NAVIGANT

Renewable Heating and Cooling for Industrial Applications

Guidance for Carbon Accounting

Published in collaboration with the Renewable Thermal Collaborative and funded by Mars Incorporated

RENEWABLE THERMAL COLLABORATIVE

MARS

Prepared by:
Navigant Consulting, Inc.
Ecofys – A Navigant Company
Kanaalweg 15-G
3526 KL Utrecht
The Netherlands

T: +31 (0)30 662-3300
navigant.com

Primary authors: Masoud Zabeti, Sacha Alberici, Jeroen de Beer, Esther Eggink, Minke Goes, Caspar Noach

Reference No.: SISNL17392

June 2018

ACKNOWLEDGEMENTS

This report was made possible through funding from Mars Incorporated, and the support and advice of several individuals and organizations. A team from Ecofys, a Navigant company, performed the work.

Navigant gratefully acknowledges the valuable expertise and recommendations of the members of the Renewable Thermal Collaborative working group: Bryn Baker and Martha Stevenson (WWF US), Mike Mazor (Dow), Joel Foster (Dupont), Alexandra Rekkas (David Gardiner and Associates), and Kevin Rabinovitch (Mars).

The report benefited greatly from the time and expertise of a number of international experts that commented on the draft version. We would like to thank John Neeft (Netherlands Enterprise Agency), Kim Cesafsky and Jennifer Jenkins (Enviva), and Stephen Russel (World Resource Institute).

GLOSSARY

Allocation	The process of assigning responsibility for GHG emissions from a specific generating unit or other system (e.g., vehicle, business unit, corporation) among its various users of the product or service.
Allowance	A commodity issued by an emissions trading program that gives its holder the right to emit a certain quantity of GHG emissions.
Avoided emissions	An assessment of emissions reduced or avoided compared to a reference case or baseline scenario.
Biogenic CO_2 emissions	CO_2 emissions related to the natural carbon cycle, as well as those resulting from the combustion, digestion, decomposition, or processing of biologically based materials.
Biogenic gas (biogas)	Methane (CH_4) that is produced from a biomass resource, such as animal waste, agricultural waste, landfill gas, municipal waste, or digester gas.
Biomass	Any material or fuel produced by biological processes of living organisms, including organic non-fossil material of biological origin (e.g., plant material), biofuels (e.g., liquid fuels produced from biomass feedstocks), biogenic gas (e.g., landfill gas), and biogenic waste (e.g., municipal solid waste from biogenic sources).
Clean Development Mechanism(CDM)	A mechanism established by Article 12 of the Kyoto Protocol for project-based emission reduction activities in developing countries. The CDM is designed to meet two main objectives: to address the sustainability needs of the host country and to increase the opportunities available to Annex 1 Parties to meet their GHG reduction commitments. The CDM allows for the creation, acquisition, and transfer of CERs from climate change mitigation projects undertaken in non-Annex 1 countries.
CO_2 equivalent (CO_2eq)	The universal unit of measurement to indicate the global warming potential (GWP) of each GHG, expressed in terms of the GWP of one unit of CO_2. It is used to evaluate releasing (or avoiding releasing) different greenhouse gases against a common basis.
Cogeneration unit/Combined heat and power (CHP)	A facility producing both electricity and steam/heat using the same fuel supply.
Direct emissions	Emissions from sources that are owned or controlled by the reporting company.
Emission factor	A factor that converts activity data into GHG emissions data (e.g., kg CO_2eq emitted per liter of fuel consumed, kg CO_2eq emitted per kilometer traveled, etc.).
EPA standards	The US environmental protection agency that manages the emission standards for the United States.
Carbon accounting	Measuring the amount of carbon dioxide equivalent (GHG emissions) emitted by an entity, project, or product.
GHG Protocol	A protocol that sets the global standards for how to measure, manage and report GHG emissions.
Global warming potential	A factor describing the radiative forcing impact (degree of harm to the atmosphere) of (GWP) one unit of a given GHG relative to one unit of CO_2.
Greenhouse gases (GHG)	For the purposes of this standard, GHGs are the seven gases covered by the UNFCCC: carbon dioxide (CO_2); methane (CH_4); nitrous oxide (N_2O); hydrofluorocarbons (HFCs); perfluorocarbons (PFCs); sulfur hexafluoride (SF_6), and nitrogen trifluoride (NF_3).

Indirect GHG emissions	Emissions that are a consequence of the operations of the reporting company, but occur at sources owned or controlled by another company. This includes Scope 2 and Scope 3.
ISO standards	An international standard setting organization consists of representatives from different national standards organizations.
Life cycle assessment (LCA)	Compilation and evaluation of the inputs, outputs, and the potential environmental impacts of a product system throughout its life cycle.
RECs	Renewable Energy Certificates
RHC	Renewable Heating and Cooling
Scope 1 emissions	Emissions from operations that are owned or controlled by the reporting company.
Scope 2 emissions	Indirect emissions from the generation of purchased or acquired electricity, steam, heat, or cooling consumed by the reporting company.
Scope 3 emissions	All indirect emissions (not included in Scope 2) that occur in the value chain of the reporting company, including both upstream and downstream emissions.
Substrate	A material that is used as a feedstock for production of biofuels

EXECUTIVE SUMMARY

A significant amount of the final energy demand of the manufacturing industry is in providing heating and cooling to processes and buildings. Reducing the greenhouse gas (GHG) emissions associated with the generation of this heating and cooling is important to achieve long-term climate mitigation goals, such as the climate goals of the Paris Agreement. One way to achieve this is by deploying renewable heating and cooling (RHC) technologies.

Whereas for the use of renewable electricity the rules for accounting GHG emissions are generally well-defined and widely accepted, this is not the case for RHC technologies. The lack of a workable and clear set of accounting rules can be perceived as a barrier to implement RHC technologies, since companies are normally averse to taking investment decisions based on poorly understood information. The risk is that a technology is implemented of which environmental claims are debated by external stakeholders and cannot be included in environmental accounting and reporting.

To alleviate the implementation barrier of missing guidance on accounting rules, the Renewable Thermal Collaborative[1] initiated a study to create a single document that demonstrates how existing GHG calculation guidance can be applied to a range of RHC technologies. A second objective of this study was to highlight where consensus has already been established on the most appropriate methodology and where scientists and other stakeholders are still debating elements of the methodology.

Navigant was commissioned to carry out this study. We reviewed an extensive number of published standards, regulations, and protocols. Based on this review the most appropriate GHG calculation methodology for selected RHC technologies are recommended.

Many combinations of renewable energy sources and energy conversion technologies are conceivable. These combinations are referred to as project types. For this project, we selected six of the most relevant project types, in our view, covering biomass and non-biomass energy sources. With this selection, we aimed to cover the key issues on carbon accounting featured in the international debate.

The table below shows per combination of energy source and technology the accounting methodology we recommend.

Project Type		Proposed Accounting Methodology
Energy Source	**Technology**	
Wood chips from virgin forestry	Biomass boiler	BioGrace-II
Wood chips from forestry residues	Biomass boiler	BioGrace-II
Wood chips from industrial residues	Biomass boiler	BioGrace-II
Biomethane	Injection into gas grid	BioGrace-II
Heat from the ground	Heat pump	GHG Protocol
Recovered heat	Heat recovery technologies	No widely accepted methodology

[1] www.renewablethermal.org

The selection of methodologies is based on seven distinct groups of design parameters, all with more detailed elements. The most important parameters were: scope of applicability, level of detail in the calculation guidance and geographical coverage (global preferred over regional coverage).

Biomass-Based Methodologies: Central Method Exists, Not Complete

For all biomass-based project types, we recommend using the BioGrace-II methodology. Our principal reason is that it is the most comprehensive GHG calculation methodology for solid and gaseous biomass technologies that is publicly available. However, an important consideration is that this methodology does not account for biogenic carbon emissions[2] (i.e., these emissions are counted as zero), since the methodology strictly follows that laid down by the European Commission which assumes that biomass is carbon neutral.

How to account for biogenic carbon emissions is a subject of scientific and political debate. The IPCC has stated definitively that bioenergy should not *automatically* be considered carbon neutral, although there is no general consensus on how to account for biogenic carbon emissions at this time. Providing guidance on this important aspect is a core area of ongoing work for the Renewable Thermal Collaborative.

The debate is primarily focused on the combustion of virgin wood (e.g., roundwood), rather than wood wastes or residues. We therefore recommend that companies take a precautionary approach in their use of biomass and utilize wood wastes or residues for RHC. Additionally, we recommend that the associated biogenic emissions are calculated and reported separately, as is required by the GHG Protocol. A separate methodology, called GWP_{bio}, for doing so is referenced. We also strongly recommend that more companies actively engage in the discussion in order to arrive at a generally accepted, accurate and practical approach to deal with biogenic emissions.

It should be noted that the BioGrace-II methodology does not account for indirect land use change, again because this aspect is not covered in the European Commission's overarching methodology. Other ongoing work on land sector accounting is seeking to build consensus around methods for accounting for direct and indirect land use change. Although the BioGrace-II methodology is the recommended methodology for bioenergy projects, it should be noted that the calculated results may lead to an incomplete estimate of the overall GHG emissions.

Ground Source Heat Pumps: Straightforward Methodology Exists

The calculation methodology for ground source heat pumps is relatively straightforward and follows the GHG Protocol on accounting CO_2-emissions to the use of electricity. Care should be taken of GHG emissions of refrigerants.

Recovered Heat: No General Consensus on Full Methodology, Proposed Method Exists

The calculation methodologies for recovered heat are not sufficiently elaborated to make actual calculations of GHG emissions that have to be allocated to this heat. There is consensus that once the heat is recovered, it is a valuable product and therefore emissions should be allocated to it. The

[2] In the context of the study, biogenic carbon emissions are defined as CO_2 emissions related to the natural carbon cycle, as well as those resulting from the combustion, digestion, decomposition, or processing of biologically based materials. [Adapted from: https://19january2017snapshot.epa.gov/climatechange/carbon-dioxide-emissions-associated-bioenergy-and-other-biogenic-sources_.htm)

allocation rule also has to be undertaken on the basis of physical relations, rather than economic value. However, there is still flexibility in the way to do this. We propose a route based on the exergy value of the heat – indicating the work potential of the heat. However, we stress that there is no general consensus on this approach.

TABLE OF CONTENTS

1. INTRODUCTION

Reducing the greenhouse gas (GHG) emissions of the manufacturing industry is crucial to meet the climate goals of the Paris Agreement. Renewable energy sources (wind, solar, biomass, geothermal and other sources) constitute an important route to decarbonize industrial energy demand and the associated CO_2 emissions. One of the prerequisites for the further uptake of renewable energy by industry is that the amount of avoided emissions can be determined in a transparent and unambiguous manner. Whereas for the use of renewable electricity the accounting rules are generally well-defined, this is not the case for renewable heating and cooling (RHC). Around renewable electricity several corporate initiatives, such as RE100 and Renewable Energy Buyers Alliance (REBA) exist and use establishing accounting rules, based on widely accepted protocols and guidelines (like GHG Protocol Scope 2). The focus of past RHC studies and initiatives has mainly been on the built environment and less on industrial applications.

Several reasons can be brought forward to explain that RHC in industry has received such low interest:

- There is a large variety of technologies, and the application depends strongly on the requirements of the industrial process.
- Adjusting heating and cooling supply may have impact on the core industrial processes. The perceived risks are still little understood.
- The investment decision process in industry is usually more complex than in the built environment.
- Heating and cooling demand can be very industry specific.

The lack of a workable and clear set of accounting rules is by itself also a reason for companies not to implement RHC technologies, as is the lack of understanding of the emission reduction that can be accounted for by the specific technology. Companies do not want to be exposed to the risk of being accused of green-washing, because they have implemented a technology where the environmental claims are debated by external stakeholders.

To alleviate the implementation barrier of missing guidance on accounting rules, the Renewable Thermal Collaborative initiated this study to create a single document that demonstrates how existing GHG calculation guidance can be applied to a range of RHC technologies.

This document aims to provide guidance for accounting GHG emissions of RHC (biomass-based and non-biomass-based) applications in industry. It should be emphasized that the purpose of this document is not to develop new calculation rules. The aim is instead to review published standards, regulations, and protocols to identify general consensus and also gaps that need to be addressed regarding the calculation of the GHG impacts of heating and cooling technologies. Based on this review the most appropriate GHG calculation methodology for selected project types will be recommended, along with the necessary caveats about ongoing gaps. The project types that are considered in this study are:

- Wood chips from virgin forestry
- Wood chips from forestry residues
- Wood chips from industry residues
- Biogas and Biomethane from manure and silage (maize and triticale)
- Recovered heat from fossil fuel use

- Ground source heat pump

By reviewing and comparing these calculation methodologies this document will:

- Make these methodologies more accessible to corporates, accelerating the implementation of RHC technologies
- Show the areas where agreement (among the reviewed publications) exists on the methodologies to be applied
- Highlight where outstanding methodological questions remain and catalyze attention to resolve those questions

This document will continue with describing the review of more than 30 published standards, regulations and GHG calculation methodologies. Based on a set of criteria, we will select in two steps the most appropriate calculation methodologies for the above-mentioned project types and will highlight the gaps in each methodology that companies should be aware of when doing the calculations.

Next, we will describe the project types in more detail and how the calculation methodologies should be applied. The data needs to make the calculation are also discussed. We will not repeat all the calculation rules. For these, reference is made to the original publications.

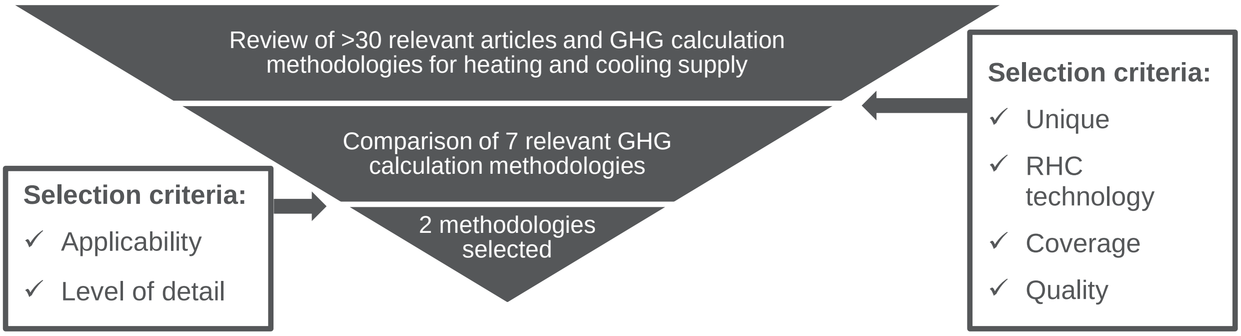
Finally, we will draw conclusions on the applicability of the calculation methodologies, referring to areas of consensus and debate.

2. REVIEW OF EXISTING GHG CALCULATION METHODOLOGIES

This chapter provides an overview of what GHG calculation methodologies for Renewable Heating and Cooling (RHC) technologies are out there and which of those can be used best for the RHC project types that have been selected. The aim of this review is not to combine different methodologies and create one ultimate one, but rather to show how they relate to each other, on what topics there is consensus and on what topics there is disagreement or a lack of guidance.

More than 30 relevant standards, regulations and GHG calculation methodologies (see Table A-1 in Annex 1 for the complete list of literature) were scanned to get an overview of what guidance and GHG calculation methodologies are available. From this list, seven relevant GHG calculation methodologies have been selected based on four selection criteria, as presented in Section 2.1. These seven methodologies have been mapped and compared on different design parameters. The mapping is shown in Section 2.2. Two calculation methodologies have been found to be most suitable for the proposed RHC project types. In Section 2.3, these two calculation methodologies will be compared in more depth.

Figure 1. Selection process of the most suitable existing GHG calculation methodology for the different project types



2.1 Literature Review

First, an inventory was created of all potentially relevant GHG calculation methodologies, based on published standards, regulations and articles referring to methodologies and accounting guidance. This inventory has been put together by an internal group of Navigant experts on carbon accounting for companies and products, biomass, LCA and industrial heating and cooling.

Over 30 documents have been reviewed. In order to separate the (company specific) guidance documents and articles from the relevant GHG calculation methodologies, four criteria have been used:

- **Unique:** The document should provide a stand-alone GHG calculation methodology. It can refer to other methodologies, but it should in itself provide new calculation guidance to prevent exact duplicates.
- **Technology:** The GHG calculation methodology should cover one or more of the RHC technologies from the project types.
- **Coverage:** The methodology should be widely accepted with a large geographical coverage.
- **Quality:** The methodology should be peer-reviewed or clearly show it has been generally accepted. This to exclude methodologies with a very specific target group.

Based on these four criteria, seven GHG calculation methodologies have been selected. Most of the reviewed documents were referring to one of these seven GHG calculation methodologies. A short description of the short-listed GHG calculation methodologies is given in Box 1.

Box 1. Short Descriptions of the Selected GHG Calculation Methodologies

BioGrace:
Documents included: BioGrace-I (2015), BioGrace-II (2015)
Authors: Consortium led by Netherlands Enterprise Agency (RVO, former Agency NL), funded by Intelligent Energy Europe Programme
Scope: Created for the European Union (EU)
Short description:
BioGrace is a GHG calculation methodology for bioenergy. BioGrace has two projects:

- BioGrace-I has been developed for GHG emissions calculation for biofuels and bioliquids and strictly follows the Renewable Energy Directive (RED) published by the European Commission (EC). The project BioGrace-I aims to harmonize calculations of GHG emissions for biofuels and bioliquids throughout the European Union.
- BioGrace-II has been developed for GHG emissions calculation for heating, cooling and electricity from biomass and follows an adapted methodology published by the European Commission.[3,4] The project BioGrace-II aims to harmonize calculations of GHG emissions for electricity, heat, and cooling from biomass throughout the European Union.

EPA: Environmental Protection Agency
Documents included: GHG Inventory Guidance for: Direct Emissions from Stationary Combustion Sources (2016); Direct Fugitive Emissions from Refrigeration, Air Conditioning, Fire Suppression, and Industrial Gases (2014) and Indirect Emissions from Purchased Electricity (2016)
Authors: United States (US) Environmental Protection Agency
Scope: Created for the US
Short description:
These guidance documents have been specifically created for the US. The GHG calculation methodology is based on the GHG Protocol. In addition, some US specific guidance is added including US emission factors.

GHG Protocol: GHG Protocols
Documents included: The GHG Protocol - Corporate Accounting and Reporting Standard (2004), GHG Protocol Scope 2 Guidance (2015), Corporate Value Chain (Scope 3) Accounting and Reporting Standard (2011), Product Life Cycle Accounting and Reporting Standard (2011), Allocation of GHG Emissions from a Combined Heat and Power (CHP) Plant (2006)
Authors: World Resource Institute (WRI) and World Business Council for Sustainable Development (WBCSD)
Scope: Applied globally
Short description: The aim of these protocols is to support organizations and other stakeholders in accounting for and publicly reporting their GHG inventories, including direct (Scope 1) and indirect (Scope 2) emissions of organizations and value chain emissions (Scope 3). Also, it provides more specific guidance on product life cycle emissions and allocation guidelines for certain technologies including for CHP plants. These protocols have been developed through a multi-stakeholder review process.

ISO: International Standards Organization
Documents included: ISO 14064-1 (2006) and ISO 14067 (2013)
Author(s): ISO Central Secretariat and The British Standards Institution
Scope: Applied globally

[3] State of play on the sustainability of solid and gaseous biomass used for electricity, heating and cooling in the EU, Commission staff working document, SWD(2014) 259.

[4] Report from the Commission to the council and the European parliament on sustainability requirements for the use of solid and gaseous biomass sources in electricity, heating and cooling, SEC (2010) 65 and 66.

Short description: These two ISO standards are expected to benefit organizations and governments, among other stakeholders worldwide by providing clarity and consistency for quantifying, monitoring, reporting, and validating GHG inventories. ISO 14064-1 is focused on GHG inventories of organizations or projects, whereas ISO 14067 is focused Carbon Footprint of Products (CFPs) and Life Cycle Analysis (LCA) of products. These standards have been developed through a multi-stakeholder development process.

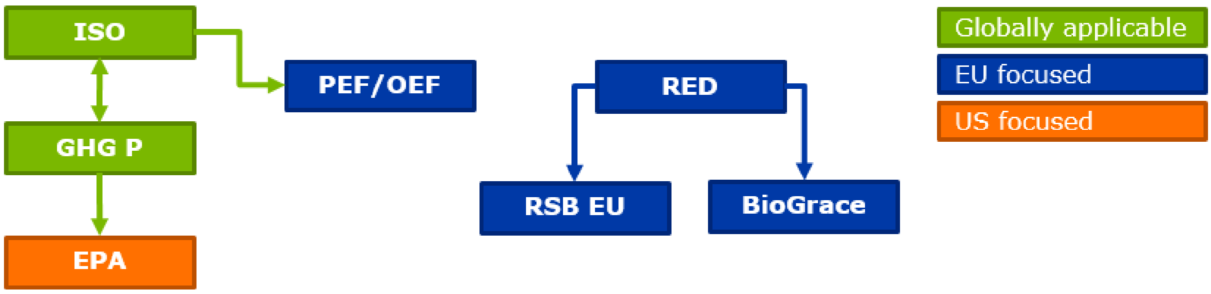
PEF/OEF: Product/Organizational Environmental Footprint
Documents included: Environmental Footprint Guidance document (2016), Commission Recommendation on the use of common methods to measure and communicate the life cycle environmental performance of products and organisations (2013)
Authors: Joint Research Centre (JRC), European Commission (EC)
Scope: Created for the EU
Short description: The EC launched the PEF/OEF guide in 2013 and recommends the use of the methodologies by companies and member states. The methodologies are being tested (2013-2017). The EC will start with a policy impact assessment in 2017 (with support from Navigant) to explore how the methods can be integrated into policy instruments. However, at this time, it is still unclear if and how the methods will be used. The related Environmental Footprint Guidance document contains guidelines developed during the pilot test. These guidelines overrule the guidelines in the PEF/OEF guide. Eventually the guidelines in both documents will be merged. It is unclear when this will happen.
RED: Renewable Energy Directive
Documents included: EC Renewable Energy Directive (2009/28/EC)
Authors: Proposed by the European Commission and approved by the European Parliament and the Council.
Scope: The EU
Short description: RED (developed by the European Commission) set out sustainability criteria for biofuels (liquids, solids, and gases), including a GHG emission calculation methodology. Separate non-binding sustainability criteria for solid and gaseous biomass, including an adapted GHG emission calculation methodology, were published separately in 2010 (SEC (2010) 65 and 66) and subsequently updated in 2014 (SWD(2014) 259).[5]

RSB: Roundtable on Sustainability Biomaterials
Documents included: RSB standard for GHG calculation methodology
Authors: Roundtable on Sustainable Biomaterials
Scope: Global and EU specific (RSB EU RED) versions are available
Short description: The aim of the RSB is to create harmonized GHG calculations guidelines to be used by certified operators. The RSB created one global guidance document and one specifically for the EU (RSB EU RED) which is fully in line with the RED. The RSB only focuses on liquid biofuels. The RSB does not include guidance on the end application of the biofuels.

Although these seven GHG calculation methodologies serve different purposes, they are closely related. All show that they have taken existing methodologies into account. Three of the seven calculation methodologies are based on or in line with the ISO standards. The GHG Protocol is fully aligned with the ISO standards and regularly refers to ISO standards for background information. In addition, the GHG Protocol has also been used as input for the ISO standards. The difference between those two methodologies is mainly the purpose of the methodology which is reflected in the chosen level of detail. The more specific, biomass related calculation methodologies (RSB EU RED and BioGrace) are also closely related. Both the RSB EU RED and BioGrace are consistent with the Renewable Energy Directive (RED). These relations are indicated in Figure 2 below.

[5] The GHG emission calculation methodology for solid and gaseous largely follows that set out in the RED for biofuels, with some minor modifications.

Figure 2. The interrelations between the seven selected protocols. The colors indicate the scope of the protocol



Accounting guidance documents that have been considered but have not been included for further review are:

- PAS 2050: Specification for the assessment of the life cycle GHG emissions of goods and services developed by the British Standard Institution (BSI) in 2008.

  The PAS 2050 has been excluded because it is focused on the UK only and the guidance provided is largely covered by the Product Standard of the GHG Protocol.

- ILCD Handbook: The International Reference Life Cycle Data system developed by the JRC, in cooperation with DG Environment, in 2010.

  The ILCD Handbook has been considered, though it has been excluded from further analysis because the PEF/OEF method (2013) builds upon the ILCD Handbook. Both have been published by the EC and in case of discrepancies between the PEF Guide and the ILCD Handbook, the PEF Guide takes precedence.

- EN15804: This methodology focuses on GHG calculation guidance of solid biomass (wood) in the construction sector, and not for RHC technologies in the manufacturing industry.
- Product Category Rule module for Roundwood and Pulp/Paper (PCR for Round Wood) published in 2015 specifies the requirements for preparing an Environmental Product Declaration (EPD) for roundwood products. This PCR requires that the life cycle impact assessment (LCIA) phase include all of the core impact categories associated with roundwood production, including ecosystem impacts and effects on biogenic carbon storage resulting from logging. For this study the focus is on GHG emissions rather than other environmental impacts.

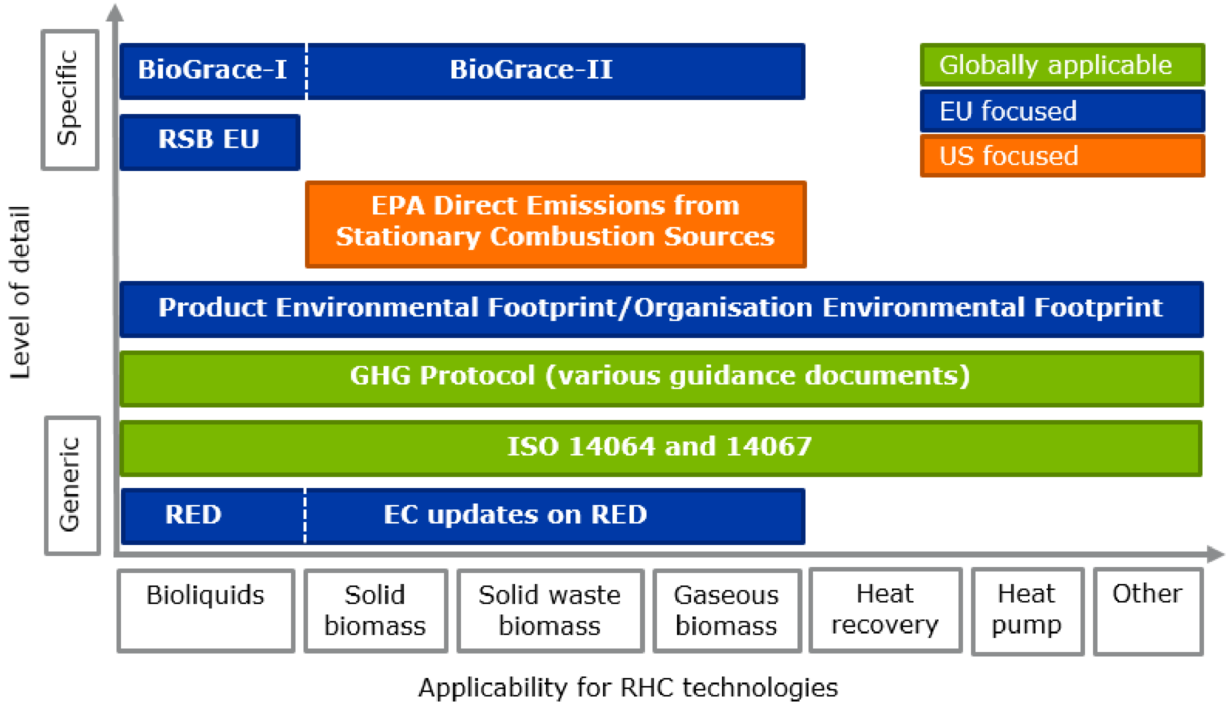
2.2 Mapping of Methodologies

The selected seven GHG calculation methodologies were compared based on many different design parameters. The most important ones for the selection were:

- Applicability: The methodological fit with carbon accounting for the different RHC technologies:
  - Inclusion of different sources of biomass (virgin, residues, and waste)
  - Aim of reporting (off-setting credit, national emissions inventories, corporate targets)
- Level of detail: The level of detail in the calculation guidance given e.g., specific allocation rules.
- Coverage: Global coverage is preferred over regional coverage.

The inventory of all design parameters that have been used to compare the GHG calculation methodologies can be found in Annex 1.

Figure 3. Mapping of seven GHG calculation methodologies based on scoping, applicability, and level of detail



This mapping has led to the selection of two protocols for the different project types researched in this study, BioGrace-II and the GHG Protocol.

BioGrace-II is the most comprehensive GHG calculation methodology for solid and gaseous biomass technologies. Solid and gaseous biomass are not covered by the RSB EU RED methodology. EPA provides some specific GHG calculation guidance on stationary combustion sources but not on biomass processes like cultivation, harvesting and other biomass specific processes. BioGrace-II is in line with the RED methodology, which is a lot less detailed. None of the other GHG calculation methodologies provide specific guidance on allocation rules and data sources for biomass project types.

For non-biomass project types like heat recovery and heat pumps, the PEF/OEF and the GHG Protocol have been considered. Both provide a methodology for company and product specific emission accounting and reporting. The PEF and OEF provide more technical guidance than the GHG Protocol. Though, there are several reasons why the GHG Protocol has been preferred over the PEF/OEF guide. The PEF/OEF documents have not been finalized yet as mentioned in the description of the methodology in the previous paragraph. Also, it requires reporting of all impact categories (water use, fossil depletion, etc.) rather than only GHG emissions and the purpose of the methodology is for use in European policy rather than corporate carbon Accounting. Therefore, the GHG Protocol has been selected as the best guidance for the non-biomass project types. The GHG Protocol is in line with the ISO standards and provides more specific guidance for companies than ISO itself. The GHG Protocol could be used for biomass project types as well, though is less detailed than BioGrace-II and does not provide specific guidance on cultivation, harvesting and other biomass specific processes.

2.3 Similarities and Differences between the Selected GHG Calculation Methodologies

More specific similarities and differences between these two selected GHG calculation methodologies have been analyzed and are shown in the tables below.

As shown in Table 1, the BioGrace-II methodology assumes that biogenic[6] CO_2 is carbon neutral and treats these emissions as zero. This is based on an assumption that uptake of CO_2 into biomass over the lifetime of the crop and emissions from use of biomass are balanced. However, this is an area of scientific and political debate and there is no general consensus and/or detailed guidance on how to account for biogenic carbon emissions at this time. The IPCC has issued a Q&A that determines biomass for bioenergy should not automatically be considered carbon neutral, but the scientific body will not issue updated guidance until the next Assessment report in 2019.[7] Meanwhile, the core of the discussion centers around whether the temporal pulse of emissions from bioenergy should be accounted for instead of assuming automatic neutrality considering the timeframe for significantly lowering carbon in the atmosphere is the next several decades.

While the RED and BioGrace-II do not take biogenic CO_2 emissions into account, other standards and protocols such as the GHG Protocol, ISO14067 and a recent protocol issued by ARENA[8] (Australian Renewable Energy Agency) require biogenic CO_2 emissions to be included in the total emissions value and reported separately in the inventory results, as a disaggregated value. The assumption that biogenic CO_2 emissions are zero may therefore result in an overestimation of the GHG benefits of biomass-based RHC projects. However, specific guidance on how to calculate the biogenic emissions is still lacking. Academia has proposed a method called GWP_{bio} that could merit further exploration and discussion.[9]

Recently, Chatham House, the UK Royal Institute of International Affairs, published a report[10] arguing that wood-based renewable energy sources are not carbon neutral. The report asserts that *"harvesting of whole trees for energy will in almost all circumstances increase net carbon emissions very substantially compared to using fossil fuels*." On the other hand, in a rebuttal[11] to the Chatham House report, IEA Bioenergy (International Energy Agency Bioenergy Technology Collaboration Programme) together with 125 scientists raised their concerns that the Chatham House report considers "*inaccurate interpretation of the impact of harvesting on forest carbon stock,*" considers "*roundwood to be the main woody bioenergy feedstock*" and fails "*to acknowledge that forest bioenergy is not a single entity but an integral part of the forest management, forestry and energy-industry system that also produces material products.*"

In this report, we apply the BioGrace-II methodology in the GHG emission calculations of the biomass projects (see Section 3.1 below), and given the lack of consensus on how to account for biogenic carbon emissions consider biomass as being carbon neutral. As indicated previously, BioGrace strictly follows the GHG methodology that is published by the European Commission. Should the European Commission publish any update to the methodology, then BioGrace will update its

---

[6] In the context of the study, biogenic carbon emissions are defined as CO_2 emissions related to the natural carbon cycle, as well as those resulting from the combustion, digestion, decomposition, or processing of biologically based materials. [Adapted from: https://19january2017snapshot.epa.gov/climatechange/carbon-dioxide-emissions-associated-bioenergy-and-other-biogenic-sources_.htm)

[7] https://www.ipcc-nggip.iges.or.jp/faq/faq.html (see Q2-10)

[8] https://arena.gov.au/wp-content/uploads/2016/05/AU21285-ARENA-LCA-Guidelines-AW2.pdf

[9] http://onlinelibrary.wiley.com/doi/10.1111/j.1757-1707.2011.01102.x/full

[10] https://www.chathamhouse.org/publication/woody-biomass-power-and-heat-impacts-global-climate

[11] http://www.ieabioenergy.com/publications/iea-bioenergy-response/

methodology and calculation tools accordingly. We therefore recommend that companies regularly (e.g., once a year) check the BioGrace website for any methodology updates.

Table 1. Similarities Relevant for Heat Supply Accounting between GHG Protocol and BioGrace-II

	GHG Protocol	BioGrace-II
Functional unit requirement	Magnitude, duration/ lifetime, and expected level of quality of the function or service. (Corporate Standard)	Final emissions are reported as gCO_{2eq}/MJ of biomass product.
Allocation rules for (by)products (like heat)	1. Avoid allocation by subdivision or system expansion 2. Physical allocation (for energy) 3. Allocation based on another relation e.g., economic value (Scope 2 Guidance, Value Chain Standard, and Product Standard)	Allocation based on the ratio of heating values, except for allocation to heat.
Allocation for waste	Definition: waste that has no economic value. No allocation to waste (except for scope reporting category 5 and 12). (Value Chain Standard and Product Standard).	No allocation to wastes[12], agricultural crop residues, including straw, bagasse, husks, cobs and nut shells, and residues from processing, including crude glycerin (glycerin that is not refined), up to the process of collection of those materials.
Biogenic carbon emissions	Emissions & removals from biogenic sources are included in the inventory results and reported separately. CH_4 and N_2O emissions should be included. (Corporate Standard, Scope 2 Guidance, and Product Standard).	Emissions of CO_2 from combustion of biomass are treated as zero. CH_4 and N_2O emission from combustion (either during processing or in final conversion) shall be included. Biogenic CO_2 emissions from the use of forest based biomass for energy are NOT included. This is a topic of discussion.
Reporting (in)direct land use change	Direct land use change included is similar to IPCC Guidelines (within 20 years). Indirect land use change is excluded. (Corporate Standard and Product Standard).	Land use change is calculated based on IPCC Guidelines. Indirect land use change is excluded[13].
CHP guidance	Based on the energy value of the different products (physical allocation). (Scope 2 Guidance and Allocation of GHG of CHP Plant).	Specifically based on exergy value.

[12] "Waste" means any material or object that the holder intends to discard after following the waste hierarchy that is: a) prevention, b) preparing for re-use, c) recycling, d) other recovery, e.g., energy recovery and e) disposal.

[13] For more information about indirect land use change please refer to GLOBIOM study: http://www.globiom-iluc.eu/

Table 2. Differences for Heat Supply Accounting between GHG Protocol and BioGrace-II

	GHG Protocol	BioGrace-II
Cut-off criteria	No cut-off allowed. Provide exclusions. (Corporate Standard and Product Standard)	Emissions contributing <0.1 gCO_{2eq}/MJ of total solid or gaseous fuel.
Reporting renewable electricity	Obligatory reporting of both location-based and market-based method for Scope 2. RECs are allowed. (Scope 2 Guidance)	Location-based method for electricity reporting. RECs are not allowed.
Allocation of waste heat	Emissions from steam, heat, or cooling that is received via direct line as “waste” from an industrial process should still be reported based on the underlying emissions from the original generation process. (Scope 2 Guidance)	No guidance.
Biomass specific guidance	No specific guidance on cultivation, harvesting, processing & transport emissions and soil N_2O.	Very specific guidance on cultivation (including soil N_2O), harvesting, processing & transport emissions.
Manure management	Avoided emissions can be included in inventory. They may be reported separately. (Corporate Standard)	For manure use as substrate a bonus of 45 gCO_{2eq}/MJ manure is added for improved agricultural and manure management.
Availability of default emission factors for heat	No default values for heat available.	Default values for heat available in gCO_{2eq}/MJ.

3. PROJECT TYPES

In this chapter the carbon accounting is described for six different projects for production of heat, cooling, and electricity. The six projects differ in their source of heat supply; four biomass-based projects (projects 1-4 from the list below) and two non-biomass projects (projects 5 and 6 from the list below). The two selected protocols, i.e., BioGrace-II and the GHG Protocol are used; BioGrace-II is used for carbon accounting of the biomass projects and GHG Protocol is used for carbon accounting of the non-biomass projects. The projects are listed below:

- Wood chips from virgin forestry
- Wood chips from forestry residues
- Wood chips from industry residues
- Biogas and biomethane from manure and silage (maize and triticale)
- Recovered heat from fossil fuel use
- Ground source heat pump

First, a short project description is provided, including the process that is followed to produce heating or cooling.

3.1 Thermal Energy from Biomass Projects for Heating and Cooling

Biomass-fired boilers are commonly used for the production of hot water or steam, and typically provide around 1 to 10 megawatts in heating capacity. The steam can be used for drying processes as well as for electricity production via a steam turbine. With larger units, cogeneration of electricity and heat via a steam turbine is possible and is referred to as a combined heat and power (CHP) plant.

The processes in the whole supply chain (in a cradle-to-gate scope) of heat generation from biomass sources, e.g., wood chips, pellets, biogas and biomethane, generally include cultivation and harvesting, storage, transport (may include several transport steps) and processing (may include several processing steps). Different methodologies may define different system boundaries of the GHG calculation for end-of-life products, by-products, and residues.

BioGrace-II uses the following formula to calculate the GHG emissions from the production of solid and gaseous biomass fuels, before the conversion to electricity, heating, and cooling.14

Equation 1

$$E = e_{ec} + e_l + e_p + e_{td} + e_u - e_{sca} - e_{ccs} - e_{ccr}$$

Where:

E = total emissions from the use of the fuel before energy conversion
e_{ec} = emissions from the extraction or cultivation of raw materials
e_l = annualized emissions from carbon stock changes caused by land use change; this takes into account above and below ground biomass, soil organic carbon, soil litter and dead wood

[14] BioGrace II methodological background document: http://www.biograce.net/app/webroot/biograce2/content/ghgcalculationtool_electricityheatingcooling/overview

e_p = emissions from processing
e_{td} = emissions from transport and distribution
e_u = emissions from the fuel in use (CH_4 and N_2O, CO_2 set as zero)
e_{sca} = emission savings from soil carbon accumulation via improved agricultural management
e_{ccs} = emission savings from carbon capture and geological storage
e_{ccr} = emission savings from carbon capture and replacement

Emissions from the manufacture of machinery and equipment are not taken into account.
The greenhouse gases taken into account for the calculation of emissions are CO_2, CH_4 and N_2O with global potential warming of 1, 25 and 298, respectively.

As mentioned in Section 2.1, BioGrace-II follows the methodology for solid and gaseous biomass set out by the European Commission.

There are few important aspects that require attention of companies when calculating the GHG emissions of biomass projects using this methodology:

- **Wastes and residues[15] shall be considered to have zero** life cycle GHG emissions up to the process of collection of those materials. Therefore, for forestry or industry residues only the emissions associated with collecting, processing, and transporting the residues are considered and upstream emissions related to the cultivation of the main source (wood) are not included in the GHG emission calculations.
- **Biogenic CO_2 emissions from the combustion of biomass are assumed to be zero** and are not included in the GHG emissions calculations (please refer to Section 2.3 for discussion about this assumption).
- **Calculation of land use change (LUC) emissions** is required for direct changes in IPCC land status type, however, conversion of natural forests to plantation forests is not (explicitly) covered.
- **Calculation of indirect land use change (ILUC) emissions** are not included in the GHG emissions calculations since it cannot be measured but only modeled.[16] Because ILUC occurs through global market mechanisms with many direct and indirect effects, it can only be modeled, not measured. The best available source for ILUC emissions is by far the GLOBIOM study.[17]
- **Please note** that the above-listed aspects may result in an overestimation of the GHG benefits from using biomass as an energy source.

To determine the total life cycle GHG emission, the emission from conversion of solid and gaseous biomass to electricity and/or heating or cooling the following formula are applied:
For installations delivering only heat:

Equation 2

$$EC_{heat} = E / \eta_{heat}$$

For installations delivering only electricity:

[15] Wastes and residues include secondary biomass and primary forest and agricultural crop residues, including tree tops and branches, straw, bagasse, husks, cobs and nut shells, and residues from processing, including crude glycerin (glycerin that is not refined).
[16] ILUC occurs through global market mechanisms with many direct and indirect effects, thus it can only be modeled, not measured.
[17] http://www.globiom-iluc.eu/globiom-model/

Equation 3

$$EC_{electricity} = E / \eta_{electricity}$$

Where:
EC_{heat} = Total GHG emissions from production of heat
$EC_{electricity}$ = Total GHG emissions from generation of electricity
E = Total GHG emission from the solid or gaseous biomass
$\eta_{electricity}$ = Electrical efficiency, defined as the annual electricity produced divided by the annual fuel input
η_{heat} = Thermal efficiency, defined as the annual useful heat output, that is heat generated to satisfy an economically justifiable demand for heat, divided by the annual fuel input

For cogeneration units, such as CHP, providing heat and electricity, the emissions are allocated to heat and electricity using the Carnot efficiency. For further details, please refer to BioGrace-II methodological background document.[18]

To determine the emission savings from use of biomass for production of electricity and/or heat or cooling, the emissions are compared against emission intensity of relevant fossil fuel comparators according to the following formula:

Equation 4

$$\text{Savings: } (EC_F - EC_B)/EC_F * 100$$

Where:
EC_F = Total emissions from the fossil fuel comparator for electricity, heating, cooling or biomethane
EC_B = Total emissions from the electricity, heating, cooling or biomethane

The fossil fuel comparators included in this report are:

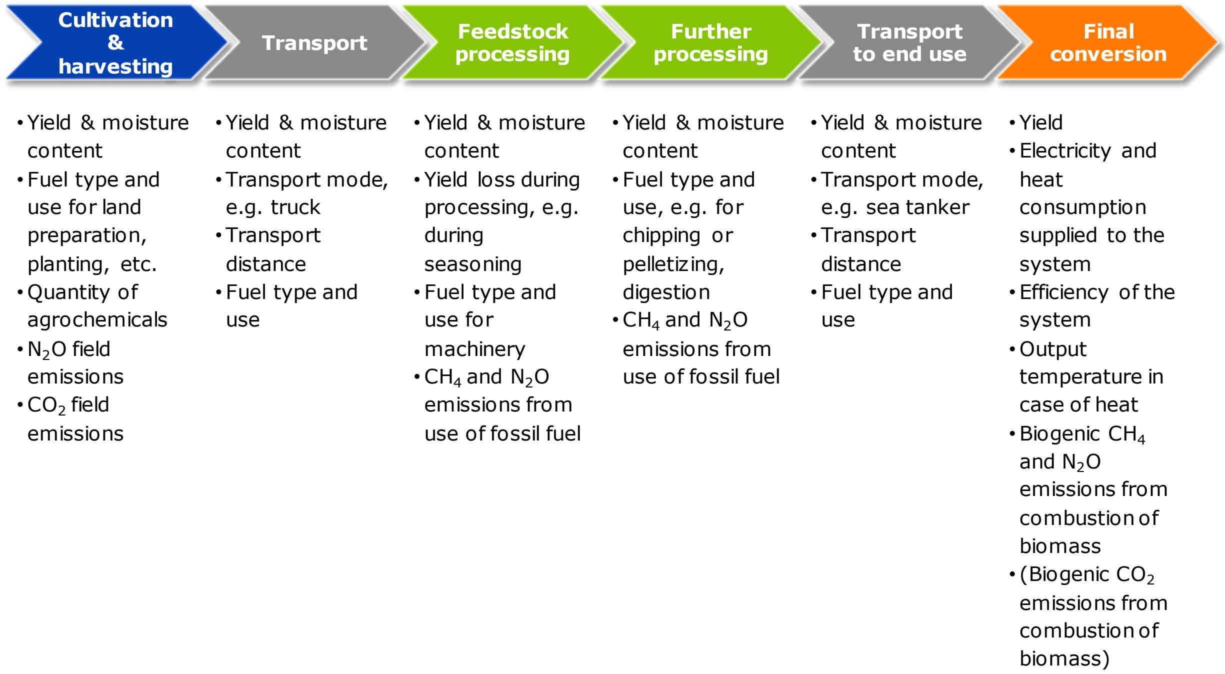
Electricity = 186 gCO_{2eq}/ MJ; Heating = 80 gCO_{2eq}/ MJ; Cooling = 47 gCO_{2eq}/ MJ; natural gas (biomethane comparator) = 72 gCO_{2eq}/ MJ

Actual values for all the relevant elements in the GHG emission calculation equation (Equation 1) have to be provided. These values are typically reported by each operator along the supply chain and transferred through the supply chain to the final fuel supplier.

A generic pathway for the production of electricity and/or heating or cooling from biomass sources and relevant sources of GHG emissions per each step of the supply chain are depicted in Figure 4, along with other key parameters that are necessary for undertaking GHG emission calculations (e.g., yield).

[18] http://www.biograce.net/app/webroot/biograce2/content/ghgcalculationtool_electricityheatingcooling/overview

Figure 4. Generic pathway for the production of electricity and/or heating or cooling from biomass sources; examples of sources of GHG emissions are provided below each step. Note that biogenic CO_2 emissions from the combustion of biomass are treated as zero in the BioGrace-II methodology. We recommend that companies calculate and record the biogenic CO_2 emissions separately.



From Figure 4 it can be seen that, for example, the GHG emissions from the production of raw materials includes emissions from cultivation and harvesting activities, such as emissions from use of agricultural machinery, emissions from production, transport and use of agrochemicals, N_2O emission from field and CO_2 emission from field which occurs due to acidification. To calculate these emissions, relevant inputs such as type and quantity of fuels used for cultivation and harvesting activities, the quantity and type of agrochemicals (fertilizers, pesticides, herbicides, etc.) are required.

The input values are further converted to GHG emissions using “standard values” (i.e., emission factors expressed as gCO_{2eq} per unit quantity of the element). In this report, the standard values were obtained from the BioGrace-II list of standard values.

Emissions from each step shall be corrected for the moisture content of the input and losses between different steps (follow the calculation steps in the accompanying Excel file and refer to the European Commission note[19]).

3.1.1 Wood Chips from Virgin Forestry

Virgin forestry includes short rotation coppice (SRC) with a 2- to7-year rotation, short rotation forestry (SRF) with 8- to 20-year rotation and conventional forestry operation with a rotation period of over 20 years. Virgin forestry such as willow, poplar and eucalyptus are commonly cultivated for wood pulping and other wood industries, however their use for bioenergy is not yet common practice. For the purpose of this project type we consider eucalyptus (as a SRF) production.

---

[19] https://ec.europa.eu/energy/sites/ener/files/documents/Note%20on%20GHG%20final.pdf

Figure 5 shows an example pathway for the production of electricity and/or heat or cooling from virgin forestry.

Cultivation: This is the establishment through planting or seeding of the plantation. The GHG emissions resulting from cultivation includes all the activities related to the production of raw material (wood). Calculations typically include emissions from fuel usage in machinery (e.g., for planting, soil preparation, etc.), from the production and use of agro-chemicals (e.g., pesticides, fertilizers), from field emissions (N_2O and CO_2 emission from soil) and from land use change (emissions due to changes in carbon stock between the reference land and the actual land in use).

Harvesting: Eucalyptus is typically harvested as chips. Emissions from this step could include fuel usage of machineries for chipping, collecting etc.

Chips seasoning: Chips are commonly stored for 3–8 months in a storage facility. During storage, losses of dry matter can happen due to bacterial activity and may result in CH_4 emissions to the atmosphere. For the storage, emissions from electricity usage and possible CH_4 emissions need to be accounted for in calculations of GHG emissions.

Transport: This includes any transport from the point of production along the supply chain to the end user. Depending on the distances to the next (or final) destination, different transport modes, i.e., trucks, trains, and bulk carriers, are used for the transportation of woodchips. Emissions from transport steps include emissions from fuel usage, for both loaded transport mode to the destination and unloaded transport mode back to the original location. In case of eucalyptus, transport may include transport of chips to a sea terminal, where they are stored to reduce their moisture content, and following this the final transport to end user.

Use in CHP: CHP is used to combust the biomass feedstock to generate electricity, heat, and steam. In general, when a CHP is used the following information needs to be provided for the calculation of emissions: fuel type, total fuel energy input, net 'useful' power output (i.e., gross power produced by the electric generator minus any parasitic electric losses), net 'useful' heat output (i.e., gross useful thermal output of the CHP system minus the thermal input), power and heat exported.

Figure 5. Example of pathway for the production of electricity and/or heat or cooling from virgin forestry

3.1.2 Wood Chips from Forestry Residues

In forest plantations, wood is grown to maximize the volume of high quality wood such as veneer. The lower quality part of wood may be used in pulping or fiber boards. What remains after these log products are wood residues including branches, bark, tree tops, tree stumps, stem wood, etc.

Within the production process of wood chips from forestry residues the following steps are relevant (See Figure 6):

Cultivation: Based on the BioGrace-II methodology the emissions from this step are zero since the feedstock is a residue.

Harvesting: Based on the BioGrace-II methodology the emissions from this step are zero since the feedstock is a residue.

Forest residue collection: The following steps are generally included in the collection of forestry residues: Forwarding, bundling/lifting, forestry machinery transport, Load/unload. Emissions from the energy use of these collection processes need to be calculated.

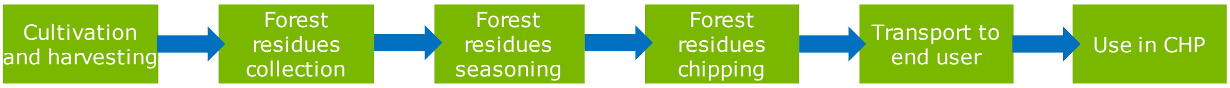
Forest residue seasoning: Seasoning is commonly performed to reduce the moisture content of wood prior to its transportation. The seasoning is typically done at the roadside for about 3–12 months to reduce the moisture between 50% to 30%. However, during seasoning a portion of dry matter losses occur due to bacterial activities and may result in CH_4 emissions to the atmosphere, which needs to be accounted for in the calculations of GHG emissions.

Forest residue chipping: The collected forest residues are loose bundles of varying sizes. As a result, an additional process for chipping is necessary. The emissions resulting from this step including use of diesel for machinery, electricity, etc. need to be accounted for.

Transport: Please refer to transport point under Section 3.1.1.

Use in CHP: Please refer to use in CHP point under Section 3.1.1.

Figure 6. Example of pathway for the production of electricity and/or heat or cooling from forestry residues



3.1.3 Wood chips from Industry Residues

Cultivation: Based on the BioGrace-II methodology the emissions from this step are zero since the feedstock is a processing residue.

Harvesting: Based on the BioGrace-II methodology the emissions from this step are zero since the feedstock is a processing residue.

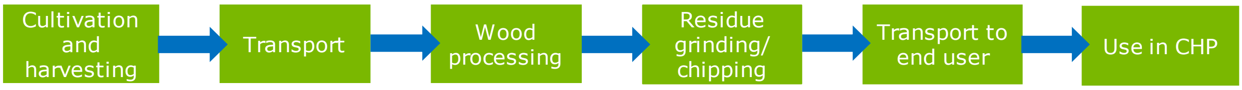
Wood processing: Includes any processing for the production of the main product up to and including the step at which the wood residue is produced. Emissions from energy usage in machinery need to be accounted for in calculations of GHG emissions.

Residue grinding/chipping: The residues are usually delivered as small chips with reduced moisture and thus do not require any additional processing before being transported.

Transport: Please refer to transport point under Section 3.1.1.

Use in CHP: Please refer to use in CHP point under Section 3.1.1.

Figure 7. Example of pathway for the production of electricity and/or heat or cooling from industry residues



3.1.4 Biomethane from Manure and Silage (Maize and Triticale)

Anaerobic digestion, a process which takes place in the absence of oxygen and the presence of microbes, is used for decomposition of organic matter such as plant materials, sewage waste, animal manure, organic waste, and industrial wastes. The process of decomposition produces biogas, a mixture of CH_4 and CO_2, which can further be upgraded to biomethane. The upgrading process includes purification of the biogas to optimize the biomethane yield. Biomethane can be injected to the gas grid for further application in heat generation.

Depending on the scope, different steps including cultivation and harvesting, storage, transport, digestion processing, upgrading processing and end use phase could be considered as system boundary of the GHG emissions calculations (Figure 8).

Cultivation: For agricultural substrates the same description as cultivation point under Section 3.1.1 applies. For wastes and residues substrates, if the BioGrace-II methodology is used, the emissions from this step are zero.

Harvesting: For agricultural substrates the same description as cultivation point under Section 3.1.1 applies. For wastes and residues substrates, if the BioGrace-II methodology is used, the emissions from this step are zero.

Digestion process: The electricity consumption for the digestion process could be different for different feedstocks. In the case of production of biomethane, the heat for the digester is provided by an external biogas boiler. Emissions from electricity usage and external heat need to be considered in calculations of GHG emissions.

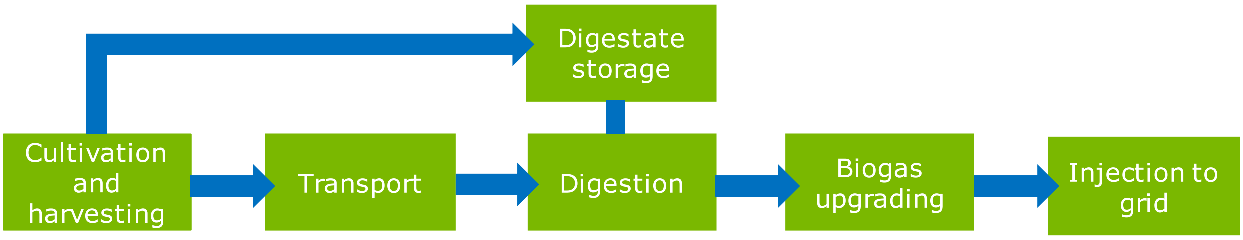
Digestate storage: Once collected from the digester, the digestate must be stored before it is again applied to the fields as a fertilizer. However, the digestion process continues during the storage period, and the gases released can have a significant impact on the final GHG balance of the pathway. The digestate can be stored in either an open or a closed tank: with the latter option, the additional biogas released during storage is recovered; with the former, CH_4 and N_2O are released to the atmosphere, which need to be taken into account in the calculation.

Biomethane upgrading: There are different technologies for biogas upgrading to biomethane. These technologies could be combined with off-gas treatment which oxidize CH_4 in off-gas to CO_2 in order to minimize CH_4 slip to the atmosphere. Depending on the upgrading technology, emissions from this step could include emissions from energy usage (e.g., electricity, heat) of the process, from production of chemicals in use and from CH_4 leakage.

Transport: Please refer to transport point under Section 3.1.1.

Injection to grid: Biomethane is commonly transported through injecting to gas grids. During injection, CH_4 leakage might occur. Therefore, emission due to possible CH_4 leakage needs to be considered in calculations of GHG emissions. In addition, emissions from energy usage in pumps need to be included.

Figure 8. Example of pathway for the production of biogas via anaerobic digestion of manure and silage (maize and triticale) and upgrading to biomethane

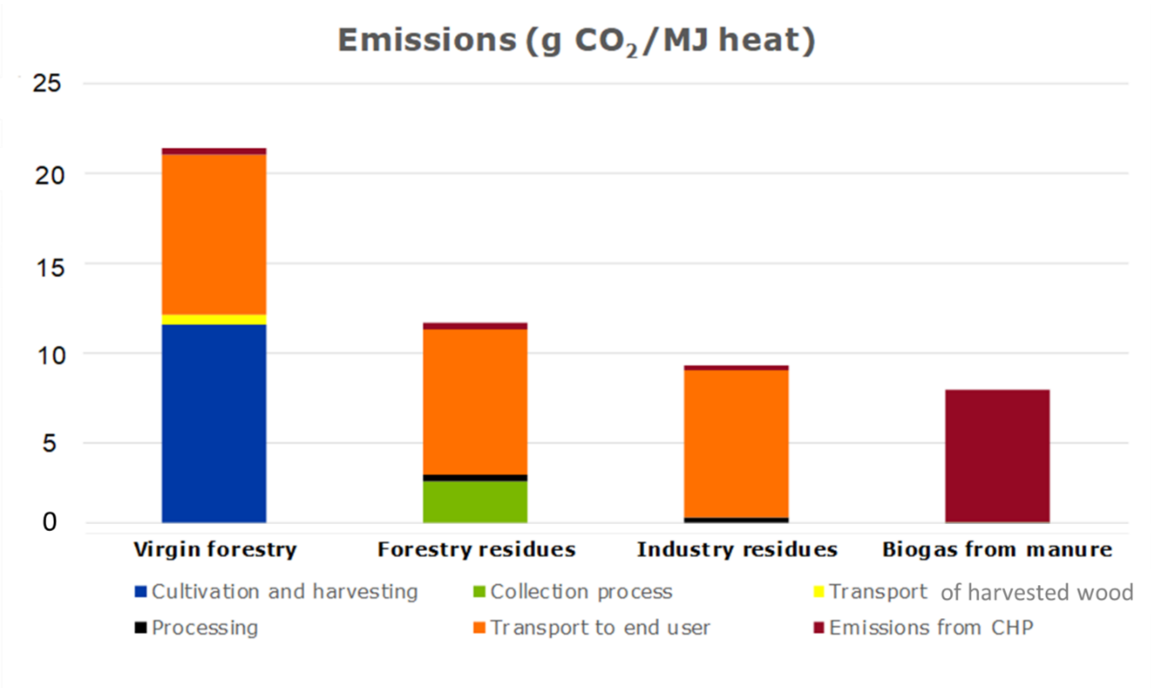


3.2 Overview Results of Biomass Pathways

Figure 9 represents the emissions per each step along the supply chain for the production of heat from different biomass projects. Emissions are calculated following the BioGrace-II methodology and are reported per MJ heat that is produced in a CHP unit**.** For simplification, we only show biogas production from one substrate, manure, in this figure. Biomethane is not shown for consistency reasons since biomethane is injected to grid rather than burnt in a CHP unit.

Please note that biogenic CO_2 emissions are not taken into account (as discussed in Section 2.3 and Section 3.1) in the results reported in Figure 9. If the biogenic CO_2 emissions are taken into account, the net GHG emission from virgin forestry will be impacted more significantly compared to other biomass project types due to relatively longer carbon payback period of virgin wood.

Figure 9. GHG emissions per step along the supply change for production of heat from different biomass pathways; actual input values were used for GHG emission calculations of all the steps; calculations were undertaken following the BioGrace-II methodology.



As can be seen from Figure 9, the main contributor to the GHG emissions is the cultivation and harvesting step. Upstream emissions, including cultivation and harvesting, for forestry residues,[20] wastes and industry residues are zero as explained earlier (Section 3.1, footnote 14). The second largest emissions originate from the transportation of solid fuels (as referred here to wood chips) to the end user. Transport emissions are direct consequence of the assumed distance, hence shorter the distance less the emissions are. In case of biogas, it is assumed that biogas is produces close to an agricultural field and requires a short transport distance; therefore, the transport emissions from biogas production are small. Solid fuels have large densities, require heavier transport modes (heavy trucks or carriers), and commonly transport longer distances to the final destination.

Emissions from CHP units are largely associated with CH_4 and N_2O emissions. These emissions are more significant in case of manure since it has high content of C and N which tend to be converted to CH_4 and N_2O in an aerobic/anaerobic environment.

The total GHG emissions from the use of manure for heat production via anaerobic digestion is negative (-47 gCO_{2eq}/MJ heat, not shown on the figure). The negative emission is due to avoided CH_4 and N_2O oxide emissions resulting from improved manure management via anaerobic digestion. The avoided emissions (-88 gCO_{2eq}/MJ biogas) are calculated based on a credit of 45 gCO_{2eq}/MJ manure (36.8 and 8.3 gCO_{2eq}/MJ manure of prevented CH_4 and N_2O emissions respectively), that is allocated to use of manure as feedstock. The BioGrace-II GHG calculation methodology includes the credit under the category "emission savings from carbon accumulation via improved agriculture management" (e_{sca} in Equation 1). This approach is consistent with the updated GHG calculation methodology published by the EC in 2014 (SWD(2014) 259 final).

It must be noted that:

- The inputs used for the calculations of GHG emissions for production of heat from biomass pathways are arbitrary and may significantly change when using the actual values. The users have to input in the respective Excel sheets the actual values for each element of the calculations.
- The inputs shown in Figure 4 are purely illustrative - other emissions must be included (provided that they are within the scope of the system boundary).
- The system boundaries given for each biomass project in the sections above are only an example and differ for different methodologies.
- In our calculations, for simplification reasons, the emissions from land use change (e_l), emissions saving from carbon capture and replacement (e_{ccr}) and emissions saving from carbon capture and geological storage (e_{ccs}) assumed to be zero for all the biomass projects.
- To our knowledge, BioGrace-II is the most comprehensive publicly available methodology for calculating GHG emissions from biomass for heating and cooling purposes. However, we acknowledge that the current BioGrace-II methodology lacks guidance on how to treat biogenic CO_2 emissions from the use of biomass for energy, since it strictly follows the methodology published by the European Commission (DG ENER and JRC). The BioGrace-II tool helps companies and advisors to comply with the European sustainability criteria for solid and gaseous biomass which have been decided upon by policymakers and will implement other methodological gaps, such as impact of biogenic CO_2 emissions, when policymakers decide how to deal with them. Moreover, to our knowledge, there is currently no other

[20] The 'RED' methodology, as applied by BioGrace, assumes that *"Wastes, secondary biomass and primary forest and agricultural crop residues, including tree tops and branches, straw, bagasse, husks, cobs and nut shells, and residues from processing, including crude glycerin (glycerin that is not refined), shall be considered to have zero life-cycle greenhouse gas emissions up to the process of collection of those materials."* As such, rice straw and corn stover (agricultural residues) would be treated the same as forestry residues.

published GHG methodology that includes a detailed calculation guidance of biogenic CO_2 emissions from the use of biomass for energy. We recommend to report biogenic emissions separately, per the GHG Protocol. The GWP_{bio}, developed by Cherubini et al., may be a viable methodology to make the calculation.[21]

- With regard to land use change calculations, BioGrace-II follows the European Commission methodology (which is largely based on the 2006 IPCC Guidelines for National Greenhouse Gas Inventories) and does not cover conversion of natural forests to plantation forests. If a natural forest is replaced by a plantation forest, then the associated direct LUC emission impact would still need to be considered. However, this is not made explicit in the guidance.
- We therefore suggest using BioGrace-II as the calculation methodology and report the biogenic CO_2 emissions separately (as recommended by the GHG Protocol).

3.3 Non-Biomass Project Type

For production of heating and cooling from non-biomass sources we considered ground source heat pumps and heat recovered from fossil fuels use. These project types are explained in the following sections.

3.3.1 Ground Source Heat Pump

With a ground source heat pump (GSHP) the heat from the ground is absorbed into a fluid and circulated through buried pipes. This absorbed heat is used, or exchanged, to produce hot water or hot air. As the ground stays at a fairly constant temperature under the surface, a GSHP can be used throughout the year.

To allocate the carbon emissions of a heat pump two parameters need to be considered, see Figure 10:

- The amount of electricity used to drive the heat pump;
- Refrigerant losses within the heat pump.

The amount of electricity can be calculated from the coefficient of performance (COP). The COP is defined as the ratio between useful heat supplied by the heat pump and the electricity required by the system.

The maximum theoretical efficiency for heating application can be calculated as follows:

Equation 5

$$COP = T_{hot} / (T_{hot} - T_{cold})$$

This formula shows that the higher the temperature difference, the lower the efficiency. The formula can be used if one does not know the COP of a heat pump, this can be estimated using the temperatures of the hot and the cold reservoir. The actual COP will be lower due to system inefficiencies. Furthermore, whereas the cold reservoir (the ground) is rather constant in temperature, the hot reservoir (the process that requires heat) might vary in temperature over the year. This aspect is covered in the Seasonal Performance Factor (SPF), which varies per climate region. However, for industrial applications we assume that the temperature of the heat demand is fairly constant over the year. Therefore, in most cases the COP is appropriate.

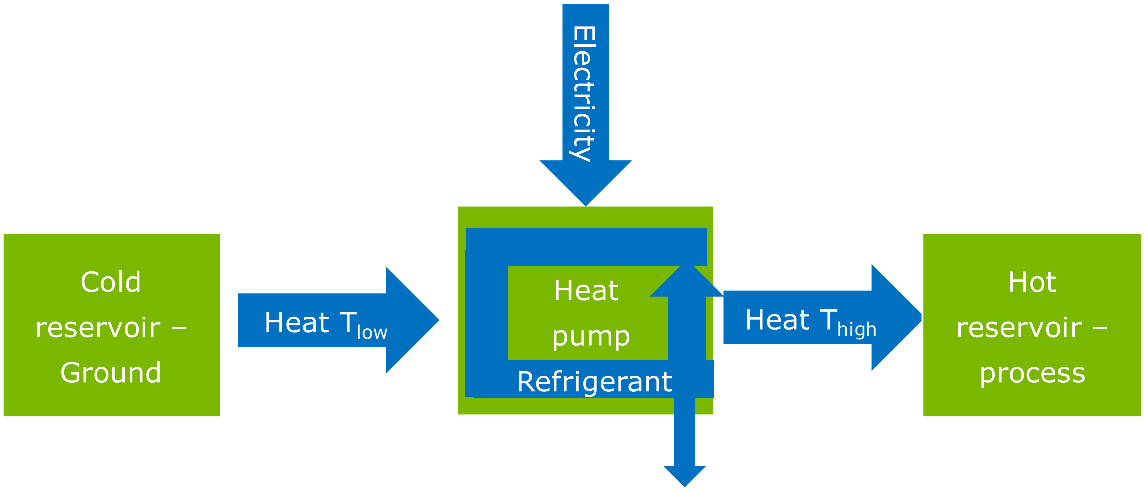
---

[21] CO_2 emissions from biomass combustion for bioenergy: atmospheric decay and contribution to global warming Cherubini et al (2011), : http://onlinelibrary.wiley.com/doi/10.1111/j.1757-1707.2011.01102.x/full

GHG emissions of GSHPs can come from two sources:

- Indirect emissions from the use of electricity
- Direct emissions form the losses of refrigerants

Figure 10. Schematic representation of a heat pump system



Following the GHG Protocol, the carbon emissions of **electricity** can be determined through two methods:

- Market-based
- Location-based

For a *location-based method* the average emission intensity of the electricity grid at the location where consumption occurs is used. A *market-based method* uses the emission intensity of the electricity that companies chose on purpose. These emission factors are derived from contractual instruments. Markets differ as to what contractual instruments are commonly available or used by companies to purchase energy or claim specific attributes about it, but they can include energy attribute certificates (RECs, GOs, etc.), direct contracts (for both low-carbon, renewable, or fossil fuel generation), supplier specific emission rates, and other default emission factors representing the untracked or unclaimed energy and emissions (termed the residual mix) if a company does not have other contractual information that meets the Scope 2 Quality Criteria.

When a company has an operation in a market where product or supplier specific data in the form of contractual instruments is provided, then companies have to account and report Scope 2 emissions in two ways and label each result according to the method: one based on the location-based method, and one based on the market-based method. If companies only have operations in markets without product or supplier specific data, then only the location-based emissions need to be reported.

Some refrigerants that are used have a global warming potential. Therefore, losses of refrigerant should be accounted for as well. The GHG Protocol does not state a method that needs to be used. In order to calculate the emissions of the refrigerant, information is required on the type of refrigerant and its global warming potential and the total losses per heat unit.

3.3.2 Heat Recovered from Fossil Fuel Use

Currently, the heat demand of industrial processes is mainly supplied by fossil fuel based processes. Residual heat of these processes is often dispatched to the environment and is therefore considered as waste heat with no value. However, once this heat is recovered and used, it is not waste heat anymore and therefore has a value. According to the GHG Protocol emissions should be allocated to all product streams that have a value.

Heat can be recovered from various streams, such as hot flue gases from a diesel generator or steam from cooling towers or even wastewater from different cooling processes. The recovery is done using a waste heat recovery unit such as heat exchangers, regenerators, heat pumps etc. After heat recovery, the heat is transported through pipes to a location where the heat can be used again.

Based on the definition of the International Energy Agency (IEA), the heat that is recovered from fossil fuel use is not considered to renewable energy. The IEA states in the Energy Statistics manual that Renewable heat is generated from a renewable source of energy which is defined as “energy that is derived from natural processes that are replenished constantly.”[22] Still it is argued that the residual heat should not be wasted, and therefore using it could be considered as sustainable heat. In fact, when heat is recovered and used within the same process, the energy efficiency of the process is improved. Heat recovery can then be considered to be an energy efficiency measure.

The methods for carbon accounting of residual heat that originates from fossil fuels are currently being discussed. As such, there is no widely accepted method at this time. The GHG Protocol provides a general guidance on carbon accounting. However, due to the room for interpretation in the guidance, the results can differ significantly. An explanation of the guidance and the most important discussion points are discussed in the following paragraph.

According to the GHG Protocol all flows that have a value should be taken into account in the emissions allocation. It requires that companies first try to avoid allocation wherever possible. If that is not possible, companies have to allocate emissions based on an underlying physical value of the product under consideration and co-products, rather than on economic values. Economic values can be difficult to establish and are subject to price impacts and inflation. However, once established, economic values can be easily compared and aggregated. Physical values are constant, but comparison between different materials and energy flows can be difficult.

As there is no widely accepted approach for allocation of emissions to recovered heat, we propose an approach that is in line with the GHG Protocol. This approach takes into account the value of the recovered heat in physical terms, namely the ability to perform work. This is known as the exergy value. For heat flows the exergy value can be calculated by using the Carnot factor. The Carnot factor accounts for the fact that 100 MJ of 1000°C has more value, i.e., you can do more work with it, than 100 MJ of 100°C.

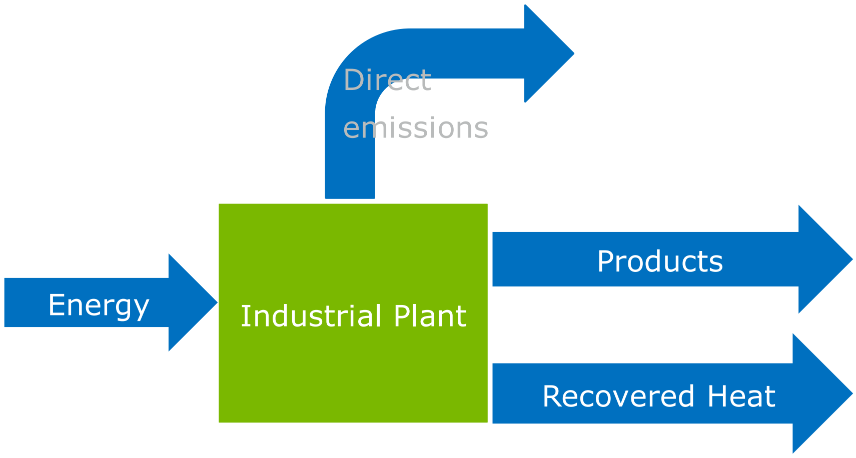
Calculating the exergy value of energy carriers is less straightforward as it depends on the reference system that is used. This is a thermodynamic consideration that is beyond the scope of this report. The difference between lower heating value and exergy value of most fossil fuels is in the order of a few percent. Since it is difficult for an industrial user to determine the exergy value of a fuel, we recommend using the lower heating value.

In Figure 11 a simplified visualization is given of an industrial process. The emissions related to the enthalpy (LHV of the fuel) that goes into the industrial plant need to be allocated to the recovered heat energy and the products. The share in emissions is determined by exergy of the recovered heat in relation to the enthalpy that goes in.

---

[22] https://www.iea.org/publications/insights/insightpublications/Insights_Renewable_Heat_FINAL_WEB.pdf

Figure 11. Schematic representation of an industrial process with heat recovery



The emissions that have to be allocated to the product is of no concern in the scope of these calculation rules for sustainable heat. Allocation of emissions to products can happen in other situations. For instance, in emission trading systems all emissions can be attributed to the product and no correction is made for emissions that may be attributed to recovered heat. This is considered to be acceptable as long as the systems are not mixed up. Once one starts aggregating all allocated emissions, extra care should be paid to avoid double counting. Since this is not the aim of these calculation rules, we consider that this is not problematic.

One of the main discussion points that is hindering the agreement on one method for carbon allocation for this case is the fear of a lock-in situation. For a climate neutral heat supply, the use of fossil fuels should be minimized. Building an infrastructure for heat transport from a source that is based on fossil fuels could lead to a reliance to this source for heat. This reliance could hinder the transition to renewable heat supply.

4. CONCLUSIONS AND RECOMMENDATIONS

In this document we propose appropriate calculation methods for six project types to provide renewable heating to industrial processes. The calculation methods we propose are based in BioGrace-II for biomass-based project types and on the GHG Protocol for ground source heat pumps and recovered industrial heat.

Since establishing carbon accounting rules for renewable heating and cooling is a relatively new field, we realize that all is not set in stone and acknowledge ongoing debates on specific topics.

Nevertheless, we found that consensus has already been achieved on many detailed aspects. For biomass project types, there is consensus on the inclusion of most of the components of the supply chain. However, two main areas of discussion remain which have not been settled in the existing protocols and guidelines. These concern the following two questions:

- How to account for biogenic emissions?
- How to account for indirect land use change?

The discussion is primarily focused on virgin wood (e.g., roundwood), rather than on wood wastes or residues. We therefore recommend that companies take a precautionary approach in its use of biomass and utilize wood waste and residues for RHC, and furthermore to report the associated biogenic emissions as a memo item (as is required by the GHG Protocol). We also strongly recommend that more companies actively engage in discussions within the Renewable Thermal Collaborative, the GHG Protocol and elsewhere, in order to arrive at a generally accepted approach to deal with biogenic emissions.

On the second question, there is multi-sector, multi-stakeholder coalition that is discussing and testing methodologies for accounting for indirect land use change more broadly, not just for bioenergy end-uses, with the goal of driving for consensus around indirect land use change accounting. The IPCC is also due to update its guidance on land use change by 2019.

The calculation methodologies for recovered heat are not sufficiently developed to enable the calculation of the allocation of GHG emissions to heat to be made. There is consensus that once the heat is recovered, it is a valuable product and therefore emissions should be allocated to it. The allocation rule also has to be undertaken on the basis of physical relations, rather than economic value. However, there is still flexibility in the way to do this. We propose a route based on the exergy value of the heat – indicating the work potential of the heat. However, we stress that there is no general consensus on this approach. On the other hand, the calculation methodology for ground source heat pumps is well established, as defined by the GHG Protocol.

Companies should play an active role to assure the sustainability of bioenergy sources used in their supply chains. This can be done, for example, through sustainability certifications that demonstrate compliance with national or regional sustainability mandates. In the EU, one way for companies to demonstrate that their bioenergy sources comply with the sustainability criteria for biofuels and bioliquids in the context of the RED is to source biomass that has been certified by the European Commission recognized voluntary schemes[23] (16 voluntary schemes are recognized at the time of writing). Some of these schemes are active internationally and certify biomass sources, such as food/feed crops, vegetable oils, from different regions in the world.

[23] https://ec.europa.eu/energy/en/topics/renewable-energy/biofuels/voluntary-schemes

ANNEX 1. DETAILED OVERVIEW OF PROTOCOLS

Design parameters

1. Focus
1.1 Goal of the standard
1.2 Technologies included e.g., solid/gaseous biomass, heat recovery from fossil fuel generation, heat pumps
1.3 Applications included e.g., heat boiler, CHP, gas grid
1.4 Linkages to other standards, protocols, calculation methodologies or guidelines
1.5 GHG emissions in scope and their GWPs
2.6 Other (environmental) impacts described

2. Boundaries
2.1 System boundary e.g., lifecycle, cradle-to-gate, cradle-to-grave
2.2 Cut-off criteria if allowed
2.3 Division/Scope e.g., Scope 1/2/3 or Direct/Indirect, etc.
2.4 Geographical scope the guidance applies to

3. Requirements
3.1 Data quality requirements for the assessment
3.2 Requirement on the functional unit
3.3 Other emission reporting requirements

4. Guidance on general relevant topics
4.1 Allocation rules and methods for the allocation of GHG emissions of (by)products (processes with multiple outputs)
4.2 Specific allocation rules for waste (streams) and recycling
4.3 Guidance for reporting on (renewable) electricity
4.4 Guidance on the treatment of biogenic carbon emissions and removals
4.5 Guidance on direct/indirect land use change
4.6 Guidance on reporting of carbon storage and delayed emissions
4.7 Guidance on emission off-setting

5. Guidance on accounting for (renewable) heat
5.1 Guidance on GHG emission reporting for heat production
5.2 Guidance on GHG reporting purchased heat
5.3 Guidance on the allocation of heat/electricity for CHP
5.4 Guidance on the allocation of waste heat
5.5 Guidance on the calculation of cultivation and harvesting emissions
5.6 Guidance on the calculation of processing emissions
5.7 Guidance on the calculation of transport emissions
5.8 Guidance on soil N_2O emissions
5.9 Guidance on manure management

6. Guidance on specific (renewable) heat technologies
6.1 Availability of default emission factors
6.2 Availability of other standard input data for calculations
6.3 Availability of specific guidance on heat boiler
6.4 Availability of specific guidance on CHP
6.5 Availability of specific guidance on district heating
6.6 Availability of other specific guidance that should be considered

Table below summarizes a list of literatures that have been reviewed in this report.

Table A-1. List of Literatures Reviewed in this Report

Literature Source	Name of the Author/Organization	Year of Publication
BioGrace-II Calculation rules	BioGrace	2015
BioGrace-II Methodological Background Document	BioGrace	2015
User manual for the BioGrace greenhouse gas calculation tool for electricity, heating and cooling	BioGrace	2015
Approved Baseline and Monitoring Methodologies for Large Scale CDM Project Activities	CDM	2016
Ketenemissies warmtelevering - Directe en indirecte CO_2-emissies van warmtetechnieken	CE Delft	2016
Greenhouse Gas Analysis and Harmonization of Methodology	Climate Investment Funds	2014
EBRD Methodology for Assessment of Greenhouse Gas Emissions - Guidance for consultants working on EBRD-financed projects	EBRD	2010
Recommendations on the use of common methods to measure and communicate the life cycle environmental performance of products and organisations	European Commission	2013
Green Gas Certification Scheme support	Ecofys	2015
Ofgem internal RHI GHG Training	Ecofys	2016
Solid biomass GHG calculation tool assessment	Ecofys	2014
Report from the **commission** to the council and the European Parliament on **sustainability** requirements for the use of solid and gaseous biomass sources in electricity, heating and cooling	European Commission	2010
State of play on the sustainability of solid and gaseous biomass used for electricity, heating and cooling in the EU	European Commission	2014
Commission recommendation of 9 April 2013 on the use of common methods to measure and communicate the life cycle environmental performance of products and organisations	European Commission	2013
Commission **r**ecommendation on the use of common methods to measure and communicate the life cycle environmental performance of products and organisations	European Commission - Joint Research Centre	2013
Environmental Footprint Guidance document	European Commission - Joint Research Centre	2016
Solid and gaseous bioenergy pathways: input values and GHG emissions	European Commission - Joint Research Centre	2015
ILCD Handbook – The International reference Life Cycle Data system	European Commission - Joint Research Centre and DG Environment	2010
CEN prEN15315	European Committee for Standardization	2005
CEN prEN15316-2	European Committee for Standardization	2014
European Investment Bank Induced GHG Footprint - The carbon footprint of projects financed by the Bank	European Investment Bank	2014
IFC Greenhouse Gas Reduction Accounting Guidance For Climate-Related Projects.	IFC Climate Business Department	2013
IEA CO_2 emissions from fuel combustion 2016 database	International Energy Agency	2016
ISO 14064-1	ISO Central Secretariat and The British Standards Institution	2006

Literature Source	Name of the Author/Organization	Year of Publication
ISO 14067: Protocol for carbon footprints of products	ISO Central Secretariat and The British Standards Institution	2013
Solid and gaseous bioenergy pathways: input values and GHG emissions	European Commission - Joint Research Centre	2014
PAS 2050 - Specification for the assessment of the life cycle GHG emissions of goods and services	The British Standard Institution	2008
NEN7125 - Energieprestatienorm voor maatregelen op gebiedsniveau (EMG) - Bepalingsmethode	The Netherlands Standardization Institute	2015
Greenhouse Gas Inventory Guidance - Direct Emissions from Stationary Combustion Sources	US Environmental Protection Agency	2016
Greenhouse Gas Inventory Guidance - Direct Fugitive Emissions from Refrigeration, Air Conditioning, Fire Suppression, and Industrial Gases	US Environmental Protection Agency	2014
Greenhouse Gas Inventory Guidance - Indirect Emissions from Purchased Electricity	US Environmental Protection Agency	2016
Allocation of GHG Emissions from a Combined Heat and Power (CHP) Plant	World Resources Institute (WRI) and World Business Council on Sustainable Development (WBCSD)	2006
Corporate Value Chain (Scope 3) Accounting and Reporting Standard	World Resources Institute (WRI) and World Business Council on Sustainable Development (WBCSD)	2011
GHG Protocol Scope 2 Guidance	World Resources Institute (WRI) and World Business Council on Sustainable Development (WBCSD)	2015
Product Life Cycle Accounting and Reporting Standard	World Resources Institute (WRI) and World Business Council on Sustainable Development (WBCSD)	2011
The GHG Protocol - Corporate Accounting and Reporting Standard	World Resources Institute (WRI) and World Business Council on Sustainable Development (WBCSD)	2004
EN15804	European Commission	2013
Product Category Rule module for Roundwood and Pulp/Paper	SCS Global Services	2015