the pellet mill was investigated as well. **Scope**: The system boundary includes growing and harvesting timber to the use of wood pellet fuel.
Technological Coverage: Harvested wood and wet/dry sawmill residues (processed wood fiber) are used to produce wood pellets. Includes every stage of woody raw material processing from forest regeneration, timber harvesting, transportation, energy production, primary wood processing, and pellet manufacturing (handling delivered logs and processed wood fibre, size reduction, including chipping and hammer milling, drying, pelletizing, cooling, and packaging of final product) to the combustion of the wood pellets.
Technological Assumptions: Primary data for pellet manufacturing facilities were collected through a detailed questionnaire from four wood pellet manufacturing mills in Wisconsin, with annual production range of 20,000 to 35,630 tons (in total about 61% of Wisconsin's total premium wood pellet production in 2009).
Methodological Assumptions: Functional Unit: 1.0 short ton of wood pellets and 1 MJ of residential heat. All substances and energy consumed were allocated (by weight) among the primary wood product and co-products on a 0% moisture basis. The system boundary: growing and harvesting timber to the use of wood pellet fuel. Data were collected from several Wisconsin wood pellet mills. many of the large-scale wood pellet production facilities also produced other products such as animal bedding and commercial wood chips. The basis of allocation of GHG emissions is unclear. LCI data from CORRIM and the National Renewable Energy Laboratory (NREL), (available through the US LCI database) were used to model the off-site timber production, timber harvesting, and primary wood production processes. Average composition of off-site electrical generation was calculated for the Northeast/North Central region. The heating efficiencies for natural gas, residual fuel oil (RFO), air-dried cordwood, and wood pellet heating devices were assumed to be 80, 83, 77, and 83 percent, respectively. Wood fuel primarily used in the drying process in the pellet mill (32.86% of total energy use). To convert volume or mass of a fuel to its energy value, higher heating values (HHVs) were used. The model assumes that trees used for wood feedstock are part of a sustainable forestry operation allowing for no net change in forest carbon stocks, with biogenic carbon sequestered in new growth of woody biomass at the same rate as biogenic carbon emissions from the forest and forest product combustion. Not clear if emissions associated with plant construction and machinery is included.
Overview of Transparency: moderate
Reviewer: Maha Elsayed
Headline Results: Total cradle-to-grave non-renewable energy inputs (MJ) for the production of 1 MJ of residential heat using cordwood is 0.035 MJ, using wood pellets is 0.307 MJ, using natural gas is 1.411 MJ, and using RFO is 1.527 MJ. GHG emissions, including biogenic CO_2 emissions from biomass combustion, associated with producing 1 MJ of residential heat are highest for wood pellets (0.1459 kg CO_2eq), followed by cordwood (0.1438 kg CO_2eq), RFO (0.1136 kg CO_2eq), and natural gas (0.0780 kg CO_2eq). GHG emissions for the biomass fuels, excluding biogenic CO_2 emissions from biomass combustion, associated with producing 1 MJ of residential heat are 0.0572 kg CO_2eq for wood pellets and 0.0255 kg CO_2eq for cordwood. The above headline results are given in the text and also illustrated graphically in the study (Figure 2), though the figure for GHG emissions shown for natural gas on the graph (approximately 0.062 kg CO_2eq /MJ) is inconsistent with the figure in the text.

NORTH ENERGY

Ref. No. 131: Details of LCA Study/Calculation Tool/Database/Review: Prospective Life Cycle Carbon Abatement for Pyrolysis Biochar Systems in the UK by J. Hammond, S. Shackley, S.Sohi, P.Brownsort, Energy Policy, 2011, 39(5), pp2646-2655,DOI:10.1016/j.enpol.2011.02.033
Stated LCA Purpose, and Defined LCA Goal and Scope: The goal was to quantify the carbon abatement and electricity generation potential from pyrolysis biochar systems (PBS) as they might occur in the UK context in the near future, for the purpose of guiding future research and policy. The scope is cradle-to-grave from char production, to application on wheat growing land and the conversion of syngas and bio-oil by-products to electricity. Results are generated for carbon abatement (CA) per odt of feedstock: per odt of biochar produced; per MWh of electricity produced; per ha of land used to produce feedstock; and CA per pyrolysis facility. Slow PBS compared with fast PBS, gasification and combustion.
Technological Coverage: Ten different feedstocks were assessed: wheat straw, barley straw, oilseed rape straw, sawmill residues, forestry residue chips, small roundwood chips, short rotation coppice chips, short rotation forestry chips, Miscanthus and forestry residue chips imported from Canada. Slow Pyrolysis for production of biochar modelled at three scales: small (processing 2,000 odt/year for 500 t/yr), medium (20,000 odt/year for 5,000t/yr) and large (100,000 odt/year 50,000 t/yr) to produce biochar (applied to wheat growing fields), syngas and bio-oil, (both converted to electricity).
Technological Assumptions: Electrical efficiency of Small pyrolysis (6-7%), Medium (12-13%), Large (14-16%). Electricity fossil fuel offset (i.e. emissions reduction from avoided electricity generation elsewhere) is 501 kg CO_2e/MWh (UK grid-average, 2008). Energy penalty of 10% and 15% of the energy embodied in syngas for wood and straw systems respectively assumed to be used for pyroliser, engine start up, feedstock drying and processing. Conversion of syngas and bio-oil to electricity assumed to be by a reciprocating engine (28-42% efficiency). Assumed some heat generated from pyrolysis was used to dry feedstocks but not elsewhere. Addition of 30 t/ha biochar assumed to deliver: 10% increase in net primary productivity, 10% decrease in rate of soil organic carbon (SOC) (i.e. carbon in the soil not provided by biochar application) decomposition, 10% decrease in N fertiliser requirements, 5% decrease in P and K requirements and 25% suppression of soil N_2O emissions. Labile (unstable) carbon assumed to make up 15% (wt) of biochar. Application of biochar to soil was assumed to consume the same amount of fuel as lime spreading. Biochar was assumed to be applied to soil shortly before normal tilling, harrowing, or disking operations, and so entailing no extra soil operations for char incorporation.
Methodological Assumptions: Uses LCA methods but explicitly claims not to be completely compliant with (ISO) methodology. States that uncertainty in pyrolysis biochar system technology (at time of writing) has led to uncertainties in data. Attributional LCA (GHG emissions /abatement directly attributed to each process) is counted, but no consequences of processes counted therefore land use not change not considered. Allocation is by price. Emissions from the combustion of syngas and bio-oil are not included in the LCA as it is assumed that the same amount of biomass crop is re-grown, thus re-capturing the same quantity of C as was removed from the field at harvest.
Overview of Transparency: moderate
Reviewer: Paula McNamee
Headline Results: CA results figures include reductions in atmospheric carbon due to soil sequestration of biochar carbon, agricultural impacts (such as reduction in fertilizer requirement, reduction in soil N_2O emissions, increased in crop yields, increased SOC) and emissions reduction from displaced grid electricity production. All PBS systems assessed showed net carbon abatement with ranges as follows: Per odt of feedstock: 0.7 to 1.3 t CO_2eq. Per hectare: 4.6-22.6t CO_2e CA calculated for slow PBS is higher than results calculated for fast PBS and for electricity production from direct combustion and combustion after gasification; the comparison given (on bar chart) is for the processing of 20,000 odt biomass/yr, giving approximate carbon abatement of 16,500, 14,000, 9,500 and 13,000 t CO_2e/yr for slow PBS, fast PBS, combustion and gasification/combustion respectively. The authors note that the CA figures are dependent on the emissions factor used for displaced electricity production, and hence these will decrease as the UK grid is decarbonised. CA for the non-PBS pathways are much more dependent on displaced electricity emission factors than the PBS pathways. (Note that the UK grid-average emissions figure used for this study's calculations is from 2008). Results for the PBS pathway are broadly similar to 'the few other estimates published'. The PBS system is compared with a published study for non-PBS systems, 'other conventional and advanced bioenergy systems' (Thornley et al.), noting that the calculated PBS CA range of 4.6-22.6t CO_2e/ha is greater than the 1-7 t CO_2e/ha range given in that study for similar feedstocks.

Ref. No. 132: Details of LCA Study/Calculation Tool/Database/Review: Quantifying GWI of Wood Pellet Production in the Southern United States and its Subsequent Utilization for Electricity Production in The Netherlands/Florida by P. Dwivedi, R. Bailis, T. G. Bush and M. Marinescu, Bioenergy Research, Vol. 4, pp. 180 - 192, 2011, DOI: 10.1007/s12155-010-9111-5.
Stated LCA Purpose, and Defined LCA Goal and Scope: The purpose of this study is to adopt a case study approach to ascertain the global warming intensity (GWI) due to the production of wood pellets in Florida and their subsequent use for electricity production in Florida and the Netherlands.
Technological Coverage: Pulpwood and forest residues from slash pine turned into pellets for electricity generation.
Technological Assumptions: The GWI of a unit of electricity produced at an 80MW power plant located at Geertruidenberg, The Netherlands, and Gainesville, Florida, are evaluated. It is assumed that the power plants would only utilize wood pellets as feedstocks, sourced from a wood pellet mill located at Cottondale, Florida. It is also assumed that the conversion efficiency of each power station is 25%.
Methodological Assumptions: Although very few necessary life cycle assessment (LCA) methodological details are given, the use of an economic model to determine the availability of different wood products from the slash pine forest implies economic allocation is used as a basis for allocating GHG emissions associated with forest operations, suggesting that this study adopts attributional LCA methodology. The functional unit is a kilowatt-hour of electricity produced at a power plant (80 MW) located in either Gainesville, Florida, or Geertruidenberg, the Netherlands. The processes considered are forest site preparation, management, harvesting, wood transport, pellet production, pellet transport and electricity production. The greenhouse gas (GHG) emissions associated with the production of all material and energy inputs came from Franklin Associates Environmental database. 35% of the total GHG emissions are allocated to pellet production but the method of allocation is not clearly stated. Uncertainty and sensitivity analysis are carried out.
Overview of Transparency: low transparency with limited details of LCA methodology and calculations.
Reviewer: Anna Evans
Headline Results: The GWI of electricity produced at power plants located at Geertruidenberg, the Netherlands and Gainesville, Florida was 296.4 and 177.5g CO_2eq/kWhe generated, respectively. Identical efficiency of 25% is assumed for each power station, with the main factor giving rise to the higher GWI for the Netherlands being transport by ship from Florida to the Netherlands. Compared to coal based electricity generation (with estimated emissions of 1.08 and 1.01 kg CO_2eq/kWh for the Netherlands and Florida respectively), an overall saving of 72.6% in GHG emissions is estimated for every kWh of electricity generated using imported wood pellets in the Netherlands and 82.4% if the same wood pellets are utilized within Florida for electricity generation rather than being exported for use at Geertruidenberg. Uptake and emissions of biogenic CO_2 are not included in these headline results.

Ref. No. 136: Details of LCA Study/Calculation Tool/Database/Review: Research to Support the Review of the Renewable Obligation Scotland and Impact of the Renewable Heat Incentive: part 2 - biomass thresholds for electricity, CHP and heat generation by N. Mortimer, C. Hatto, G. Jenkins and O. Mwabonje, North Energy Associates Ltd, Sheffield, United Kingdom, on behalf of Forestry Commission Scotland for the Scottish Government, DOI: Not available.
Stated LCA Purpose, and Defined LCA Goal and Scope: The stated purpose was to address: "the potential use of wood in Scotland for different energy purposes, in terms of possible prioritising specific uses, mainly from the perspective of comparative greenhouse gas (GHG) emissions". This was intended to answer the basic questions such as: "do wood-fired heat and CHP plants have lower total GHG emissions than those of power only plants that use the same source of wood fuel?" Calculations were to be performed according to the Renewable Energy Directive (RED) methodology extended to cover the use of biomass for heat and/or power generation. The functional unit is one MWh and the GHG emissions are expressed as kg CO_2eq/MWh.
Technological Coverage: Forest roundwood, forest residues, and clean and unclean waste wood as logs, chips, pellets and briquettes, used for domestic heating, commercial and industrial heating, CHP generation and dedicated electricity only generation by combustion of wood chips and pellets.
Technological Assumptions: Domestic heating (15 kW to 320 kW) by combustion of wood briquettes, logs and pellets; commercial and industrial heating (50 kW to 20 MW) by combustion of wood chips; combined heat and power generation (1.8 MW to 125 MW of heat and 0.4 MW and 50 MW of electricity) by combustion of wood chips; and dedicated electricity only generation (5 MW to 350 MW) by combustion of wood chips and pellets in Scotland.
Methodological Assumptions: The LCA calculations are performed according to the EU RED methodology; calculations exclude impacts associated with the manufacture and maintenance of machinery, equipment and plant and the provision of forest residues, and clean and unclean waste wood. Forest carbon stock changes are also excluded. All other identified inputs to the sequence of process stages that make up the biomass energy chain are included. Allocation is based on the energy content, or net calorific value, of the co-products. No effects of reference systems are taken into account. The GWPs specified in the RED are 23 kg eq. CO_2/kg CH_4 and 296 kg eq. CO_2/kg N_2O which is consistent with the Intergovernmental Panel on Climate Change (IPCC) Third Assessment Report for a 100-year time horizon.
Overview of Transparency: high transparency; the report and the Excel workbook from which results were derived are available on request.
Reviewer: Anna Evans
Headline Results: On the basis of comparing 1 MWh of electricity directly with 1 MWh of delivered heat, these results demonstrated that, assuming typical ranges for wood fuel transport distances and for plant design specifications, total GHG emissions associated with all wood-fired heating applications, and heating from all CHP applications and electricity from some CHP applications are markedly lower than those for power only generation. However, some overlap occurs in total GHG emissions associated with power only generation and the generation of electricity from woodfired CHP plants that combine large scale, low overall energy efficiency and large wood fuel delivery distances. The use of forest wood fuels, derived from roundwood and forest residues, and clean and unclean waste wood fuels from Scottish sources in domestic, commercial and industrial heating, commercial and industrial CHP generation and power only generation has total GHG emissions that are approximately an order of magnitude lower than those of equivalent heat and/or electricity production from conventional fossil fuels. Wood fired domestic heating: 19-60 kg CO_2eq/MWh; Wood fired commercial/industrial heat only plant: 11-60 kg CO_2eq/MWh; Wood fired commercial/ industrial heat from CHP: 2-59 kg CO_2eq/MWh; Wood fired commercial/industrial electricity from CHP: 4-117 kg CO_2eq/MWh; Wood fired electricity from power only plant: 24-127 kg CO_2eq/MWh. Uptake and emissions of biogenic CO_2 are not included in these headline results.

Ref. No. 142: Details of LCA Study/Calculation Tool/Database/Review: Simulation of Environmental Impact Scores within the Life Cycle of Mixed Wood Chips from Alternative Short Rotation Coppice Systems in Flanders (Belgium) by B. Rugani, K. Golkowska, I. Vázquez-Rowe, D. Koster, E. Benetto and P. Verdonckt, Applied Energy, 2015, 156, pp 449-464, DOI: 10.1016/j.apenergy.2015.07.032.
Stated LCA Purpose, and Defined LCA Goal and Scope: The goal (not explicitly defined) was to predict the environmental performance associated with the use of wood chips from 7 SRC plantations in Belgium (established in 2012 and composed of varying mixes of willow/poplar clones and native tree species) and to compare this with the environmental performance of hardwood chips for identical end-uses. The cradle-to-end use pathway is split into two separate analyses, covering (i) cradle-to-field gate for SRC chip production and (ii) field gate-to- industrial gate or end use for wood chips: The cradle-to-field gate analysis covers seedling production, growing, harvesting and chipping. The functional unit is 1m^3 of loose wood chips. The field gate-to-industrial gate/end use analysis takes the form of a rough approximation of the environmental benefits of 4 alternatives uses of wood chips including (i) production of methanol and associated road transportation processes, (ii) electricity generation at a co-generation plant, (iii) heat at a co-generation plant, (iV)l small-scale heat production from wood. The 4 functional units relating to each alternative use are (i) transport of one passenger by car, FU = 100-person km, (ii) electricity generation at 1,400kW$_{th}$ co-gen plant, FU = 1 kWh, (iii) heat production at 1,400kW$_{th}$ co-gen plant, FU = 1GJ, (iv) heat production at 50kW furnace, FU = 1GJ$_{th}$.
Technological Coverage: The conversion technologies covered: wood chips combustion for electricity and heat at co-generation 1,400 kW$_{th}$ facility, heat generation at a 50kW furnace 50 kW and conversion to methanol for transport in a passenger car. None of these technologies is investigated in detail.
Technological Assumptions: The study relies on data from the ecoinvent database giving the following specification for the ecoinvent models used: "Electricity, at cogen ORC 1400 kWth, wood, allocation energy/CH. Heat, at cogen ORC 1400 kWth, wood, allocation energy/CH. Heat, hardwood chips from forest, at furnace 50 kW/CH U. Transport, passenger car, methanol/CH." ORC being organic rankine cycle and 'CH' likely to indicate Switzerland as the source of the data. The meaning of 'U' is a mystery.
Methodological Assumptions: The study was undertaken before the first harvest from the SRC plantations (foreseen as winter 2015), so a model (CO_2FIX v3.2 from Lettens and colleagues) was used to simulate harvest yields on regular 3 to 7-year rotations up to year 2033. ReCiPe method was used to perform the Life Cycle Impact Assessment (LCIA) of the SRC systems in SimaPro, evaluated both at the midpoint and endpoint scales. Foreground system data were retrieved from Inagro (Dutch agricultural research centre) and collected using questionnaires. The collected information regarding field operations (e.g. consumption of diesel, use of tractors and other machinery, consumption of chemicals, etc. during the phases of plantation, field preparation, fertilization, assumed harvest, etc.) did not refer to each single analysed site but rather to average SRC practices. For background information, all data were retrieved from the ecoinvent database v2.2. Data for the post-field gate analyses were taken from the ecoinvent database v2.2 and thereafter were modified to enable a consistent comparison with the original processes using hardwood chips. Ecoinvent was mainly used to associate the foreground model with the life cycle of each field operation and agricultural machinery upstream. The entire LCI was implemented in the LCA software SimaPro 7.3.
Overview of Transparency: moderate; whilst this study shows good transparency in some areas, it is also confusing and hard to follow in other areas and the units used are not always clearly defined.
Reviewer: Paula McNamee
Headline Results: Predicted yields (over 21 years) for the 7 sites range from 4.21 to 15.28 odt/ha/yr. Having stated that the FU for the cradle-to-field gate analysis is m^3 loose wood chips, the study does not report results in terms of this functional unit. The only GWP results given are for one of the sites, Oostkamp (mixed willow/poplar), being GHG emissions of 21.2t CO_2eq/ha over the full 21-year cycle (establishment to plantation removal). For the field gate-to-industrial gate/end-use analysis, some 'original' and 'modified' results are presented for the 4 paths, but it is not possible to determine what these results represent (e.g. whether the results include carbon sequestered, biogenic carbon dioxide emitted on combustion, fossil carbon dioxide emissions). Hence these results are not given here.

Ref. No. 143: Details of LCA Study/Calculation Tool/Database/Review: Soil Organic Carbon Changes in the Cultivation of Energy Crops: implications for GHG balances and soil quality for use in LCA by M. Brandão, Llorenç Milà i Canals, and R. Clift, Biomass and Bioenergy, 2011, 35(6), pp 2323–2336, DOI: 10.1016/j.biombioe.2009.10.019
Stated LCA Purpose, and Defined LCA Goal and Scope: The purpose of the study was to compare different land uses for energy and to assess the importance of soil organic carbon (SOC) changes for the GHG balance and for the soil quality impacts of energy crops. The goal is to determine which life-cycle stages of representative biomass feedstocks (SRC willow, OSR, Miscanthus and forest residues) contribute to the greatest environmental impacts, including land-use related soil emissions and to compare the different land issues in the UK to produce biomass/biofuels. The scope of this study is cradle-to-gate, from extraction of raw materials through agricultural activities and production to the point where the crop is harvested and ready for transport. The impact categories analysed included: Primary energy use (measured in MJ); Climate change (measured as GWP of the GHG emitted including emissions from SOC degradation); acidification potential; eutrophication potential; and soil quality (through changes in SOC). The emissions are annualised over single total rotation: 19 years for miscanthus and 16 years for SRC willow (temporal boundary). The functional unit is 1 hectare of land per year converted in to indicative values for the whole fuel cycle as 1GJ.
Technological Coverage: Cultivation, cutting, transport drying and storage.
Technological Assumptions: OSR straw assumed to ploughed back in to land (equalling reduction of C losses as 0.16 t C/ha but overall SOC loss as 0.24 t C/ha, from 0.40 t C/ha. Assumed 1-year establishment for Miscanthus and 19 years of production. Assume 20% losses during harvest and storage of miscanthus. 16-year rotation assumed for SRC willow. Stick harvesting and baling of SRC willow assumed.
Methodological Assumptions: Environmental load of transport and milling of saw logs were allocated to timber as the primary product. Generic LCA used for farm operations including fuel, farm machinery and steel production for machinery spares is derived from ecoinvent 2000 v 1.2. Fertiliser production data obtained from an existing study as well as common practice in the field in the UK. The study states that since the residues will be produced whether they are used or not, allocation of the environmental load between forest residues and the other co-products (sawlogs and small roundwood) was not necessary as forest residues are essentially waste. Part of the residues originates from chunks from the sawlogs route. The chunks were considered to be a waste product and their transformation into chips regarded as a means of valorisation; therefore, all inputs related to chipping of chunks were allocated to the chips. Nutrient related emissions from soil derived from literature. Data for effects on SOC are taken from literature. It is assumed that all C captured as SOC comes from atmospheric CO_2 through photosynthesis, and that all SOC degraded is emitted as CO_2 to the atmosphere. The impact assessment phase has been performed using mainly the CML 2001 method. Values used for sequestration rates of carbon as SOC are calculated as mid-term trends. All transformation impacts are allocated to subsequent 100 years of cropping. Changes in soil quality due to land use have been assessed relative to a situation where this activity is not undertaken.
Overview of Transparency: moderate
Reviewer: Paula McNamee
Headline Results: Total GHG emissions per GJ NCV biomass at gate: OSR: 77 kg CO_2eq; Miscanthus: -9.0 kg CO_2eq (negative emissions); Willow SRC: 2.6 kg CO_2eq; Forest Residues: 7.4 kg CO_2eq

Ref. No. 149: Details of LCA Study/Calculation Tool/Database/Review:
The Economical and Environmental Performance of Miscanthus and Switchgrass Production and Supply Chains in a European Setting by E. M. W. Smeets, I. M. Lewandowski and A. P. C. Faaij, Renewable and Sustainable Energy Reviews, 2009, 13, pp 1230–1245, DOI: 10.1016/j.rser.2008.09.006.

Stated LCA Purpose, and Defined LCA Goal and Scope:
Study does not state that it is an LCA.
The purpose is to analyse the economic and environmental performance of switchgrass and Miscanthus production and supply chains in the European Union for the years 2004 and 2030.
The goal is to provide insight in to the possibilities and limitations of Miscanthus and switchgrass production in the EU to minimise the costs and optimise the production towards maximum production capacity and minimum environmental impacts.
The scope covers 5 regions in 5 countries that are 'potentially promising producers', covering site establishment, crop production, fertilising, weeding, harvesting, storage, pelleting and transport for the years 2004 and 2030. Environmental impact categories investigated include energy use and GHG emissions, soil erosion (through action of water), water use and biodiversity. 1 oven dry tonne (odt) is the functional unit.

Technological Coverage:
For harvesting operating two systems considered: self-propelled forage harvester and pull-type harvester baler). Pelleting of feedstock is also covered (in an 80kt plant).

Technological Assumptions:
Assume work capacity of harvesting will increase by an arbitrary 25% because of technological improvements and optimisation of harvesting. Storage in open air covered with plastic sheeting. An 80kT pelleting facility was considered the most appropriate. Energy calculations assume: energy requirement for drying of 2.226 MJ/kg.t evaporated water and a dryer that uses natural gas and has a drying efficiency of 85% and electrical demand of 26kWhe/t pellets. It is assumed that biomass is derived from circular area around the facility and 15% of agricultural land is used to produce SG and M. Total transportation distance is assumed to be 1.3x the average distance from within any point of the circular production area of the biomass processing facility in the middle (tortuosity factor).

Methodological Assumptions:
Miscanthus yields in 2004 were calculated using a spreadsheet model specifically developed for predicting Miscanthus yields (August harvest). As no model for switchgrass was available, switchgrass yields assumed to be 80% of the Miscanthus yields. Study assumes that switchgrass yields will increase exponentially 1.5% year from 2004 to 2030 (with bandwidth of 1 and 2%). GHG and primary energy use calculated for the use of energy during each stage, direct and indirect emissions of N_2O due to application of fertilisers, production of fossil energy during each stage, manufacturing of agri-inputs and the production, maintenance and repair of agricultural machinery. GHG emissions from changes in above or below ground biomass, soil organic matter and litter due to the conversion of land to crop plantation are ignored. Soil erosion rates calculated using the Universal Soil Loss Equation (USLE). Data on water use and impact on biodiversity determined from literature review.

Overview of Transparency: moderate

Reviewer: Paula McNamee

Headline Results:
GWP Miscanthus:
2004: 69-86 kg CO_2eq/odt (3.8-4.7 kg CO_2eq/GJ)
2030: 67-83 kg CO_2eq/odt (3.7-4.5 kg CO_2eq/GJ)
GWP Switchgrass:
2004: 118-140 kg CO_2eq/odt (6.4 -7.7 kg CO_2eq/GJ)
2030: 117-137 kg CO_2eq/odt (6.4 -7.5 kg CO_2eq/GJ)
Uptake and emissions of biogenic CO_2 are not included in these headline results.

NORTH ENERGY

Ref. No. 153: Details of LCA Study/Calculation Tool/Database/Review: The Potential Contribution of a Short Rotation Willow Plantation to Mitigate Climate Change by L. van Bussel (Thesis). 2006. Wageningen University. All rights reserved. The work may not be copied in whole or in parts without the written permission of the supervisor. DOI: not available.
Stated LCA Purpose, and Defined LCA Goal and Scope: The goal (not explicitly defined) of the study is to understand the potential contribution SRC Salix can make towards mitigating climate change in the Netherlands, with an aim of roughly evaluating the balance of the greenhouse gases CO_2 and N_2O of a Salix plantation under Dutch conditions and comparing with the CO_2 emissions of a coal-powered power plants. The scope of the study is cradle to farm gate covering the preparation of land through cultivation, harvest, coppicing, chipping, transport and uprooting. Carbon sequestration in soil is estimated and accounted for. The functional unit is a SRC Salix stand of one hectare over its assumed 15-year lifespan.
Technological Coverage: The study analyses two Salix clones: Jorr and Tora, grown in monocultures and covers mowing and ploughing, production and transport of plants, seed bed prep, planting, production and transport of fertiliser and herbicide, harvesting which includes application of herbicide and fertilisation, coppicing, chipping and transport and uprooting.
Technological Assumptions: The study considers the following: site preparation, planting and coppicing take place during year 1 with 2-year cutting cycle with removal of stools after 7 cutting cycles (total 15 years). The assumption was made that after the first cutting cycle, structural/woody root biomass increases with 5% each year.
Methodological Assumptions: Global warming potentials from IPCC (2001) are used. The level of management activities was not the same for both Salix clone reports; average numbers for each management activity applied in this research were calculated based on both reports. No soil data was available for the site therefore it was assumed that the conditions of the sites resemble the conditions in the research by Rebelo de Mira and Kroeze (2006). Calculation of soil emissions was based on Rebelo de Mira and Kroeze (2006). N_2O release from leaf litter through anaerobic digestion was performed based on the result of Heller et al. (2003). A mass balance of the major ecosystem pools and fluxes of carbon in a short rotation forestry stand was used to calculate the carbon sequestration under a Salix plantation.
Overview of Transparency: moderate
Reviewer: Paula McNamee
Headline Results: Results for the two Salix varieties are significantly different (based on 15 year rotation lifespan): Biomass energy yield (GJ/ha/15yr): Jorr: 3,912. Tora: 2,552. Carbon sequestration (t CO_2eq/ha/15yr): Jorr: 24.96. Tora: 7.6. GHG emissions, including due to plantation management, soil emissions and sequestration (t CO_2eq/ha/15yr): Jorr: 2.14 (plantation management 11.49, soil emissions 15.61, sequestration -24.96). Tora: 17.35 (plantation management 11.49, soil emissions 13.46, sequestration -7.6). GHG emissions in terms of biomass energy production (kg CO_2eq/GJ): Jorr: 0.55. Tora: 6.79. For GHG emissions due to plantation management, the most significant contributions were from the following management operations: Production and transport of fertiliser (38% of total management operation emissions) and harvesting (33% of total management operation emissions).

Ref. No. 154: Details of LCA Study/Calculation Tool/Database/Review: The Potential for Short-Rotation Woody Crops to Reduce US CO_2 Emissions by R. L. Graham, L. L. Wright and A. F. Turhollow, Climatic change, 1992, 22 (3), pp 223-238, DOI: 10.1007/BF00143029.
Stated LCA Purpose, and Defined LCA Goal and Scope: Does not state it is an LCA. The goal (not explicitly defined) is to estimate the potential for short-rotation woody crop (SRWC) technology to reduce US CO_2 emissions in view of both current and future technologies, investigating how much SRWC energy feedstock could be produced annually in the US, how much electricity and/or fuel could it produce, how much fossil fuel could it displace and what would be the net mitigation benefit to the atmosphere. The scope covers the cultivation of SRWC through to its conversion to electricity or ethanol.
Technological Coverage: Feedstock is SRWC grown in the United States. Conversion technologies include electricity production and ethanol production from SRWC.
Technological Assumptions: The paper suggests that 159 million ha of cropland or potential cropland could, under current conditions, support SRWC without the use of irrigation and that 91 million of these hectares might support SRWC yields of more than 11 Mg/ha/a (where Mg = Megagram = tonne). The average yield on these lands was projected to be 14 Mg/ha/yr. Electricity is assumed to be generated 75% from coal and 25% from non-fossil sources. Assume electric production efficiencies of 33% for both wood and coal and an ethanol conversion efficiency of 41% (344 L of ethanol plus 184 kWh of electricity per megagram of wood). For future scenario, it assumes electric production efficiencies of 42% for both wood and coal and an ethanol-conversion efficiency of 60% (503 L of ethanol plus 101 kWh of electricity per megagram of wood).
Methodological Assumptions: The study considered coal displacement (for electricity) and gasoline displacement (ethanol production) and net carbon benefits. The study states that the combustion of wood or ethanol (products of SRWC) does emit carbon into the atmosphere, but these emissions are balanced by the carbon taken up by the SRWC energy plantations (provided there are no soil carbon changes) but acknowledges fossil carbon inputs. In this analysis, soil carbon is assumed not to change, and all carbon inputs to the production, harvesting, and transportation of SRWC are assumed to be carbon emissions that reduce the benefit derived from fossil fuel displacement.
Overview of Transparency: moderate
Reviewer: Paula McNamee
Headline Results: Carbon emissions reductions are calculated as carbon displaced (through generation of electricity and displacement of gasoline by ethanol) less fossil carbon inputs for biomass/ethanol production). Accounting is for carbon only and it should be noted that the 'current scenario' refers to 1992 and the 'future scenario' to post-1992. For electricity production from SRWC combustion: Current Scenario: 5.22 Mg C/ha/year Future Scenario: 8.63 Mg C/ha/year For ethanol production from SRWC: Current Scenario: 2.37 Mg C/ha/year Future Scenario: 5.28 Mg C/ha/year Uptake and emissions of biogenic carbon are not accounted for in the results.

Ref. No. 156: Details of LCA Study/Calculation Tool/Database/Review: The UK Solid and Gaseous Biomass Carbon Calculator, E4tech, Office of Gas and Electricity Markets (Ofgem) website, 2015, DOI: Not available.
Stated LCA Purpose, and Defined LCA Goal and Scope: Attributional life cycle assessment (LCA) tool to calculate carbon intensity and fossil greenhouse gas (GHG) emissions per unit of product, including heat delivered and electricity generated. Intended as a tool for UK producers to assess compliance with GHG emissions limits specified by the Renewable Heat Incentive and Renewables Obligation financial support mechanisms.
Technological Coverage: Feedstocks derived from forestry, agriculture and waste streams including bagasse, energy crops (including whole crop rye, maize and wheat), grass, olive, palm kernel, rapeseed meal, refuse derived fuel, straw, sorghum meal, sugar beet, wheat DDGS and wood. The applications considered are anaerobic digestion, aerobic processing, drying, pelletisation, heat and electricity generation, biogas upgrading.
Technological Assumptions: The UK Solid and Gaseous Biomass Carbon Calculator software is designed to help companies calculate the carbon intensity of the electricity, heat or bio-methane produced from solid biomass or biogas for the purpose of reporting under the Renewables Obligation scheme. It can also help electricity generators report the carbon intensity of their electricity to Ofgem on an annual basis.
Methodological Assumptions: The life cycle calculation methodology used is that set out in the Renewables Obligation Order and in the Renewables Obligation: Sustainability Criteria guidance from Ofgem. Consistency with EC-calculated biofuels and bioliquids default values has been ensured where relevant. Process steps are feedstock production, treatment, drying and storage, transport stages, processing and use for energy generation. Allocation is by energy content. For all fuel chains, the nitrous oxide emission rate was calculated using the IPCC Tier 1 methodology based on the nitrogen fertiliser application rate. Land use change and change in carbon stocks are considered. Default fuel chains, fuel consumption factors and emissions factors are provided and comparators where appropriate. In line with the European Commission the methodology for calculating default values for fuels derived from biomass, UK Solid and Gaseous Biomass Carbon Calculator takes a conservative approach by multiplying the processing step by a factor of 1.47, thereby increasing emissions from processing.
Overview of Transparency: high transparency; supporting information is supplied with the calculator.
Reviewer: Anna Evans
Headline Results: No relevant headline results as this is a tool and data is entered by the user.

Ref. No. 158: Details of LCA Study/Calculation Tool/Database/Review: Using a Life Cycle Assessment Approach to Estimate the Net Greenhouse Gas Emissions of Bioenergy by N. D. Bird, A. Cowie, F. Cherubini and G. Jungmeier, IEA Bioenergy:ExCo:2011:03, DOI: n.a.
Stated LCA Purpose, and Defined LCA Goal and Scope: Purpose: "to produce an unbiased, authoritative statement aimed especially at practitioners, policy advisors, and policy makers". The statement is intended to "address… the key methodological aspects of life cycle assessment (LCA) with respect to greenhouse gas (GHG) balances of bioenergy systems". Goal: To identify key criteria for comprehensive LCAs based on IEA Bioenergy Task 38 case studies, and to summarise and outline the key methodological aspects of LCA with respect to GHG balances of bioenergy systems. Scope: LCAs of the GHG balance of 4 different bioenergy systems and their counterpart reference system are highlighted using case study examples. This study gives guidance using a review of case studies as illustrative examples; it is not an LCA in itself.
Technological Coverage: The 4 cases considered are: 1. Heat production from woody biomass and Miscanthus in England; 2. Electricity production from thinning, harvest and sawmill residues from Eucalyptus plantations in Australia, using undried biomass for electricity only production (20% efficiency) and the same biomass 5% co-fired at a coal power plant; 3. Biogas production for combustion in CHP plant in Austria, with feedstock of dedicated energy crops, animal manure and grass silage; 4. Biodiesel production from rape in Croatia for use in transport vehicles.
Technological Assumptions: 1.Heat: 150 kW woodchip-fired heating system and a 70 kW Miscanthus-fired systems, compared with equivalent oil-fired systems. 2.Electricity: 30 MW new wood-fired electricity generating station using circulating fluidised bed boiler steam turbine technology and co-firing of plantation residues in an existing 500 MW wood/coal-fired generating station, both compared to electricity production in a 500MW coal-fired power station. 3.Biogas: 2 stage digestion with 100-day residency, considered with and without closed storage of digestate. Delivery of pig and cow manure is by tractor and pipeline. Performance is compared with electricity from a 500 MW natural gas closed cycle power plant and the heat supplied by oil and wood boilers. 4.Biodiesel: produced with rapeseed cake and glycerine co-products, used in public buses and private vehicles, compared to equivalent use of fossil diesel.
Methodological Assumptions: All 4 cases consider reference systems for heat and/or electricity production displaced and the alternative use of land used for biomass production and also incorporate some degree of system expansion to account for items such as land use change and co-products. It is implied that some of the process emissions are calculated using co-product allocation rather than system expansion (for example, production of rapeseed cake and glycerine as biodiesel co-products). The study utilizes the examples of reference systems (or lack of reference systems) to illustrate the importance of defining the system boundary so that the bioenergy and reference fossil systems provide equivalent products and services. The accounting treatment of plant construction and machinery manufacture in the case studies is not given. Functional units appropriate to the case studies are used: kWh_{th} for heat and kWh_e for electricity; kWh_{total} for CHP. The functional unit for the biodiesel case study is given as Km, though it is unclear whether this refers to vehicle-km or passenger-km and whether based on utilisation in cars or buses. Outline details/assumptions for the 4 case studies: Heat: Wood source is local forest thinnings and slab wood from a local sawmill, all air dried to 25% moisture content. Zero forest carbon stock change is assumed (compared to the same forest unmanaged). In the reference system, the slab wood would have been used in a board mill so has to be replaced by a supply of slab wood from elsewhere – but the counterfactual use of this replacement slab wood was not considered (highlighted as a shortcoming of the case study). Miscanthus biomass is harvested annually from the land (4.5 ha) surrounding the complex – in the reference system this land is set-aside land, cut one time a year with cut grass left on the ground. Electricity: 30 MW facility: Biomass is obtained from thinning, harvest and sawmill residues from existing and newly established hardwood plantations and is not dried before combustion. In the reference system these residues are left to decay or are burned. Carbon stock changes are modelled over 100 years using 'FullCAM' carbon stock flow model. 500 MW facility: the biomass is trucked 360km to the power station, but other parameters are the same as for the 30MW system. Biogas CHP: in the reference system, maize used for biogas would have been used for animal feed and the displaced maize substituted by increased yield from additional fertilizer use and imports of soya. Maximum biogas to heat/power conversion efficiency of 75% calculated, but actual efficiency of 49% is used as not all heat output is utilised. Biodiesel: the case study assumes that rape production is on degraded and underutilised 'set aside' land that, in the reference system, would remain as set-aside land. Two alternative uses of the glycerine co-product are considered: as a substitute for either synthetically produced glycerine in the food or pharmaceutical sectors or for fuel oil in a combined heat and power (CHP) facility. No net change in carbon stock in soil is assumed to occur in the conversion of degraded set-aside land to rape production.
Overview of Transparency: moderate; results are compiled from case studies.
Reviewer: Maha Elsayed
Headline Results: GHG emissions for Reference System | Study system | Net savings (reference less study): Heat: Wood 379|52|327, Miscanthus 396|101|295 g CO_2eq/kWh_{th}. Electricity: 30MW GS 709|-201|909, 500MW GS 774|-59|853 g CO_2eq/kWh_e. The negative emissions for the study systems are due to increases in carbon stocks in the forests. Biogas CHP: Closed storage of digestate 473|266|207, open storage of digestate 473|344|129 g CO_2eq/kWh_{total}. Biodiesel: when glycerine co-product used as an energy source 192|157|34, when glycerine used as a chemical feedstock 192|111|80 g CO_2eq/km.

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These references are referenced by text in Appendix B.

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