WORKING PAPER

Emission balances of first- and second-generation biofuels

Case studies from Africa, Mexico and Indonesia

Dorian Frieden
Naomi Pena
David Neil Bird
Hannes Schwaiger
Lorenza Canella

CIFOR

Working Paper 70

Emission balances of first- and second-generation biofuels

Case studies from Africa, Mexico and Indonesia

Dorian Frieden
Joanneum Research

Naomi Pena
Joanneum Research

David Neil Bird
Joanneum Research

Hannes Schwaiger
Joanneum Research

Lorenza Canella
Joanneum Research

Working Paper 70

Frieden, D., Pena, N., Bird, D.N., Schwaiger, H. and Canella, L. 2011 Emission balances of first- and second-generation biofuels: case studies from Africa, Mexico and Indonesia. Working Paper 70. CIFOR, Bogor, Indonesia

Oil palm plantation, Port Dickson, Sepang, Malaysia

This report has been produced with the financial assistance of the European Union, under a project titled, 'Bioenergy, sustainability and trade-offs: Can we avoid deforestation while promoting bioenergy?' The objective of the project is to contribute to sustainable bioenergy development that benefits local people in developing countries, minimises negative impacts on local environments and rural livelihoods, and contributes to global climate change mitigation. The project will achieve this by producing and communicating policy relevant analyses that can inform government, corporate and civil society decision-making related to bioenergy development and its effects on forests and livelihoods. The project is managed by CIFOR and implemented in collaboration with the Council on Scientific and Industrial Research (South Africa), Joanneum Research (Austria), the Universidad Nacional Autónoma de México and the Stockholm Environment Institute. The views expressed herein can in no way be taken to reflect the official opinion of the European Union.

CIFOR
Jl. CIFOR, Situ Gede
Bogor Barat 16115
Indonesia

T +62 (251) 8622-622
F +62 (251) 8622-100
E cifor@cgiar.org

www.cifor.org

Table of contents

List of tables and figures

Tables

Figures

List of abbreviations

CH_4	Methane
CHP	Combined heat and power
CO_2	Carbon dioxide
CSL	Corn steep liquor
(t) d.m.	(tonne) dry matter
EU Renewable Energy Directive (RED)	Directive 2009/28/EC of the European Parliament and of the Council of 23 April 2009 on the promotion of the use of energy from renewable sources and amending and subsequently repealing Directives 2001/77/EC and 2003/30/EC
FAME	Fatty acid methyl esters (biodiesel)
FFB	Fresh fruit bunches (oil palm)
FT	Fischer–Tropsch
HFO	Heavy fuel oil
HVO	Hydrogenated vegetable oil
GHG	Greenhouse gas
GWP	Global warming potential
HAC	High activity clay
IPCC	Intergovernmental Panel on Climate Change
LUC	Land use change
MJ	Megajoule
N_2O	Nitrous oxide
NG	Natural gas
POME	Palm oil mill effluent
RFA	Renewable Fuels Agency (UK)
SOCREF	Reference soil carbon stock
SRC	Short rotation coppice
WM	Wet matter

Summary

This report examines the greenhouse gas (GHG) emissions of alternative biofuel production pathways. Selected first- and second-generation pathways were examined in Mexico, Indonesia and Africa. Differences in the crops, conversion technologies and input parameters used in each country result in different GHG emissions per unit of energy in the fuel (i.e. GHGs per megajoule). Results are therefore country, feedstock and conversion-technology specific. The emissions analysed include GHG emissions from land use change (LUC), cultivation, processing and transport of biofuels up to their first point of distribution and potential export to Europe. Calculations, except for the LUC component, were made using the EU-funded BioGrace tool, which was designed to meet requirements set out in the EU Directive on the promotion of the use of energy from renewable sources.

The biofuel production pathways analysed in this study are:

- biodiesel from palm oil in Indonesia;
- biodiesel from jatropha in South Africa and Mexico;
- bioethanol from sugarcane in South Africa, Mexico and Indonesia;
- bioethanol from wood in South Africa and Mexico; and
- Fischer–Tropsch diesel from wood in South Africa and Mexico.

The following GHGs are considered: carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O). GHG emissions are allocated to the biofuel and its co-products (e.g. seedcake) using the energy allocation method, that is, according to their relative energy content.

Three sensitivity analyses were carried out:

- domestic use of the biofuel vs. its export to the EU in cases where both scenarios are considered likely;
- different jatropha productivity rates in Mexico; and
- use of the co-product for fertilisation vs. export of the co-product and use of mineral fertilisers in the case of biodiesel from jatropha in Africa.

Emissions from LUC are considered based on results derived using the GLOBIOM model. From these results, 3 default values for LUC emissions were derived: 118 g CO_2-eq per MJ fuel produced for non-wood feedstocks, 0.4 g CO_2-eq per MJ fuel for wood taken from short rotation coppices and –10.7 g CO_2-eq per MJ fuel for residues and woodchips from existing forests.

The results show that, where the highest default value for LUC emissions is used, this value dominates all other sources of emissions along the biofuel pathways. Where the lowest default value is used, emissions from LUC contribute only a minor share of the total emissions. The dominance of the high LUC value means that the lowest emission pathways use wood as feedstock. All of these require second-generation conversion technologies. The 2 first-generation pathways with the lowest emissions are bioethanol from sugarcane in Mexico and Indonesia.

The sensitivity analysis on emissions from transport shows that, even where exports to the EU occur, transport emissions mostly constitute only a minor share of the total emissions. The relative importance of transport emissions increases particularly when LUC emissions are low, that is, for pathways using wood as feedstock.

The sensitivity analyses on jatropha show that the feedstock productivity strongly influences emissions from cultivation. This may be an artefact of our assumption of the same amount of inputs independent of the productivity of the location. The 2 jatropha pathways in Mexico are amongst the 3 pathways with the highest total emissions. Their high emissions from cultivation are primarily due to disposal of nutshell meal, meaning that no emissions

are allocated to the meal. The analysis on use of artificial fertilisation compared with fertilisation with the by-product seedcake in jatropha cultivation in Africa shows that use of artificial fertiliser leads to much higher emissions from cultivation. Even though an important share of these emissions is allocated to the seedcake when it is exported from the system, pathway emissions remain lower if the seedcake is used as fertiliser.

As data on country-specific pathways are limited, it is not possible to differentiate clearly between countries or regions. However, differentiation is possible for the importance of particular factors such as feedstock productivity, fertiliser use and allocation of co-products or the need for specific conversion technologies.

1. Introduction

This chapter describes the background, goal and scope of the analysis.

1.1 Background

Greater production and use of biofuels are being promoted to support, amongst other goals, mitigation of climate change. Governments in both developed and developing nations are adopting mandates and incentives to drive greater use of biofuels for transport. In response to these new drivers, use of proven crops, conversion technologies and fuels (first-generation pathways) is increasing; at the same time, research into and testing of new crops, conversion technologies and fuels (second-generation elements) are accelerating.

Biofuel pathways tend to be evaluated against a number of criteria, including: cost; technological readiness, for which cost relative to commercially produced fuels provides an indication; and environmental footprint, including greenhouse gas (GHG) emissions and efficiency of land use. GHG profiles are important because reduction of GHG emissions is a major reason developed countries – key potential importers of biofuels and financers of projects – are interested in biofuels. This report draws on case studies to analyse the GHG profiles of selected existing and potential first- and second-generation biofuel pathways in Mexico, Africa and Indonesia.

In June 2009, the EU published 'Directive 2009/28/EC of the European Parliament and of the Council on the promotion of the use of energy from renewable sources' (hereinafter referred to as the 'Renewable Energy Directive' or 'RED'). This directive sets out a procedure for calculating the GHG emissions of biofuels (EC 2009).

The GHG calculation tool of the EU-funded project 'Harmonised calculations of biofuel greenhouse gas emissions in Europe (BioGrace)' was used to facilitate calculations for the case studies presented in this report. The aim of the BioGrace project is to harmonise calculations of biofuel GHG emissions and thus support the incorporation of the EU Renewable Energy Directive (2009/28/EC) and the EU Fuel Quality Directive (2009/30/EC) into national laws (http://www.BioGrace.net/). The results of BioGrace calculations can be used to verify whether a fuel's GHG emissions are sufficiently low to meet the EU's Renewable Energy Directive requirements (e.g. 35% lower than the fuel for which it is substituted). Even though compliance with EU standards is not the focus of this analysis, the BioGrace tool has been judged useful for providing a systematic framework for calculations. In addition, it allows for comparison with the RED default values calculated in a similar way.

To supplement the case studies presented here, an overview of the state of the art of primary biofuel production options, including economic considerations and generic indications of biofuel GHG profiles, is provided in the report 'Overview of existing liquid biofuel for transportation technologies', which is part of the same project deliverable.

1.2 Goal of the analyses

The goal of this analysis is to add region-specific information to the relatively well-known technical features of selected existing and potential future biofuel production pathways. As well as examining potential regional differences, the report provides a comparison of the emission balances of first- and second-generation biofuels.

In a joint Work Package 5.1 discussion during a project meeting held in Bogor, Indonesia, in February 2010, partners identified both region-specific first- and second-generation technologies and feedstocks of major interest. For the analysis, chain definitions were set up (Figure 1), and data were collected on non-land use change components along the biofuel production chain.

Joanneum Research provided information on typical feedstock types and amounts, appropriate technology,

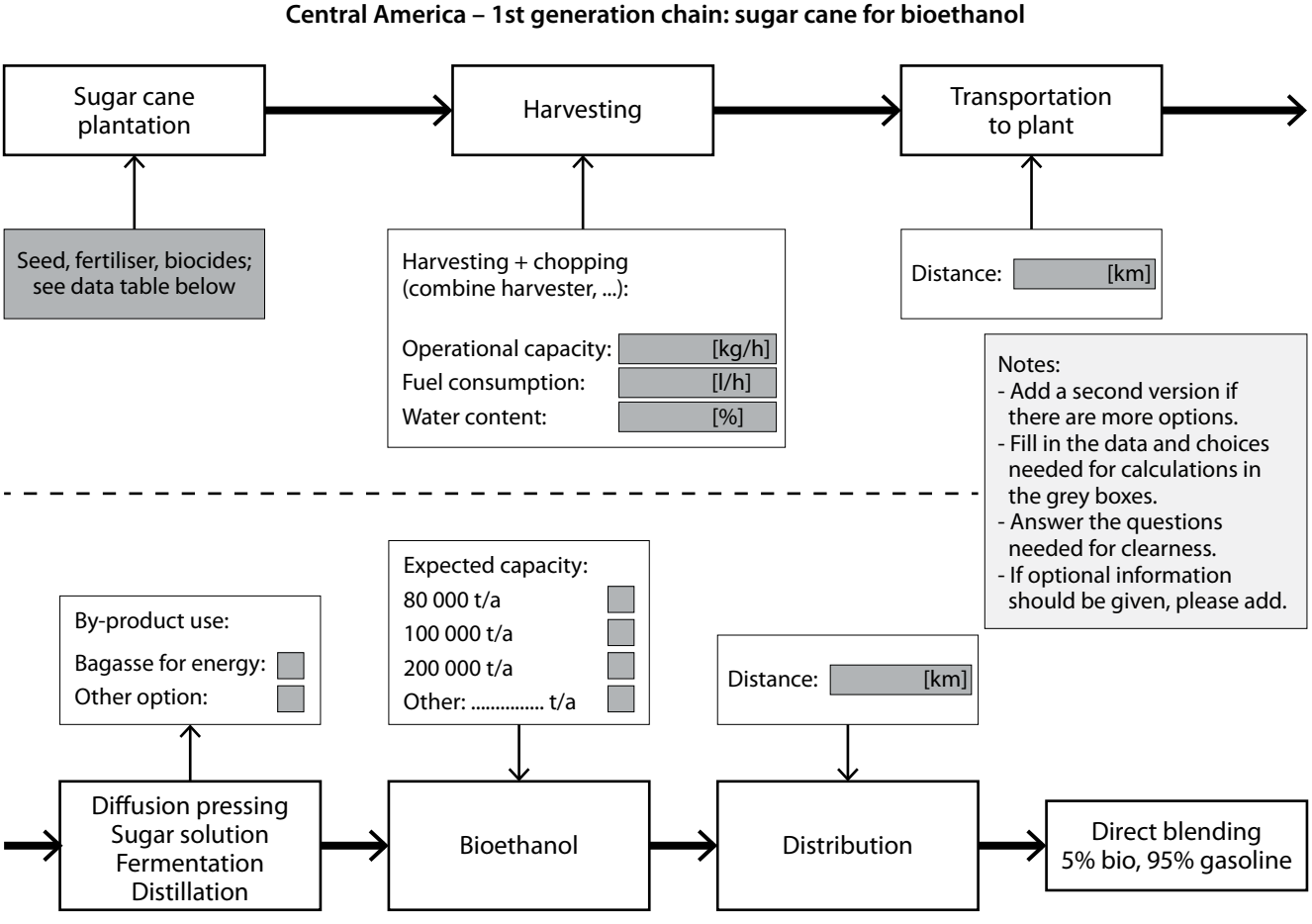
plant size and energy requirements based on the results of the report 'Overview of existing liquid biofuel for transportation technologies'. Region-specific partners ('national experts') provided data on feedstock production and information for in-country transportation of feedstocks and biofuels.

The following production pathways were chosen for analysis:

- biodiesel from palm oil in Indonesia;
- biodiesel from jatropha in South Africa and Mexico;
- bioethanol from sugarcane in South Africa, Mexico, and Indonesia;
- bioethanol from wood in South Africa and Mexico; and
- Fischer–Tropsch diesel from wood in South Africa and Mexico.

1.3 Scope of analyses

GHG emissions due to biofuel production are calculated from cultivation through to the first point of distribution in the country of production. In some cases, emissions due to export to the EU are also provided. Figure 2 compares the lifecycle of biofuel production with that of fossil fuels from a GHG emissions perspective. The black dotted line shows the section for estimating emissions from land use change (LUC), and the grey dotted line shows the non-LUC section of the system, which is the subject of this report.



yield	water-content	fertiliser N	fertiliser P	fertiliser Ca	fertiliser K	biocides	seeds	fuel
[kg_{WM}/(ha*a)]	[%]	[kg/(ha*a)]	[kg/(ha*a)]	[kg/(ha*a)]	[kg/(ha*a)]	[kg/(ha*a)]	[kg/(ha*a)]	[l/(ha*a)]

WM: Wet Matter

Figure 1. Sample sheet for collecting country-specific data on biofuel pathways

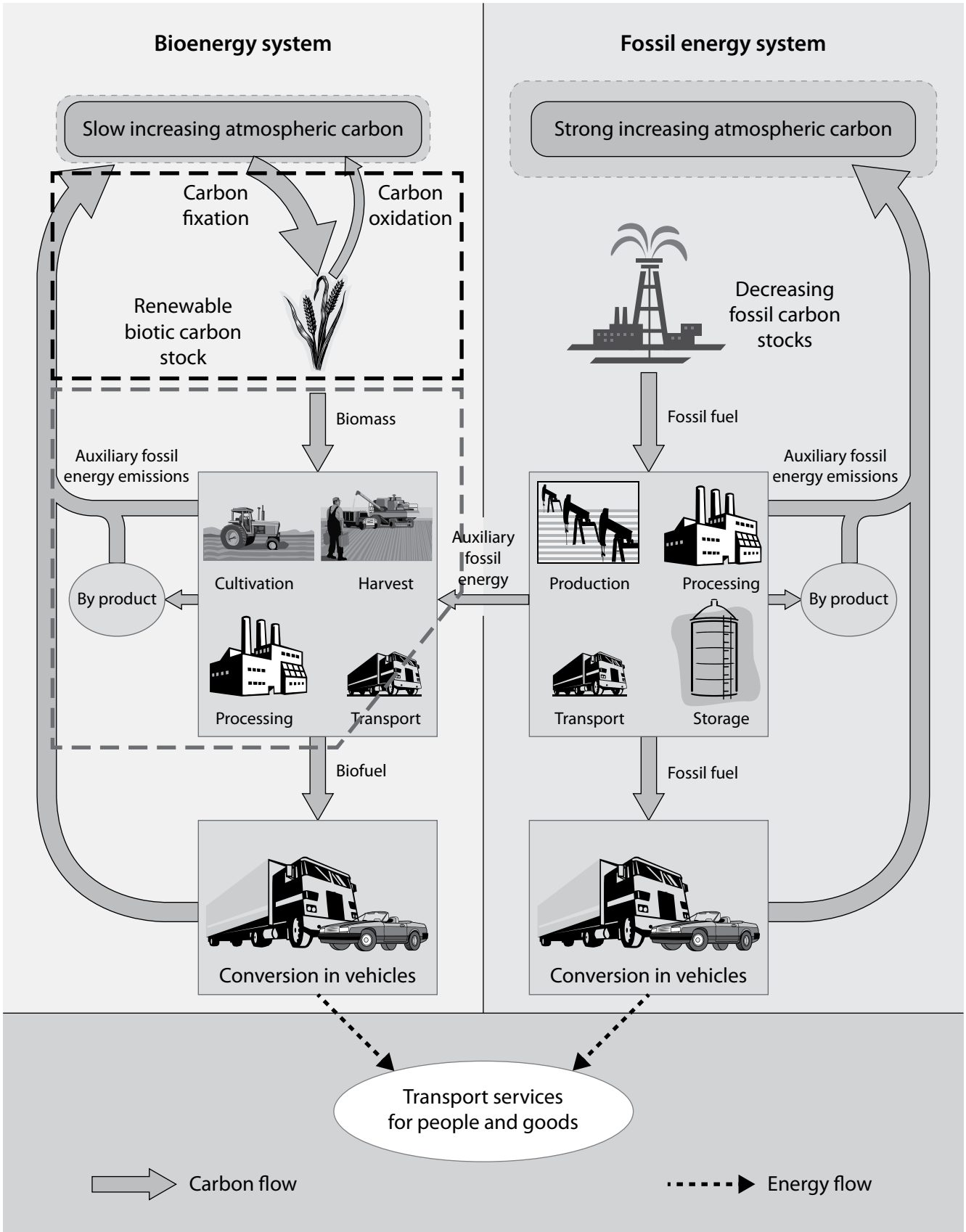


Figure 2. Carbon and energy flows for greenhouse gas emissions of a transport system with bioenergy (e.g. bioethanol) compared with those for fossil energy (e.g. gasoline) (based on Jungmeier *et al.* 1999, 2002). The black (LUC component) and grey (non-LUC component) dotted lines show the boundaries of the system analysed in this study.

Fossil fuels and their emissions are taken into account where such fuels are needed for cultivating biomass, processing it into biofuel and transporting the biofuels. Transport to the final consumer is not taken into account. For in-country calculations, transport ends at the first point of distribution, that is, where blending is done. Where export to Europe is taken into account, the calculated transport emissions end at the arrival harbour in Europe.

In cases where the biodiesel is to be used in Europe, it is assumed that unrefined oil is exported and then refined and further processed in Europe. In these cases, the emissions due to refining and processing in Europe are included in the analysis but no transport inside Europe is taken into account.

This first focus of the study is the relative contribution to the total emissions of each step, or part of each step, along the chain from biomass production through to conversion and then delivery to a distribution centre. The second focus is on the comparison of emissions from first- versus second-generation biofuel pathways. Comparison of emissions due to biofuel use with emissions due to use of fossil fuels is beyond the scope of this study.

Three sensitivity analyses are carried out to compare the influence of different factors on the overall GHG emissions balance:

1. domestic use of the biofuel compared with its export to the EU in cases where both scenarios are considered likely (sensitivity analysis 1);
2. in the case of biodiesel from jatropha in Africa, use of co-products for fertilisation compared with export of the co-products and use of mineral fertilisers (sensitivity analysis 2); and
3. different jatropha productivity rates in Mexico (sensitivity analysis 3).

2. Methodology

The description of the methodology begins with an overview of biofuel GHG emissions. Following this is an explanation of how the systems are modelled using the BioGrace calculation tool, and then a review of the allocation approach and how LUC emissions are calculated.

2.1 Greenhouse gas emissions of biofuels: Overview

The study considers the following sources of GHG emissions, including emissions due to energy inputs and auxiliary materials:

- land use change (LUC);
- cultivation of feedstocks;
- transport of feedstocks to the bioethanol plant;
- production of the biofuel and its co-products;
- co-products exported from the system;
- transport of the biofuel, either to the first point of distribution in-country or including exports to the EU; and
- emission savings from excess electricity from cogeneration (electricity export).

In accordance with the RED, emissions from the manufacture of machinery and equipment are not taken into account (EC 2009). With the exceptions of GHG emissions due to LUC and nitrous oxide (N_2O) emissions due to application of fertilisers, all of these emissions are calculated using the public version 3 of the BioGrace tool (the tool is introduced in Section 1.1; further explanation is provided in Section 2.2). The methodology used to calculate emissions due to LUC is described in Section 2.4. For feedstocks that are part of BioGrace, N_2O emissions due to use of fertiliser are calculated using BioGrace public version 4 (see below).

The GHGs carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) are considered.

Carbon dioxide (CO_2), an odourless and flavourless carbon–oxygen compound, is the main product of combustion of carbon-containing materials. The amount of CO_2 emitted per unit of energy obtained depends on – amongst other factors – the carbon content and heating value of the material. CO_2 is removed from the atmosphere by plants and converted into carbon-containing material via the photosynthesis process (e.g. cultivation of corn). In the case of plant materials used for biofuels, it is assumed that, over the course of a year, plants remove an amount of CO_2 from the atmosphere that is equal to the amount of CO_2 released when the fuels are combusted. Consequently, uptake and release of CO_2 by plants are not taken into account; a closed carbon cycle of CO_2 fixation by plant growth cultivation and release of CO_2 emissions from biofuels and their co-products is assumed.

Methane (CH_4) is a flammable hydrocarbon compound. It is the main component of natural gas and can be a product of incomplete combustion processes. Methane is also produced by the anaerobic degradation of biomass. CH_4 emissions also occur during coal mining and the extraction of raw oil and natural gas.

Nitrous oxide (N_2O) is a colourless and toxic nitrogen–oxygen compound that is formed in combustion processes under certain conditions. The amount of N_2O emitted depends on the nitrogen content of the fuel and the combustion temperature. N_2O emissions also occur as a result of nitrification and de-nitrification processes in soils in agricultural cultivation, particularly if nitrogenous fertiliser is applied.

Global warming potentials (GWPs) are used to express the contribution of each gas to global warming using a common unit. CO_2 is used as the standard, and the warming impact of a kilogram of other GHGs is expressed in relation to the warming impact of a kilogram of CO_2. Consequently, the impact of 1 kg of gases other than CO_2 is indicated as a multiple of the impact of 1 kg of CO_2. By using these multipliers, referred to as 'equivalent factors', emissions of CH_4 and N_2O are converted into

equivalent amounts of CO_2 emissions (CO_2-eq). Equivalent factors for these 3 gases are:

- 1 kg CO_2 = 1 kg CO_2-eq
- 1 kg CH_4 = 25 kg CO_2-eq
- 1 kg N_2O = 298 kg CO_2-eq

To calculate N_2O emissions from soils, the N_2O calculator of the BioGrace public version 4 was used. This tool includes both direct and indirect emissions of N_2O from use of nitrogen fertilisers, using the tier 1 approach provided in the 2006 Intergovernmental Panel on Climate Change (IPCC) Guidelines (volume 4, chapter 11) for the calculation of N_2O emissions from managed soils. Data used in this approach are feedstock yield and humidity content, amount of N fertiliser applied and, in some cases, specific default values (e.g. amount of N applied in using bagasse as a fertiliser in sugarcane cultivation). However, this study includes feedstocks for which neither the BioGrace calculation tool nor the IPCC guidelines provide the necessary data. For these feedstocks, only direct emissions from N inputs were taken into account using the IPCC emission factor for direct emissions from N application: 0.01 kg N_2O-N per kg N applied (IPCC 2006).

2.2 Greenhouse gas modelling based on the BioGrace tool

GHG emissions are calculated using the BioGrace tool. This tool was designed to be consistent with the RED. The EU RED requires that GHG emissions from the production and use of biofuels be calculated using the following formula (EC 2009):

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

where:

- E = total **emissions from the use** of the fuel
- e_{ec} = emissions from the extraction or cultivation of raw materials
- e_l = annual emissions from carbon stock changes caused by LUC
- e_p = emissions from processing
- e_{td} = emissions from transport and distribution
- e_u = emissions from the fuel in use
- e_{sca} = emission savings from soil carbon accumulation via improved agricultural management
- e_{ccs} = emission savings from carbon capture and sequestration
- e_{ccr} = emission savings from carbon capture and replacement
- e_{ee} = emission savings from excess electricity from cogeneration

As mentioned above, emissions from the manufacture of machinery and equipment are not taken into account (EC 2009).

The above formula calculates emissions from biofuels up to the point of final consumption. This allows straightforward comparison between biofuels and fossil-based transport fuels. Since the purpose of this study is to examine emissions from alternative biofuel production pathways, emissions calculated in the study do not include emissions from fuel use (e_u) or emissions from distribution. In addition, no management changes are considered, and it is assumed that no carbon capture equipment will be in operation. Thus, for the purpose of this study, the RED formula is simplified as follows:

$$E_{pt} = e_{ec} + e_l + e_p + e_t - e_{ee}$$

where:

- E_{pt} = total **emissions from the production and transport** of the fuel
- e_{ec} = emissions from the extraction or cultivation of raw materials
- e_l = annual emissions from carbon stock changes caused by LUC
- e_p = emissions from processing
- e_t = emissions from transport (transport within Europe and electricity consumption at the point of distribution are not considered)
- e_{ee} = emission savings from excess electricity from cogeneration

In accordance with this more limited formula, the BioGrace tool was employed in a more limited fashion than would have been the case if emissions were calculated to determine compliance with the RED. The BioGrace tool, which consists of a Microsoft Excel sheet, covers the 22 biofuel production pathways given in the Renewable Energy Directive Annex V part A. These pathways are

production pathways already used to a significant extent (first generation). Of the pathways analysed in this study, the following are including in this list and thus are standard pathways in the BioGrace tool:

- biodiesel from palm oil; and
- bioethanol from sugarcane.

For the following pathways, the tool had to be supplemented:

- biodiesel from jatropha;
- bioethanol from wood; and
- Fischer–Tropsch diesel from wood.

For the pathways that are not included in the BioGrace tool, new process chains were integrated using processing data from the GEMIS database (GEMIS: Global Emission Model for Integrated Systems, www.oeko.de/service/gemis).

To the extent possible, national data were input into the BioGrace Excel worksheets. In cases where no national data were available but the feedstock and process are included in the BioGrace tool, BioGrace default values were used. This was frequently the case for processing data, including excess electricity. In most cases, national data were available for cultivation and transport.

2.3 Allocation of emissions to co-products

During production of biofuels, co-products such as seedcake and glycerol are produced. Allocation of emissions between the biofuel and the co-product is undertaken when the co-products are 'exported' from the biofuel production system to another user, for example, sold for animal feed or as feedstocks for the production of goods such as soap. Co-products are not 'exported' when they are fed back into the production system, such as when biomass residues are used to fertilise the cultivation of the biomass. Co-products are also considered as 'not exported' if they end up as waste.

Where co-products are exported, allocation of the GHG emissions between the biofuel and co-products is done using the energy allocation method. Thus, emissions from bioethanol and co-products such as seedcake and glycerol are divided amongst the various products based on their energy content.

The RED states the following regarding the allocation of GHG emissions (EC 2009):

> Where a fuel production process produces, in combination, the fuel for which emissions are being calculated and one or more other products (co-products), greenhouse gas emissions shall be divided between the fuel or its intermediate product and the co-products in proportion to their energy content (determined by lower heating value in the case of co-products other than electricity).
>
> For the purposes of the calculation […], the emissions to be divided shall be $e_{ec} + e_l$ + those fractions of e_p, e_{td} and e_{ee} that take place up to and including the process step at which a co-product is produced. If any allocation to co-products has taken place at an earlier process step in the life-cycle, the fraction of those emissions assigned in the last such process step to the intermediate fuel product shall be used for this purpose instead of the total of those emissions
> […]
>
> where […]:
> e_e = emissions from the extraction or cultivation of raw materials;
> e_l = annualised emissions from carbon stock changes caused by land-use change;
> e_p = emissions from processing;
> e_{td} = emissions from transport and distribution; […]
> e_{ee} = emission saving from excess electricity from cogeneration

In essence, emissions that occur up to the point of 'export' of a co-product are subtracted from the biofuel emissions, in proportion to the energy content of the co-product compared with the energy content of the biofuel. Emissions from the following processes are relevant for the allocation process:

- cultivation of the feedstock;
- transport of the feedstock; and
- production of biofuel and co-products.

Emissions due to LUC are not allocated amongst products but are attributed in entirety to the biofuel because LUC emissions are already computed per unit of biofuel produced.

Figure 3 depicts the system boundaries for the energy allocation method.

Figure 3 illustrates both the emissions taken into account and the products to which emissions would be allocated in the case of a typical ethanol plant. As explained above, in this study, a biofuel's emissions are taken into account up to the biofuel's first point of distribution. The pathway to this point is contained within the grey box. All emissions occurring within this system boundary are taken into account for each biofuel. For allocation, only emissions within the green box are taken into account in determining emissions to be allocated between the biofuel and the co-products exported from the system. In essence, when co-products are 'exported' from the system, their emissions are also 'exported' based on their energy content.

2.4 Emissions from land use change due to biofuel production

For the LUC component, we used the emission values for afforestation and deforestation developed in the Activity 2.1 report. LUC emissions per MJ biofuel produced are calculated based on modelled global averages.

We start with the LUC emissions as calculated using the GLOBIOM model (Havlik *et al*. 2010).

This study developed LUC occurring in 4 biofuel scenarios using a partial equilibrium economic model. The 4 biofuel scenarios are:

a. no increase in biofuels above 2005 values;
b. baseline: by 2030, 60% of biofuels are produced using first-generation technologies and 40% using second-generation technologies;
c. all increases in biofuels beyond 2005 values are produced using first-generation technologies; and
d. all increases in biofuels beyond 2005 values are produced using second-generation technologies.

In scenario (a) above, LUC occurs only in the case of increasing food demand. In scenarios (b), (c) and (d), LUC occurs in the case of increases in both food and biofuel demand. LUC due to biofuels is calculated as the difference between these scenarios and scenario (a).

In this study, the 'first generation only' scenario (scenario c) was used for all pathways except those using wood as feedstock, for which the 'second generation only' scenario (scenario d) was used. In the GLOBIOM scenarios, scenario (d) is further divided into wood from agricultural land, wood from marginal land and wood from existing forests. Here,

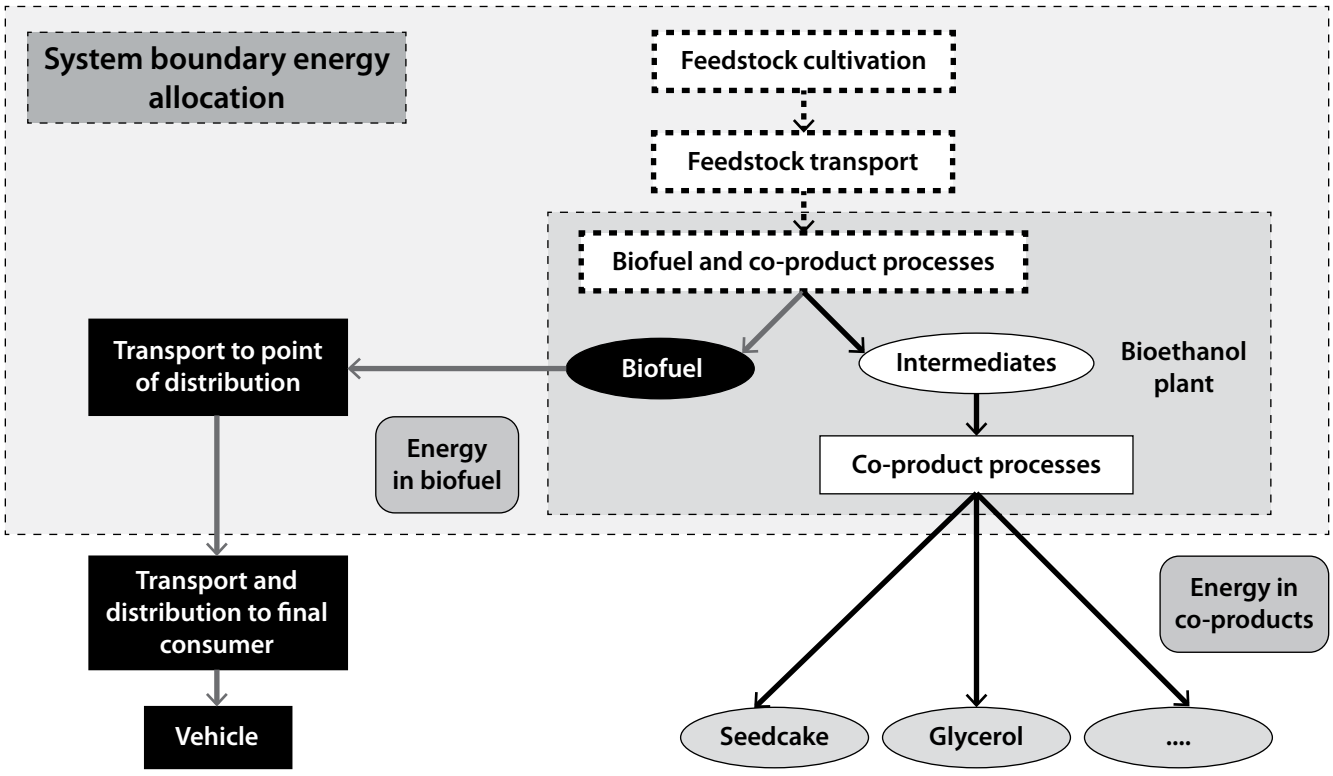


Figure 3. System boundaries for the energy allocation method

for short rotation coppices, scenario (d) assumed that wood from agricultural land was used. For wood residues/woodchips from existing forests, scenario (d) assumed that wood from existing forests was used.

The following values were used:

- 118 g/MJ fuel produced for the 'first generation only' scenario (scenario c) (applied to non-wood pathways);
- 0.4 g/MJ fuel produced for the 'second generation only' scenario (scenario d), assuming wood comes from agricultural land (applied to short rotation coppices); and
- –10.7 g/MJ fuel produced for the 'second generation only' scenario (scenario d), assuming wood comes from existing forests (applied to wood residues/woodchips from existing forests)

The Havlik study provides estimates of emissions due to changes in live biomass (above and below ground) at 2000 and 2030. In Activity 2.1, as an 'add-on', we interpolated the emissions and LUC between 2000 and 2030, and included emissions due to changes in deadwood, litter and soil organic carbon.

For the interpolation, we assumed that the cumulative emissions and LUC by year are proportional to the cumulative demand for bioenergy by year, as calculated by the International Energy Agency 450 Scenario (IEA 2010).

The carbon emissions or removals in litter, deadwood and soil due to LUC were calculated as the difference in carbon stock in each of the 3 pools before [C(0)] and after [C(1)] deforestation or change from natural forest to short rotation forest. The carbon stock pools were estimated using the default values provided in the 2006 IPCC Guidelines (IPCC 2006). The calculations are done at the regional level for 11 regions (Central-East Europe, Former Soviet Union, Latin America, Mid-East and North Africa, North America, Other Pacific Asia, Pacific OECD, Planned Asia-China, South Asia, Sub-Saharan Africa, Western Europe).

It is assumed that changes in the litter and deadwood pool occur only with deforestation, whereas no change is assumed in other cases (e.g. forest management changes). A carbon loss equal to the amount of carbon in the litter and deadwood is accounted for when a forest is cleared and converted to cropland or grassland. This assumption is based on an IPCC tier 1 approach, which considers no accumulation of litter and deadwood in cropland and grassland. Therefore, deforestation produces a loss of carbon in these 2 pools. Initial values of litter and deadwood carbon in forests were derived from Table 2.2 of the 2006 IPCC Guidelines (IPCC 2006) and Table 3.2.2 of the 2003 IPCC Guidelines (IPCC 2003). Regarding afforestation, the data only include conversions to short rotation plantations, which accumulate very little litter and deadwood compared with cropland or grassland. Therefore, we conservatively assumed that no carbon is accumulated in litter and deadwood when land is converted to short rotation plantations.

The emissions/removals in soil are calculated based on equation 2.25 and default factors in the 2006 IPCC Guidelines. According to this method, the carbon stock in the soil, under a specific land use, is calculated by first selecting a so-called 'reference soil carbon stock' (SOCREF; Table 2.3, IPCC 2006). The SOCREF represents the carbon stock in reference conditions, that is, native vegetation that is not degraded or improved. The SOCREF is the value that we used for soil carbon stock in forestland. For other land uses, the soil carbon stock is calculated by multiplying the SOCREF by default factors that are specific for each land use, land management and level of organic inputs (Tables 5.5, 5.10 and 6.2, IPCC 2006). Default SOCREF values were chosen from the values reported for high activity clay (HAC) soils, which include most of the existing soil types.

For more details on the methodology for calculating emissions from land use change, see the Activity 2.1 report (Bird *et al.* 2011).

3. Biofuel pathway descriptions and data used

This chapter provides the generic data used across all case studies, brief descriptions of the various biofuel pathways considered and biofuel-pathway-specific data. The first section provides generic data that are independent of feedstocks and processing technologies. Subsequent information is organised by biofuel pathway. Each biofuel pathway section includes technology-specific data such as biofuel yields per MJ feedstock and country-specific data such as feedstock productivity or fertiliser use. Where no country-specific data were available, default values were used; these are the same for the various cases.[1]

The biofuel pathway sections include very brief descriptions of the processes. A more detailed overview of the biofuel feedstocks and production pathways, as well as their classification into first- and second-generation feedstocks and technologies, is given in the report 'Overview of existing liquid biofuel for transportation technologies', which is part of WP5.1 of this project. For some pathways, such as the Fischer–Tropsch process, the process can be carried out with different objectives in relation to the desired mix of biofuel, electricity or heat generation. As biofuel production is the focus of this study, in such cases the process is assumed to be optimised for biofuel production.

In tables in the following sections, totals may differ slightly from aggregation of subtotals due to rounding.

3.1 Generic data

The generic data used in this study, which are independent of the specific feedstock and conversion technology used, include:

- GWPs for CO_2, CH_4 and N_2O (see Section 2.1);
- country-specific emission factors for electricity;
- emission factors for liquid fuels and natural gas;
- transport efficiencies and exhaust gas emissions for road and maritime transport;
- emission factors for fertilisers and pesticides;
- emission factors for conversion inputs;
- emission factors for steam and electricity generation from biomass; and
- transport distances to Europe (where export occurs).

Tables 1 to 8 provide an overview of the generic data used.

In some of the processes, a CHP (combined heat and power) plant produces heat and power using process residues as feedstock. Such residues include bagasse from sugarcane and lignin from wood. Depending on the specific pathway, the resultant energy will either reduce the need for electricity from the national grid, lead to full energy self-sufficiency of the system or produce excess electricity, which can be fed into the national grid assuming a suitable grid connection is available. In these cases, CH_4 and N_2O emissions from the combustion of this residue biomass are included in the calculations. Given the scarcity of information on emission factors for specific types of biomass residues, the standard values provided in BioGrace were used. These values for CH_4 and N_2O are based on combustion of wheat straw. Where combustion of biomass residues results in excess electricity being fed into the grid, it is assumed that it replaces electricity coming from a similar source, that is, electricity produced from wheat straw (see Table 7).[2] Emissions from any replaced energy are subtracted from the emissions for biofuel processing.

Where export of the biofuel to Europe is assumed, the shipping distances given in Table 8 are used in combination with the emission factors shown in Table 3.

1 The BioGrace calculation procedure is designed to use either default or case-specific values for an entire process step in order to comply with RED requirements. Since compliance with the RED is not the purpose of this study, case-specific values are used where available, even if some default values must also be used for a given step. However, this has to be considered a source of error.

2 This corresponds to the RED and the standard calculations in the BioGrace tool.

Table 1. Emission factors for electricity

Electricity emissions	CO_2 per kWh (g)	Conversion to CO_2 per MJ (1 kWh = 3.6 MJ)
Indonesia	726	202.00
Mexico	440	122.00
South Africa	835	232.00
Europe		128.25

Source: IEA database (values from 2008). The value for Europe is derived from the BioGrace standard values, public version 3 (http://www.BioGrace.net).

Table 2. Emission factors for liquid fuels for transport, all countries

Fuel emissions	g CO_2-eq/MJ
Diesel	87.64
Heavy fuel oil (HFO) for maritime transport	87.20

Source: BioGrace standard values, public version 3 (http://www.BioGrace.net)

Table 3. Transport efficiencies and exhaust gas emissions, all countries

Transport	Fuel efficiency	Transport exhaust gas emissions	
	MJ/t.km	g CH_4/t.km	g N_2O/t.km
Truck for dry products (diesel)	0.94	0.005	0.0000
Truck for liquids (diesel)	1.01	0.005	0.0000
Truck for FFB transport (diesel)	2.01	0.005	0.0000
Tanker truck MB2318 for vinasse transport	2.16	0.000	0.0000
Tanker truck with water cannons for vinasse transport	0.94	0.000	0.0000
Dumpster truck MB2213 for filter mud transport	3.60	0.000	0.0000
Ocean bulk carrier (fuel oil)	0.20	0.000	0.0007
Ship/product tanker 50 kt (fuel oil)	0.12	0.000	0.0000
FFB: fresh fruit bunches (oil palm)			

Source: BioGrace standard values, public version 3 (http://www.BioGrace.net)

Table 4. Emission factors for fertilisers and pesticides, all countries

Agro-inputs	CO_2	CH_4	N_2O	CO_2-eq
	[g/kg]			
N fertiliser (N)	2827.0	8.68	9.6418	5880.6
Ca fertiliser (CaO)	119.1	0.22	0.0183	129.5
K fertiliser (K_2O)	536.3	1.57	0.0123	576.1
P fertiliser (P_2O_5)	964.9	1.33	0.0515	1010.7
Pesticides	9886.5	25.53	1.6814	10 971.3

Source: BioGrace standard values, public version 3 (http://www.BioGrace.net)

Table 5. Emission factors for conversion inputs (input in kg), all countries

Conversion inputs	CO_2	CH_4	N_2O	CO_2-eq
		[g/kg]		
Phosphoric acid (H_3PO_4)	2776.0	8.93	0.1028	3011.7
Fuller's earth	197.0	0.04	0.0063	199.7
Hydrochloric acid (HCl)	717.4	1.13	0.0254	750.9
Sodium carbonate (Na_2CO_3)	1046.0	6.20	0.0055	1190.2
Sodium hydroxide (NaOH)	438.5	1.03	0.0240	469.3
Potassium hydroxide (KOH)	0.0	0.00	0.0000	0.0
Pure CaO for processes	1013.0	0.65	0.0076	1030.2
Sulphuric acid (H_2SO_4)	193.9	0.55	0.0045	207.7
Ammonia	2478.0	7.84	0.0087	2660.8
Cycle-hexane	723.0	0.00	0.0000	723.0
Lubricants	947.0	0.00	0.0000	947.0

Source: BioGrace standard values, public version 3 (http://www.BioGrace.net)

Table 6. Emission factors for conversion inputs (input in MJ)

Conversion inputs	CO_2	CH_4	N_2O	CO_2-eq
		[g/MJ]		
n-Hexane	80.08	0.0146	0.0003	80.50
Hydrogen (for HVO)	80.87	0.2765	0.0003	87.32

HVO: hydrogenated vegetable oils

Source: BioGrace standard values, public version 3 (http://www.BioGrace.net)

Table 7. Emission factors for burning of straw and natural gas in CHP plants and for replaced electricity

CHP	CO_2	CH_4	N_2O	CO_2-eq
		[g/MJ]		
Burning of wheat straw	1.75	0.0013	0.0001	1.80
Electricity from straw (replaced by export from the system)	5.56	0.0042	0.0002	5.72
Burning of natural gas (NG)	61.58	0.1981	0.0002	66.59
CH_4 and N_2O emissions from NG boiler (per MJ steam)		0.0028	0.0011	0.40

Source: BioGrace standard values, public version 3 (http://www.BioGrace.net)

Table 8. Transport distances to Europe (ship)

Transport distances to Europe	Distance to Marseille per ship (km)
Indonesia (Jakarta)	12 523
Mexico (Veracruz)	10 166
South Africa (Cape Town)	10 660

Distances calculated using http://www.searates.com/reference/portdistance. Nautical miles converted to kilometres using http://www.metric-conversions.org/length/nautical-miles-to-kilometers.htm.

3.2 Biodiesel from palm oil (first generation)

3.2.1 Introduction

The processing steps of biodiesel (fatty acid methyl ester, FAME) production from palm oil consist of oil extraction, oil refining and esterification. Co-products considered in this study are kernel meal from oil extraction and glycerol from esterification. Both co-products are exported from the system for use for energy, animal feed, land application (kernel meal) or industrial processes (glycerol), and emissions are allocated to these co-products using the energy content method.

Two alternative pathways are considered: with and without capture of CH_4 emissions from palm oil mill effluent (POME) from the extraction process. Where CH_4 is captured, it is assumed to be used for generation of electricity occurring outside the analysed system. In this case, an exception is made, and no emissions are allocated to the energy content of the exported CH_4. In these 2 pathways, both in-country consumption of biodiesel and export to the EU are considered.

Tables 9 and 10 provide country-independent data for processing palm oil into biodiesel. Table 11 provides data for oil palm cultivation and transport for Indonesia.

Table 9. Data for extraction and refining of palm oil

Extraction and refining of palm oil	Unit	Value
Energy content of FFB dry matter	MJ/kg	24.0000
Palm oil yield from extraction	MJ_{Oil}/MJ_{FFB}	0.5300
By-product kernel meal	MJ_{meal}/MJ_{FFB}	0.0268
Electricity consumed for extraction	MJ/MJ_{Oil}	0.0086
Electricity surplus (export)	MJ/MJ_{Oil}	0.0040
CH_4 emissions from palm oil mill effluent (process without CH_4 capture)	g/MJ_{Oil}	1.3218
Yield from refining of oil	MJ_{Oil}/MJ_{Oil}	0.9600
Natural gas input for refining (boiler)	MJ/MJ_{Oil}	0.0130
Grid electricity for refining	MJ/MJ_{Oil}	0.0008
Use of Fuller's earth for refining	kg/MJ_{Oil}	0.0002

FFB: fresh fruit bunches

Source: BioGrace standard values, public version 3 (http://www.BioGrace.net); electricity consumption and exports from Schmidt (2007)

Table 10. Data for biodiesel production from palm oil (esterification)

Esterification of palm oil	Unit	Value
Biodiesel yield	MJ_{FAME}/MJ_{Oil}	0.993600
Co-product: refined glycerol	$kg/tonne_{FAME}$	105.600000
Electricity consumed	MJ/MJ_{FAME}	0.006100
Natural gas consumed	MJ/MJ_{FAME}	0.112000
Phosphoric acid (H_3PO_4)	kg/MJ_{FAME}	0.000064
Hydrochloric acid (HCl)	kg/MJ_{FAME}	0.000753
Sodium carbonate (Na_2CO_3)	kg/MJ_{FAME}	0.000094
Sodium hydroxide (NaOH)	kg/MJ_{FAME}	0.000253
Methanol	kg/MJ_{FAME}	0.081800

Source: BioGrace standard values, public version 3 (http://www.BioGrace.net); electricity consumption and export from extraction from Schmidt (2007)

3.2.2 Indonesia

Table 11. Data for oil palm cultivation, Indonesia

Palm cultivation	Unit	Value	Data source
Yield (FFB)	kg_{WM}/(ha*a)	17 950 .00	Schmidt (2007)
Water content	%	34.00	BioGrace
N fertiliser	kg N/(ha*a)	228.00	National expert
Ca fertiliser	kg CaO/(ha*a)	0.00	National expert
K fertiliser	kg K_2O/(ha*a)	344.00	National expert
P fertiliser	kg P_2O_5/(ha*a)	123.00	National expert
Pesticides	kg/(ha*a)	3.42	Nazir and Setyaningsih (2010)
Energy consumption	MJ/(ha*a)	413.00	Nazir and Setyaningsih (2010) (transport)
Field N_2O emissions	kg N_2O/(ha*a)		Own calculation based on IPCC tier 1 methodology

WM: wet matter; FFB: fresh fruit bunches

Source: BioGrace standard values, public version 3 (http://www.BioGrace.net)

Table 12. In-country transport distances for biodiesel production from palm oil, Indonesia

In-country transport distances	km	Source
Feedstock transport to plant (diesel truck)	30	National expert
Biofuel transport to point of distribution (in-country, diesel truck)	200	Schmidt (2007)

3.3 Biodiesel from jatropha (second generation)

3.3.1 Introduction

As with production of biodiesel from palm oil, the processing steps when jatropha is the feedstock consist of oil extraction, oil refining and esterification. Jatropha processing is not considered a first-generation technology because of the limited experience with growing jatropha at commercial scales. Glycerol from esterification is considered a co-product exported from the system. Nutshell meal is assumed to be either exported from the system, used as fertiliser outside the system to replace synthetic fertilisers or disposed of as waste. Where the meal is disposed of as waste, emissions based on its energy content are not subtracted from the biofuel emissions. The remaining seedcake is used for supply energy for the process. Cultivation is assumed to be done mainly by hand, and additional energy input is considered negligible.

Data for extraction and refining of jatropha are provided in Table 13; these data are mainly taken from the GEMIS database. Table 14 shows values for esterification taken from BioGrace. As a comparison of Tables 13 and 14 reveals, BioGrace provides the same esterification values for all biodiesel pathways included in the tool. These values have been applied to biodiesel produced from jatropha. For the esterification step, country-specific values are used only for the electricity mix.

Tables 15 to 18 provide country-specific information on cultivation of jatropha and transport of the diesel for Mexico (Tables 15 and 16) and South Africa (Tables 17 and 18). The IPCC guidelines provide no data for calculating N_2O emissions from jatropha cultivation. Therefore, for field N_2O emissions from cultivation, only direct emissions from the application of nitrogen fertiliser are taken into account.

The range of seed yields for jatropha is very high, ranging from ≤ 500 kg/ha/a up to > 5 t/ha/a.[3] Given the scarcity of country-specific experience, the yield values used in the study should be regarded as indicative only.

3 See, for example, Borman (2011).

Table 13. Data for extraction and refining of jatropha oil

Extraction and refining of jatropha oil	Unit	Value
Energy content of nuts (dry matter)	MJ/kg	24 .0000
Oil yield from extraction	MJ_{Oil}/MJ_{fruit}	0.2604
By-product: nutshell meal	MJ_{meal}/MJ_{fruit}	0.5208
Electricity consumed for extraction and refining	MJ/MJ_{Oil}	0.0260
n-Hexane for extraction	MJ/MJ_{Oil}	0.0043
Yield from refining of oil	MJ_{Oil}/MJ_{Oil}	0.9600

Source: GEMIS database. The yield from refining and the amount of n-Hexane used for extraction are BioGrace standard values, public version 3 (http://www.BioGrace.net)

Table 14. Data for biodiesel production from jatropha oil (esterification)

Esterification of jatropha oil	Unit	Value
Biodiesel yield	MJ_{FAME}/MJ_{Oil}	0.993600
Co-product: refined glycerol	$kg/tonne_{FAME}$	105.600000
Electricity consumed	MJ/MJ_{FAME}	0.006100
Natural gas consumed	MJ/MJ_{FAME}	0.112000
Phosphoric acid (H_3PO_4)	kg/MJ_{FAME}	0.000064
Hydrochloric acid (HCl)	kg/MJ_{FAME}	0.000753
Sodium carbonate (Na_2CO_3)	kg/MJ_{FAME}	0.000094
Sodium hydroxide (NaOH)	kg/MJ_{FAME}	0.000253
Methanol	kg/MJ_{FAME}	0.081800

Source: BioGrace standard values, public version 3 (http://www.BioGrace.net); electricity consumption and export from extraction from Schmidt (2007)

Even though jatropha is considered a second-generation feedstock, LUC emissions for the 'first generation only' scenario have been applied because jatropha cultivation is considered comparable to any agriculturally produced feedstock.

3.3.2 Mexico

For Mexico, 2 productivity rates of jatropha are considered: 1100 kg/ha and 3000 kg/ha. As there is currently no use for seedcake, it is assumed that the nutshell cake is disposed of as waste, that is, no emissions based on its energy content are allocated to it.

3.3.3 Africa (South Africa)

For South Africa, 2 pathway options are compared: use of nutshell meal for fertilisation with no artificial fertiliser input, and export of nutshell meal from the system with artificial fertiliser used in cultivation.

Table 17 shows the data used for jatropha cultivation and transport in South Africa. The only country-specific datum available is an estimate of productivity. All other cultivation data are taken from the Mexico case study. The fertiliser data and field N_2O emissions shown are only used in the option in which artificial fertiliser is used.

3.4 Bioethanol from sugarcane (first generation)

3.4.1 Introduction

Bioethanol is produced from sugarcane via a simple pathway involving fermentation of sugar available in the plant juice. Solid residues from pressing, known as 'bagasse', are used as fuel, resulting in a pathway with very low fossil fuel requirements. Energy from the bagasse is sufficient to cover processing energy needs. Emissions from processing are therefore low and mainly stem from the auxiliary conversion

Table 15. Data for jatropha cultivation, Mexico

Jatropha cultivation	Unit	Value	Data source
Yield (FFB)	kg_{WM}/(ha*a)	1100 and 3000	National expert
Water content	%	7	GEMIS
N fertiliser	kg N/(ha*a)	228	National expert
Ca fertiliser	kg CaO/(ha*a)	0	National expert
K fertiliser	kg K_2O/(ha*a)	344	National expert
P fertiliser	kg P_2O_5/(ha*a)	123	National expert
Pesticides	kg/(ha*a)	6	National expert
Field N_2O emissions	kg N_2O/(ha*a)	0.6	IPCC tier 1

WM: wet matter; FFB: fresh fruit bunches

Table 16. In-country transport distances for biodiesel production from jatropha, Mexico

In-country transport distances	km	Source
Feedstock transport to plant (diesel truck)	170	National expert
Biofuel transport to point of distribution (in-country, diesel truck)	10	Assumption

Table 17. Data for jatropha cultivation, South Africa

Jatropha cultivation	Unit	Value	Data source
Yield (FFB)	kg_{WM}/(ha*a)	2000.0	Estimate based on literature[a]
Water content	%	7.0	GEMIS
N fertiliser	kg N/(ha*a)	228.0	National expert (Mexico)
Ca fertiliser	kg CaO/(ha*a)	0.0	National expert (Mexico)
K fertiliser	kg K_2O/(ha*a)	344.0	National expert (Mexico)
P fertiliser	kg P_2O_5/(ha*a)	123.0	National expert (Mexico)
Pesticides	kg/(ha*a)	6.0	National expert (Mexico)
Field N_2O emissions	kg N_2O/(ha*a)	0.6	IPCC tier 1, where fertiliser is applied

a See, for example, Jongschaap *et al.* (2007)

WM: wet matter; FFB: fresh fruit bunches

Table 18. In-country transport distances for biodiesel production from jatropha, South Africa

In-country transport distances	km	Source
Feedstock transport to plant (diesel truck)	150	National expert
Biofuel transport to point of distribution (in-country, diesel truck)	10	National expert

inputs and, to a limited extent, from CH_4 and N_2O emissions from bagasse burning. No export of co-products is assumed in the calculations.

The country-independent process data are as follows.

The country-specific data for cultivation of sugarcane include CH_4 emissions from burning residues from sugarcane plants in the fields. A linear correlation between the CH_4 emissions from residue burning and the sugarcane yield was assumed, with the value calculated by establishing a relation between the emissions from residue burning and the sugarcane yield. This calculation was based on default values in the BioGrace tool and resulted in a factor of 0.00028447.

Table 19. Data for sugarcane ethanol plants

Ethanol generation from sugarcane	Unit	Value
Energy content of sugarcane	MJ/kg d.m.	19.600000
Ethanol yield from conversion	$MJ_{Ethanol}/MJ_{cane}$	0.530000
By-products	MJ/MJ_{cane}	0.000000
Electricity consumed in ethanol plant	$MJ/MJ_{Ethanol}$	0.300000
Grid electricity	MJ/MJ_{Oil}	0.000000
Pure CaO for processes	$kg/MJ_{Ethanol}$	0.000670
Cycle-hexane	$kg/MJ_{Ethanol}$	0.000040
Sulphuric acid (H_2SO_4)	$kg/MJ_{Ethanol}$	0.000598
Lubricants	$kg/MJ_{Ethanol}$	0.000010

d.m.: dry matter

Source: BioGrace standard values, public version 3 (http://www.BioGrace.net); electricity consumption from GEMIS

3.4.2 Mexico

Tables 20 and 21 show the country-specific data for sugarcane cultivation and transport in Mexico.

Table 20. Data for sugarcane cultivation, Mexico

Sugarcane cultivation	Unit	Value	Data source
Yield (sugarcane)	$kg_{WM}/(ha*a)$	70 000.00	National expert
Water content	%	50.00	National expert
N fertiliser	kg N/(ha*a)	126.00	National expert
K fertiliser	kg K_2O/(ha*a)	150.00	National expert
P fertiliser	kg P_2O_5/(ha*a)	42.00	National expert
Pesticides	kg/(ha*a)	2.00	National expert
Energy consumption	MJ/(ha*a)	3900.00	National expert
Field N_2O emissions	kg N_2O/(ha*a)	3.83	BioGrace N_2O calculator
CH_4 from trash burning	kg/(ha*a)	19.91	Factor based on BioGrace default values

WM: wet matter

Table 21. In-country transport distances for ethanol production from sugarcane, Mexico

In-country transport distances	km	Source
Feedstock transport to plant (diesel truck)	45	National expert
Biofuel transport to point of distribution (in-country, diesel truck)	300	National expert

3.4.3 Africa (South Africa)

Tables 22 and 23 show the country-specific data for sugarcane cultivation and transport for South Africa.

Table 22. Data for sugarcane cultivation, South Africa

Sugarcane cultivation	Unit	Value	Data source
Yield (sugarcane)	kg_{WM}/(ha*a)	60 000.0	Mashoko *et al.* (2010)
Water content	%	72.5	BioGrace default
N fertiliser	kg N/(ha*a)	120.0	Mashoko *et al.* (2010)
K fertiliser	kg K_2O/(ha*a)	125.0	Mashoko *et al.* (2010)
P fertiliser	kg P_2O_5/(ha*a)	30.0	Mashoko *et al.* (2010)
Pesticides	kg/(ha*a)	1.7	Mashoko *et al.* (2010)
Energy consumption	MJ/(ha*a)	2232.0	National expert
Field N_2O emissions	kg N_2O/(ha*a)	3.6	BioGrace N_2O calculator
CH_4 from trash burning	kg/(ha*a)	17.07	Factor based on BioGrace default values

WM: wet matter

Table 23. In-country transport distances for ethanol production from sugarcane, South Africa

In-country transport distances	km	Source
Feedstock transport to plant (diesel truck)	90	Mashoko *et al.* (2010)
Biofuel transport to point of distribution (in-country, diesel truck)	750	National expert

3.4.4 Indonesia

Tables 24 and 25 show the country-specific data for sugarcane cultivation and transport in Indonesia.

Table 24. Data for sugarcane cultivation, Indonesia

Sugarcane cultivation	Unit	Value	Data source
Yield (sugarcane)	kg_{WM}/(ha*a)	68 110.00	Dinas Perkebunan Jawa Timur[a]
Water content	%	20.00	Yukamgo and Yuwono (2007)
N fertiliser	kg N/(ha*a)	74.60	Disbunjatim (2010)
K fertiliser	kg K_2O/(ha*a)	180.00	Disbunjatim (2010)
P fertiliser	kg P_2O_5/(ha*a)	76.80	Disbunjatim (2010)
Pesticides	kg/(ha*a)	2.00	BioGrace[b]
Energy consumption	MJ/(ha*a)	1963.00	BioGrace default
Field N_2O emissions	kg N_2O/(ha*a)	1.60	BioGrace N_2O calculator
CH_4 from trash burning	kg/(ha*a)	1.59	Factor based on BioGrace default values

a http://www.disbunjatim.go.id/tebu.php

b BioGrace, public version 3 (http://www.BioGrace.net)

WM: wet matter

Table 25. In-country transport distances for ethanol production from sugarcane, Indonesia

In-country transport distances	km	Source
Feedstock transport to plant (diesel truck)	50	National expert
Biofuel transport to point of distribution (in-country, diesel truck)	200	BioGrace default

3.5 Bioethanol from wood (second generation)

3.5.1 Introduction

To convert the lignocellulosic materials in woody biomass to ethanol, the cellulose needs to be released from the surrounding lignin and hemicellulose. A number of pathways can be used to achieve this purpose. This study considers production of ethanol via enzymatic hydrolysis. Production of biodiesel from wood via the Fischer–Tropsch process is described in Section 3.6.

In the enzymatic hydrolysis pathway, the sugars are freed, and then fermentation is used to convert them into ethanol. As the feedstock is wood without bark, the bark content must be subtracted from total wood supply. The energy need for processing can be covered entirely by combustion of lignin.

Country-independent process data are given in Table 26.

Following are country-specific data for wood supply sources in Mexico and Africa.

3.5.2 Mexico (woodchips)

In the case of Mexico, wood is assumed to be taken from existing native forests not primarily dedicated to biofuel production. Because these forests are not managed intensively and because the wood used for biofuel production consists of residues from roundwood harvesting, no emissions from cultivation except diesel consumption for hauling and loading are considered. This diesel consumption amounts to 3 l per tonne dry wood, corresponding to 179 MJ/ha/a based on forest productivity of 2 t d.m./ha/a. Transport distances are 36 km for wood and 289 km for ethanol (national expert).

For the emissions from LUC, the 'second generation only' scenario, which assumes that wood is taken from existing forests, was applied.

3.5.3 Africa (short rotation coppice, Uganda)

Wood is assumed to be taken from short rotation coppices, as described in Zanchi *et al.* (2011). These coppices are assumed to be located in northern Uganda and composed of *Eucalyptus grandis* with a 6-year rotation and replanting every third rotation.

For a production system targeting an annual wood supply of 30 t d.m., Zanchi *et al.* (2011) assume that the coppice used could have either a productivity rate of 5 t d.m./ha/a on an area of 6 ha or a productivity rate of 15 t d.m./ha/a on an area of 2 ha. They suggest total annual emissions from cultivation of 1014 kg CO_2-eq for the low-productivity option and 415 kg CO_2-eq for the high-productivity option. For the purposes of this study, a mean of 715 kg CO_2-eq from a coppice with a productivity rate of 10 t d.m./ha/a and an area of 3 ha was assumed. This results in emissions of 238 kg CO_2-eq/ha/a. This value includes emissions from fertiliser and herbicide production

Table 26. Data for wood ethanol plants

Ethanol production from wood	Unit	Value
Energy content of wood	MJ/kg d.m.	17.000
Ethanol yield from conversion	$MJ_{Ethanol}/MJ_{wood}$	0.430
Electricity consumed in ethanol plant	$MJ/MJ_{Ethanol}$	0.116
Electricity export	$MJ/MJ_{Ethanol}$	0.230
SO_2	$g/MJ_{Ethanol}$	3.633
NH_3 (28 w/w% in H_2O)	$g/MJ_{Ethanol}$	5.166
Molasses (80% DM)	$g/MJ_{Ethanol}$	2.590
Corn steep liquor (CSL) (50% DM)	$g/MJ_{Ethanol}$	6.891
Diammonium phosphate $(NH_4)_2HPO_4$ (DAP)	$g/MJ_{Ethanol}$	0.866

d.m./DM: dry matter

Source: Data from GEMIS database. Electricity consumption and export are taken from 'EtOH from wood'.

and fuel consumption and is used for the cultivation component of the emissions calculation. As no N fertiliser is applied, no N_2O field emissions are taken into account.

In-country transport distances are assumed to be 50 km for wood and 150 km for ethanol.

For the emissions from LUC, the 'second generation only' scenario, which assumes that wood is taken from short rotation coppices on agricultural land, was applied.

3.6 Fischer–Tropsch diesel from wood (second generation)

3.6.1 Introduction

The Fischer–Tropsch (FT) process consists of gasification of the feedstock to generate a synthesis gas, which can then be converted to the desired fuel. The process until production of the raw diesel is energy self-sufficient, but refining the raw diesel requires additional electricity input. No co-products are produced for export.

Attempts to produce diesel using the FT method are limited. To calculate emissions from this pathway using BioGrace, conversion data from the GEMIS database were used.

Country-specific data would primarily consist of cultivation and transport data. However, for the purposes of this study, it was assumed that wood residues served as feedstock, in which case no emissions due to cultivation would be involved. Consequently, differences in country emissions would be determined by differences in transport distances. Because transport emissions are likely to play a minor role in overall emissions and because no specific transport data were available for the study countries, only one data set for FT diesel from wood residues is shown, using Mexican transport data as an indication.

Table 27 shows the technology-specific, country-independent data for the generation of FT diesel from wood.

3.6.2 Mexico (short rotation coppice)

A short rotation plantation with *Eucalyptus camaldulensis* and a mean annual increment of 7.8 t d.m/ha/a was assumed. Fertiliser is applied only at plantation establishment; emissions from this were judged negligible and so no field N_2O emissions were accounted for. Pesticides and herbicides are applied during the first 3 years after plantation establishment at a rate of 3 kg annually. The rotation is 15 years. Similarly to the case of woodchip production for ethanol, diesel consumption of 3 l per tonne dry

Table 27. Data for FT diesel production from wood

FT diesel plant	Unit	Value
Energy content of wood	MJ/kg d.m.	17.00
Raw diesel yield from FT process	$MJ_{FT\text{-}raw\ diesel}/MJ_{wood}$	0.60
By-products	MJ/MJ_{wood}	–
Olivine	$g/MJ_{FT\text{-}raw\ diesel}$	1.58
Synthesis catalyst cobalt	$g/MJ_{FT\text{-}raw\ diesel}$	0.01
Zinc oxide (ZnO)	$g/MJ_{FT\text{-}raw\ diesel}$	0.01
Potassium carbonate (K_2CO_3)	$g/MJ_{FT\text{-}raw\ diesel}$	0.02
Yield from refining	$MJ_{FT\ diesel}/MJ_{FT\text{-}raw\ diesel}$	0.93
Grid electricity for refining	$MJ/MJ_{FT\ diesel}$	0.07
H_2 for refining	$g/MJ_{FT\text{-}raw\ diesel}$	0.50

d.m.: dry matter

Source: GEMIS database

wood (here 681 MJ/ha/a) and in-country transport distances of 36 km (wood) and 289 km (biodiesel) were assumed (national expert).

The LUC emissions from the 'second generation only' scenario, which assumes that wood is taken from short rotation coppices on agricultural land, were applied.

3.6.3 Africa (short rotation coppice, Uganda)

The same production system and transport distances as described for ethanol production from wood in Uganda (Section 3.5) were assumed. No field N_2O emissions were taken into account.

The LUC emissions from the 'second generation only' scenario, which assumes that wood is taken from short rotation coppices on agricultural land, were applied.

3.6.4 FT diesel from logging and wood residues

As explained above, a sound country-specific differentiation was not possible for FT diesel from logging and wood residues. Transport distances are estimated based on the pathways for Mexico. The LUC emissions from the 'second generation only' scenario, which assumes that wood is taken from existing forests, were applied. An average shipping distance to Europe of 11 000 km was assumed. Emissions from cultivation are ignored.

4. Results: Emission balances of first- and second-generation biofuel pathways

This chapter presents the results of the analysis for each biofuel pathway and country, in terms of GHG emissions per MJ biofuel produced. Due to necessary rounding, aggregation of subtotals may differ slightly from totals in the following tables.

Results derived directly from the BioGrace tool are presented in overview tables. The overview tables also contain, where available, comparisons with standard values from the RED or from other sources where the biofuel pathway is not included in the RED. In particular, the RED does not include default values for jatropha. For comparison, values from the UK's former Renewable Fuels Agency (RFA) are used (see results tables).[4] Jatropha is assumed to be cultivated mainly by hand; therefore, no emissions from the use of fossil fuel for cultivation are considered.

To provide a comprehensive overview of the composition of the default values, emission sources not taken into account in this study are also incorporated into the tables. These include emissions and biomass losses from storage, transport and distribution of biofuels to the final user. Whilst storage losses and emissions can be regarded as negligible, differences between the calculated and default values for transport partly stem from omissions due to system boundary differences, in particular where no export to Europe is assumed. Allocation factors refer to the allocation of emissions to co-products; that is, they show what portion of the emissions from each step is allocated to the produced biofuel.

To complement the overview tables, figures are included to give a better overview of the relative relevance of different sources of emissions. These graphs show the same values as in the overview tables. In addition, because the analysis revealed that emissions from N fertiliser and field N_2O emissions often form a major part of emissions during the cultivation stage, these emission sources are displayed separately in the overview graphs even though they do not form part of the BioGrace tables.

One observation, valid for all pathways, is that where 'first generation only' scenarios are used for LUC emission calculations, these emissions constitute the major part of the total emissions from biofuel. The relative relevance of the other sources of emissions greatly differs for each pathway.

4.1 Biodiesel from palm oil

4.1.1 Indonesia

Tables 28 to 31 provide overviews of the results calculated using the BioGrace tool. Figures 4 to 10 illustrate these values in order to give a better impression of the relative importance of the different sources of emissions.

The results show that CH_4 emissions from POME during the extraction phase have a major impact on the overall emissions balance. Where there is no CH_4 capture, emissions from processing are responsible for around one-quarter of total emissions – the largest share after LUC emissions and more than twice as much as cultivation emissions. With CH_4 capture, the share of processing emissions falls to 10–15% – slightly below emissions from cultivation.

Transport emissions are responsible for a relatively small share of the overall balance, including where export to the EU is assumed. Where export and no CH_4 capture are assumed, processing and transport emissions are close to the RED default values. Emissions from cultivation are clearly higher than the RED default values, mainly because the fertilisation rates used were higher than those in the RED.

4 www.dft.gov.uk/excel/173019/718141/detailed_carbon_intensity_data.xls

Table 28. Overview of emissions due to biodiesel production from palm oil without CH_4 capture, Indonesia (in-country consumption)

All results in g CO_2-eq / MJ_{FAME}	Non-allocated results	Allocation factor (%)	Allocated results	Total	Default values RED Annex V.D
Cultivation e_{ec}				**20.9**	**14.00**
Cultivation of FFB	23.00	91.0	20.94		14.26
Storage of FFB	0.00	91.0	0.00		0.00
Processing e_p				**49.9**	**49.00**
Extraction of oil	34.64	91.0	31.54		31.53
Refining of vegetable oil	1.14	95.7	1.09		17.88
Esterification	18.05	95.7	17.27		
Transport e_{td}				**0.8**	**5.00**
Transport of FFB	0.31	91.0	0.28		0.19
Transport of oil	0.00	95.7	0.00		3.55
Transport of FAME	0.48	100.0	0.48		0.83
Filling station	0.00	100.0	0.00		0.44
Land use change e_l	**118.00**	**100.0**	**118.00**	**118.0**	**0.00**
$e_{sca} + e_{ccr} + e_{ccs}$	**0.00**	**100.0**	**0.00**	**0.0**	**0.00**
Totals	**195.60**			**189.6**	**68.00**

FFB: fresh fruit bunches; FAME: fatty acid methyl ester

Table 29. Overview of emissions due to biodiesel production from palm oil without CH_4 capture, Indonesia (export of oil to EU)

All results in g CO_2-eq / MJ_{FAME}	Non-allocated results	Allocation factor (%)	Allocated results	Total	Default values RED Annex V.D
Cultivation e_{ec}				**20.9**	**14.00**
Cultivation of FFB	23.00	91.0	20.94		14.26
Storage of FFB	0.00	91.0	0.00		0.00
Processing e_p				**49.9**	**49.00**
Extraction of oil	34.64	91.0	31.54		31.53
Refining of vegetable oil	1.14	95.7	1.09		17.88
Esterification	18.05	95.7	17.27		
Transport e_{td}				**4.4**	**5.00**
Transport of FFB	0.31	91.0	0.28		0.19
Transport of oil	4.33	95.7	4.14		3.55
Transport of FAME	0.00	100.0	0.00		0.83
Filling station	0.00	100.0	0.00		0.44
Land use change e_l	**118.00**	**100.0**	**118.00**	**118.0**	**0.00**
$e_{sca} + e_{ccr} + e_{ccs}$	**0.00**	**100.0**	**0.00**	**0.0**	**0.00**
Totals	**199.50**			**193.3**	**68.00**

FFB: fresh fruit bunches; FAME: fatty acid methyl ester

Table 30. Overview of emissions due to biodiesel production from palm oil with CH_4 capture, Indonesia (in-country consumption)

All results in g CO_2-eq / MJ_{FAME}	Non-allocated results	Allocation factor (%)	Allocated results	Total	Default values RED Annex V.D
Cultivation e_{ec}				**20.9**	**14.00**
Cultivation of FFB	23.00	91.0	20.94		14.26
Storage of FFB	0.00	91.0	0.00		0.00
Processing e_p				**18.4**	**49.00**
Extraction of oil	-0.01	91.0	-0.01		31.53
Refining of vegetable oil	1.14	95.7	1.09		17.88
Esterification	18.05	95.7	17.27		
Transport e_{td}				**0.8**	**5.00**
Transport of FFB	0.31	91.0	0.28		0.19
Transport of oil	0.00	95.7	0.00		3.55
Transport of FAME	0.48	100.0	0.48		0.83
Filling station	0.00	100.0	0.00		0.44
Land use change e_l	**118.00**	**100.0**	**118.00**	**118.0**	**0.00**
$e_{sca} + e_{ccr} + e_{ccs}$	**0.00**	**100.0**	**0.00**	**0.0**	**0.00**
Totals	**161.00**			**158.1**	**68.00**

FFB: fresh fruit bunches; FAME: fatty acid methyl ester

Table 31. Overview of emissions due to biodiesel production from palm oil with CH_4 capture, Indonesia (export of oil to EU)

All results in g CO_2-eq / MJ_{FAME}	Non-allocated results	Allocation factor (%)	Allocated results	Total	Default values RED Annex V.D
Cultivation e_{ec}				**20.9**	**14.00**
Cultivation of FFB	23.00	91.0	20.94		14.26
Storage of FFB	0.00	91.0	0.00		0.00
Processing e_p				**18.4**	**49.00**
Extraction of oil	-0.01	91.0	-0.01		31.53
Refining of vegetable oil	1.14	95.7	1.09		17.88
Esterification	18.05	95.7	17.27		
Transport e_{td}				**4.4**	**5.00**
Transport of FFB	0.31	91.0	0.28		0.19
Transport of oil	4.33	95.7	4.14		3.55
Transport of FAME	0.00	100.0	0.00		0.83
Filling station	0.00	100.0	0.00		0.44
Land use change e_l	**118.00**	**100.0**	**118.00**	**118.0**	**0.00**
$e_{sca} + e_{ccr} + e_{ccs}$	**0.00**	**100.0**	**0.00**	**0.0**	**0.00**
Totals	**164.80**			**161.7**	**68.00**

FFB: fresh fruit bunches; FAME: fatty acid methyl ester

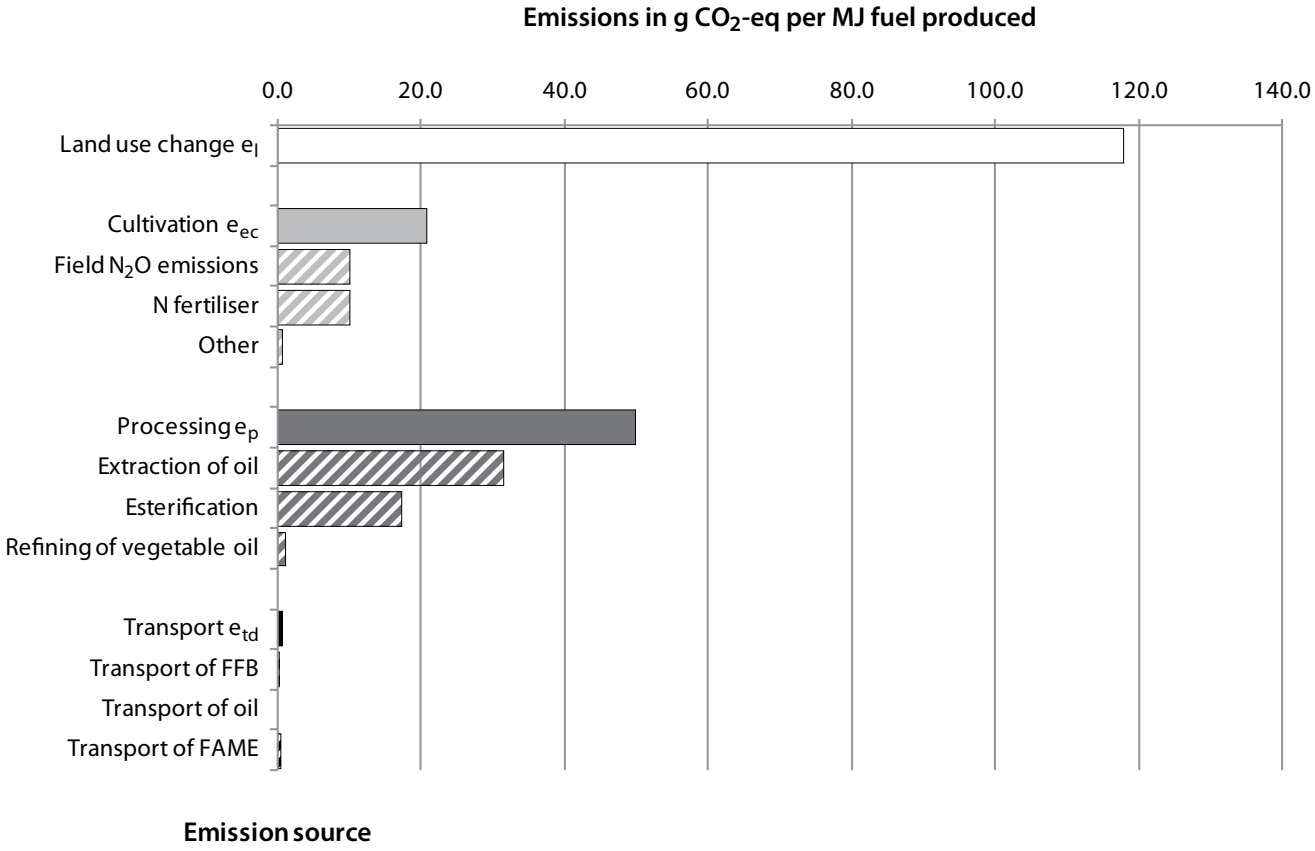


Figure 4. Emission sources for biodiesel production from palm oil without CH_4 capture, Indonesia (in-country consumption)

FFB: fresh fruit bunches; FAME: fatty acid methyl ester

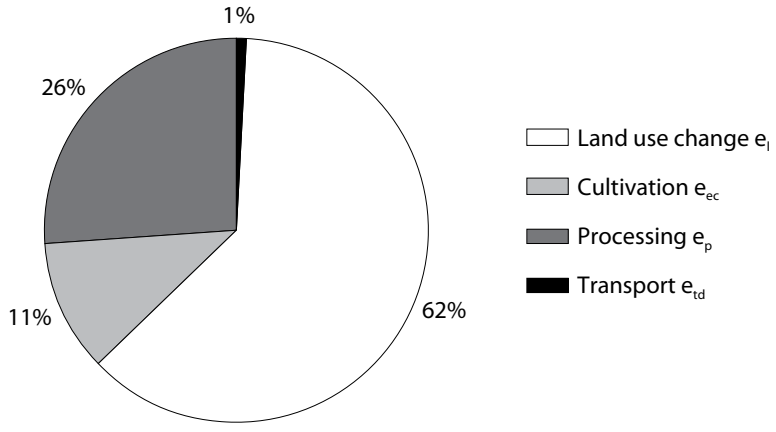


Figure 5. Proportion of emissions from each main source for biodiesel production from palm oil without CH_4 capture, Indonesia (in-country consumption)

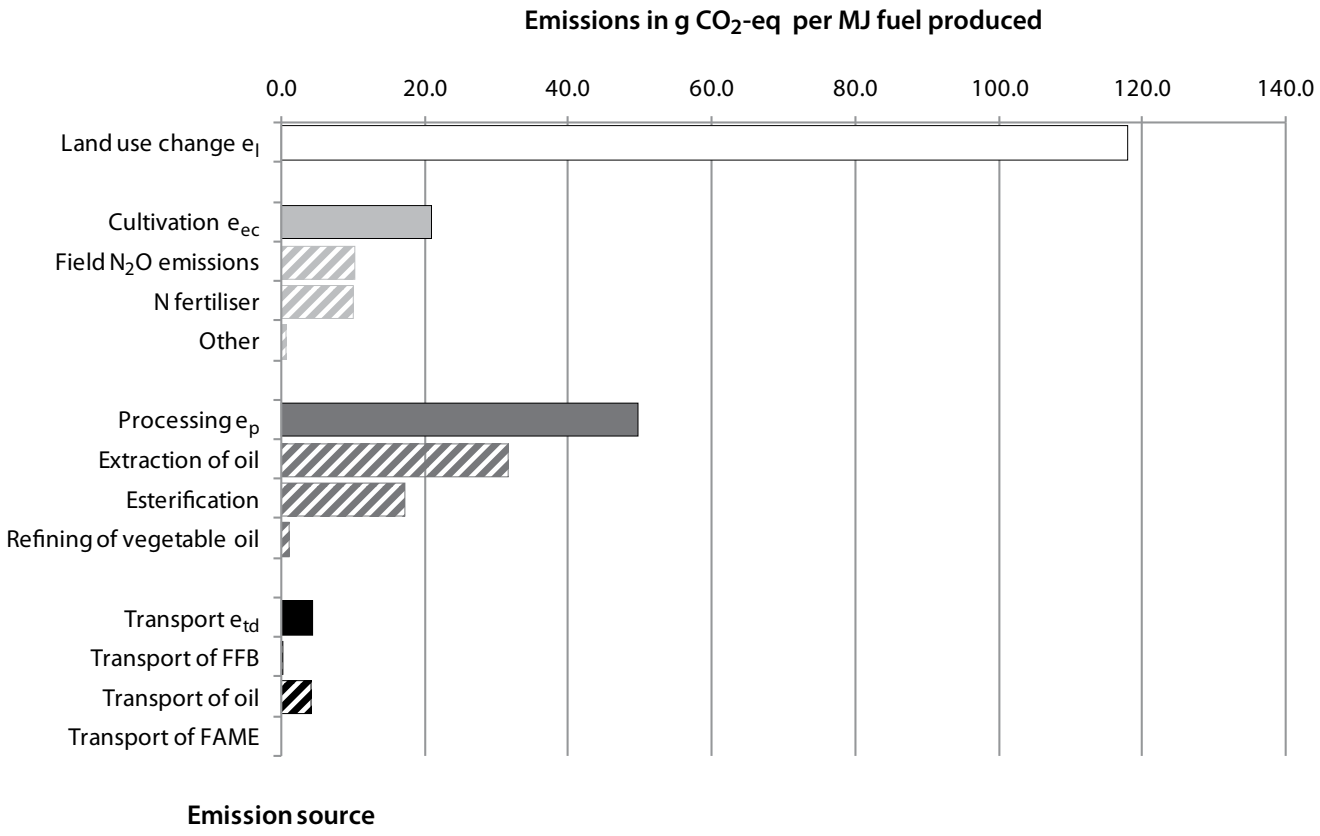


Figure 6. Emission sources for biodiesel production from palm oil without CH_4 capture, Indonesia (export of oil to EU)

FFB: fresh fruit bunches; FAME: fatty acid methyl ester

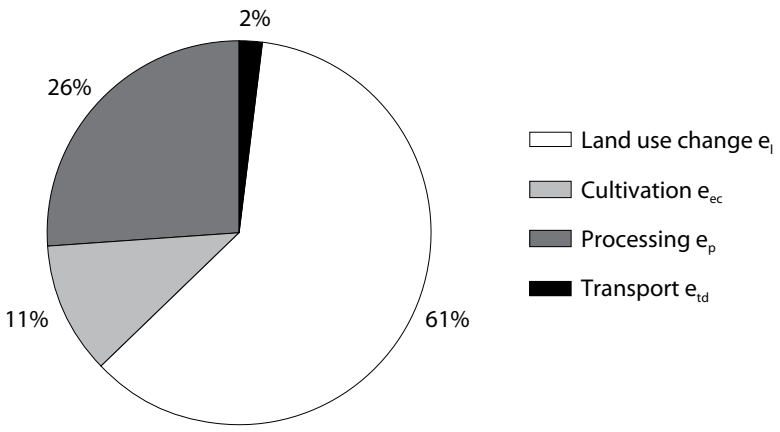


Figure 7. Proportion of emissions from each main source for biodiesel production from palm oil without CH_4 capture, Indonesia (export of oil to EU)

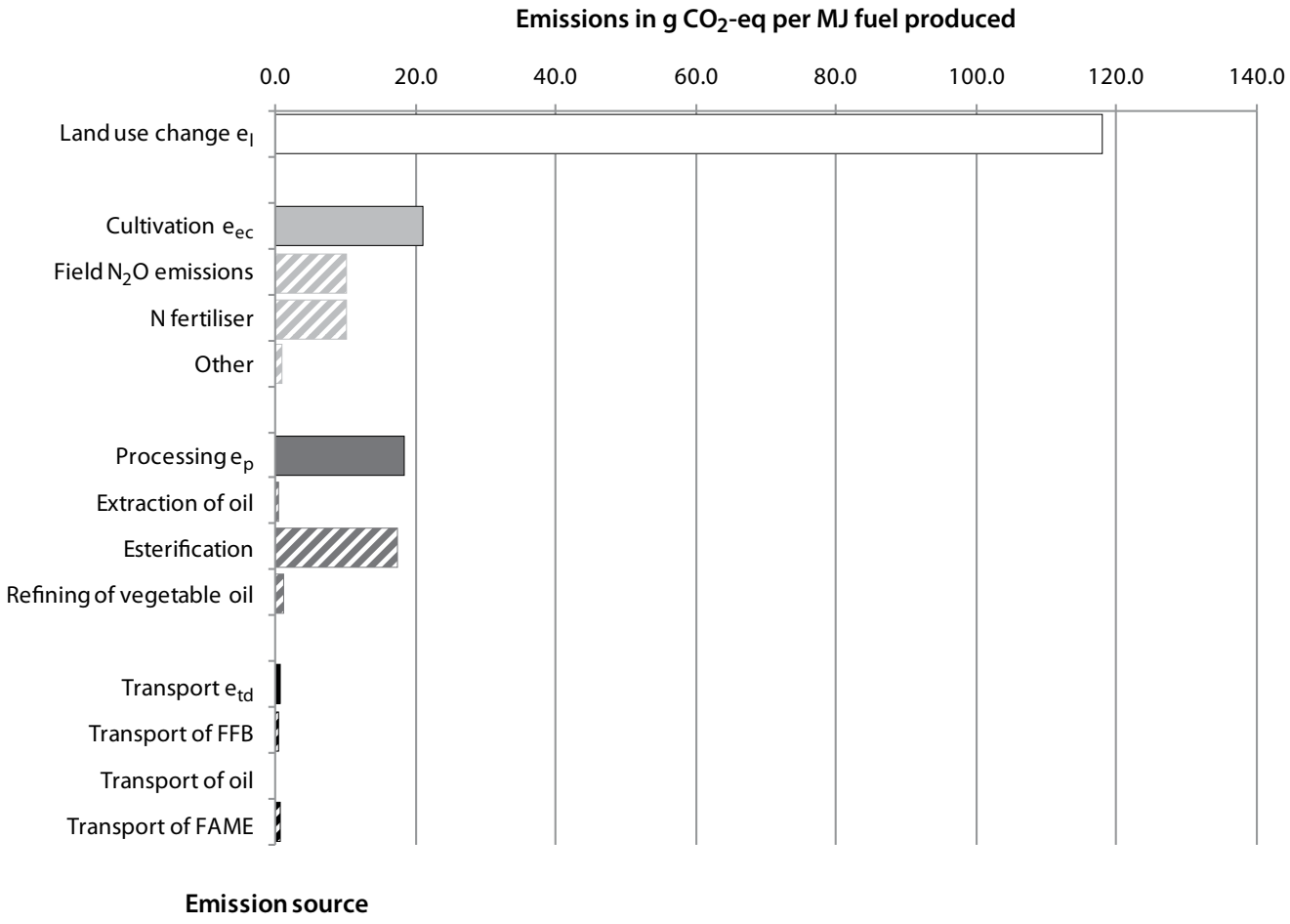


Figure 8. Emission sources for biodiesel production from palm oil with CH_4 capture, Indonesia (in-country consumption)

FFB: fresh fruit bunches; FAME: fatty acid methyl ester

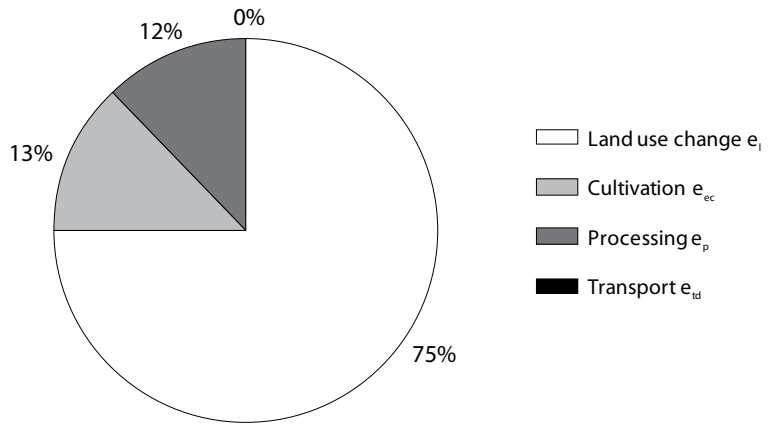


Figure 9. Proportion of emissions from each main source for biodiesel production from palm oil with CH_4 capture, Indonesia (in-country consumption)

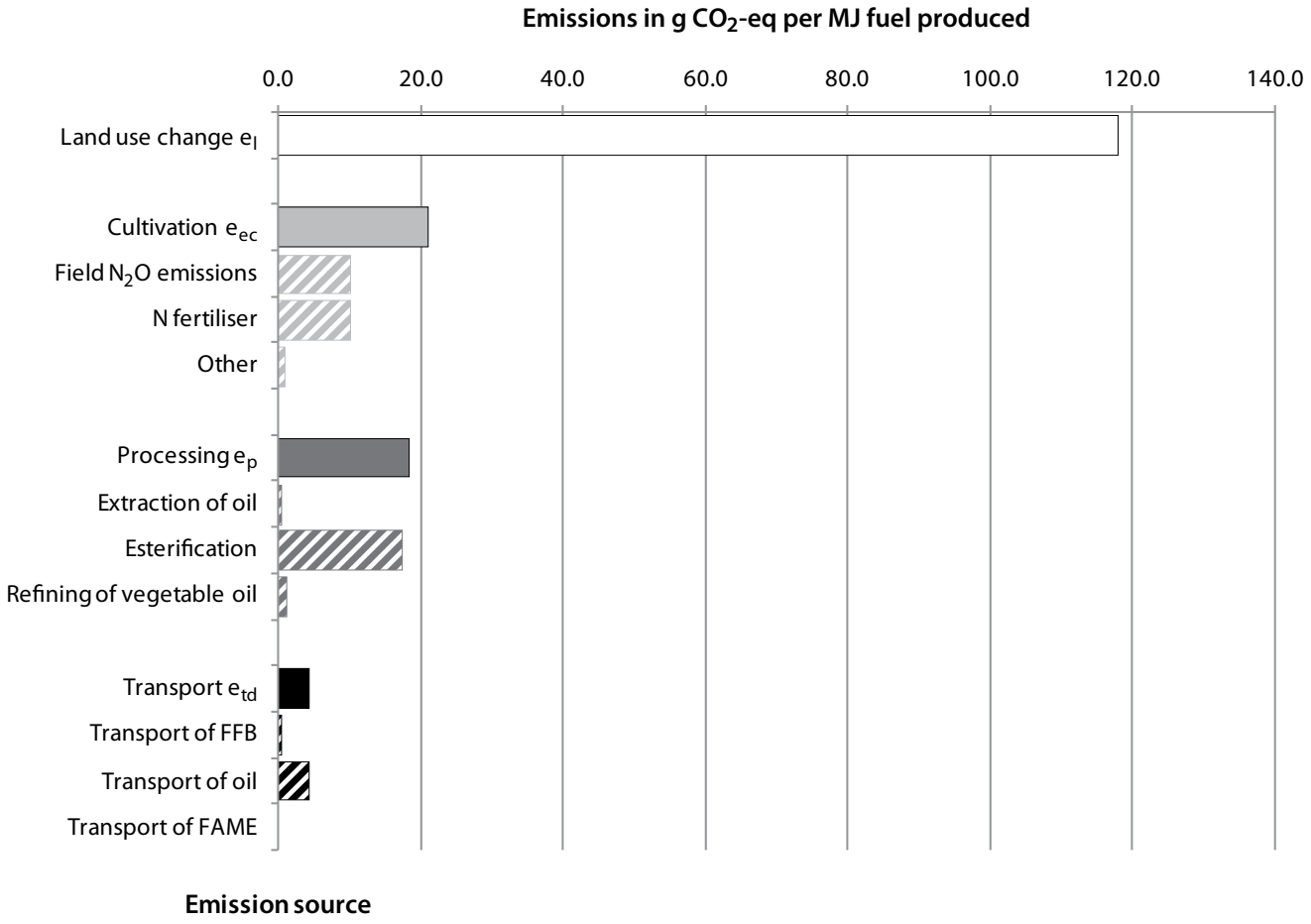


Figure 10. Emission sources for biodiesel production from palm oil with CH_4 capture, Indonesia (export of oil to EU)

FFB: fresh fruit bunches; FAME: fatty acid methyl ester

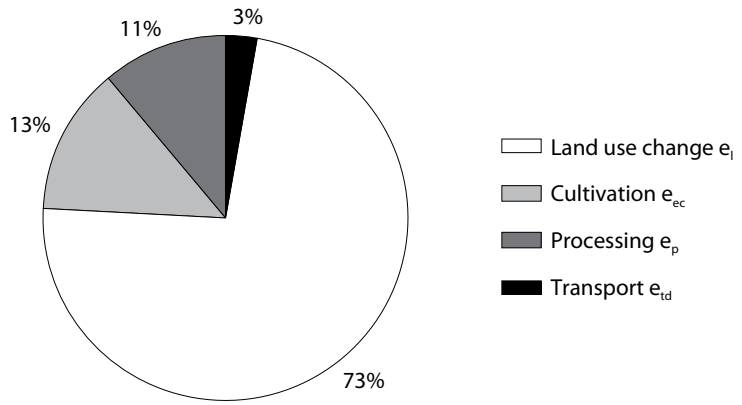


Figure 11. Proportion of emissions from each main source for biodiesel production from palm oil with CH_4 capture, Indonesia (export of oil to EU)

4.2 Biodiesel from jatropha

4.2.1 Mexico

The results show that emissions from cultivation are more than twice as high for the pathway that assumes low productivity for jatropha. This is primarily because the same amount of agro-inputs per ha as in other pathway was attributed to a lower amount of seed output per ha. For the low-productivity scenario, emissions from cultivation were about two-thirds the amount of emissions from LUC; for the high-productivity scenario, they were about one-quarter the volume of LUC emissions.

Even when LUC emissions are not taken into account, the results are clearly higher than the RFA default values. This may be because of the

Table 32. Overview of emissions due to biodiesel production from jatropha, Mexico (low productivity, in-country consumption)

All results in g CO_2-eq / MJ_{FAME}	Non-allocated results	Allocation factor (%)	Allocated results	Total	Default values RFA
Cultivation e_{ec}				**79.8**	
Cultivation of Jatropha	83.38	95.7	79.75		
Processing e_p				**19.7**	
Extraction of oil	0.36	95.7	0.35		
Refining of vegetable oil	3.20	95.7	3.06		
Esterification	17.07	95.7	16.33		
Transport e_{td}				**2.4**	
Transport of seeds	2.52	95.7	2.41		
Transport of oil	0.00	95.7	0.00		
Transport of FAME	0.02	100.0	0.02		
Land use change e_l	**118.00**	**100.0**	**118.00**	**118.0**	
$e_{sca} + e_{ccr} + e_{ccs}$	**0.00**	**100.0**	**0.00**	**0.0**	
Totals	**224.60**			**219.9**	**31**

FAME: fatty acid methyl ester; RFA: Renewable Fuels Agency

Table 33. Overview of emissions due to biodiesel production from jatropha, Mexico (low productivity, export of oil to EU)

All results in g CO_2-eq / MJ_{FAME}	Non-allocated results	Allocation factor (%)	Allocated results	Total	Default values RFA
Cultivation e_{ec}				**79.8**	
Cultivation of Jatropha	83.38	95.7	79.75		
Processing e_p				**19.9**	
Extraction of oil	0.36	95.7	0.35		
Refining of vegetable oil	3.36	95.7	3.21		
Esterification	17.09	95.7	16.34		
Transport e_{td}				**5.4**	
Transport of seeds	2.52	95.7	2.41		
Transport of oil	3.14	95.7	3.00		
Transport of FAME	0.00	100.0	0.00		
Land use change e_l	**118.00**	**100.0**	**118.00**	**118.0**	
$e_{sca} + e_{ccr} + e_{ccs}$	**0.00**	**100.0**	**0.00**	**0.0**	
Totals	**227.80**			**223.1**	**31**

FAME: fatty acid methyl ester; RFA: Renewable Fuels Agency

relatively low productivity of jatropha compared with the scenario where fertiliser is used and because emissions from esterification are high, which is due to an electricity import for esterification. Alternative pathways may cover part of this electricity consumption by using residues as energy, which would reduce emissions from this processing step.

Because of the low proportion of emissions from transport, graphs are shown only for the pathways in which oil is exported to the EU.

Table 34. Overview of emissions due to biodiesel production from jatropha, Mexico (high productivity, in-country consumption)

All results in g CO_2-eq / MJ_{FAME}	Non-allocated results	Allocation factor (%)	Allocated results	Total	Default values RFA
Cultivation e_{ec}				**29.2**	
Cultivation of Jatropha	30.57	95.7	29.24		
Processing e_p				**19.7**	
Extraction of oil	0.36	95.7	0.35		
Refining of vegetable oil	3.20	95.7	3.06		
Esterification	17.07	95.7	16.33		
Transport e_{td}				**2.4**	
Transport of seeds	2.52	95.7	2.41		
Transport of oil	0.00	95.7	0.00		
Transport of FAME	0.02	100.0	0.02		
Land use change e_l	**118.00**	**100.0**	**118.00**	**118.0**	
$e_{sca} + e_{ccr} + e_{ccs}$	**0.00**	**100.0**	**0.00**	**0.0**	
Totals	**171.70**			**169.4**	**31**

FAME: fatty acid methyl ester; RFA: Renewable Fuels Agency

Table 35. Overview of emissions due to biodiesel production from jatropha, Mexico (high productivity, export of oil to EU)

All results in g CO_2-eq / MJ_{FAME}	Non-allocated results	Allocation factor (%)	Allocated results	Total	Default values RFA
Cultivation e_{ec}				**29.2**	
Cultivation of Jatropha	30.57	95.7	29.24		
Processing e_p				**19.9**	
Extraction of oil	0.36	95.7	0.35		
Refining of vegetable oil	3.36	95.7	3.21		
Esterification	17.09	95.7	16.34		
Transport e_{td}				**5.4**	
Transport of seeds	2.52	95.7	2.41		
Transport of oil	3.14	95.7	3.00		
Transport of FAME	0.00	100.0	0.00		
Land use change e_l	**118.00**	**100.0**	**118.00**	**118.0**	
$e_{sca} + e_{ccr} + e_{ccs}$	**0.00**	**100.0**	**0.00**	**0.0**	
Totals	**175.00**			**172.6**	**31**

FAME: fatty acid methyl ester; RFA: Renewable Fuels Agency

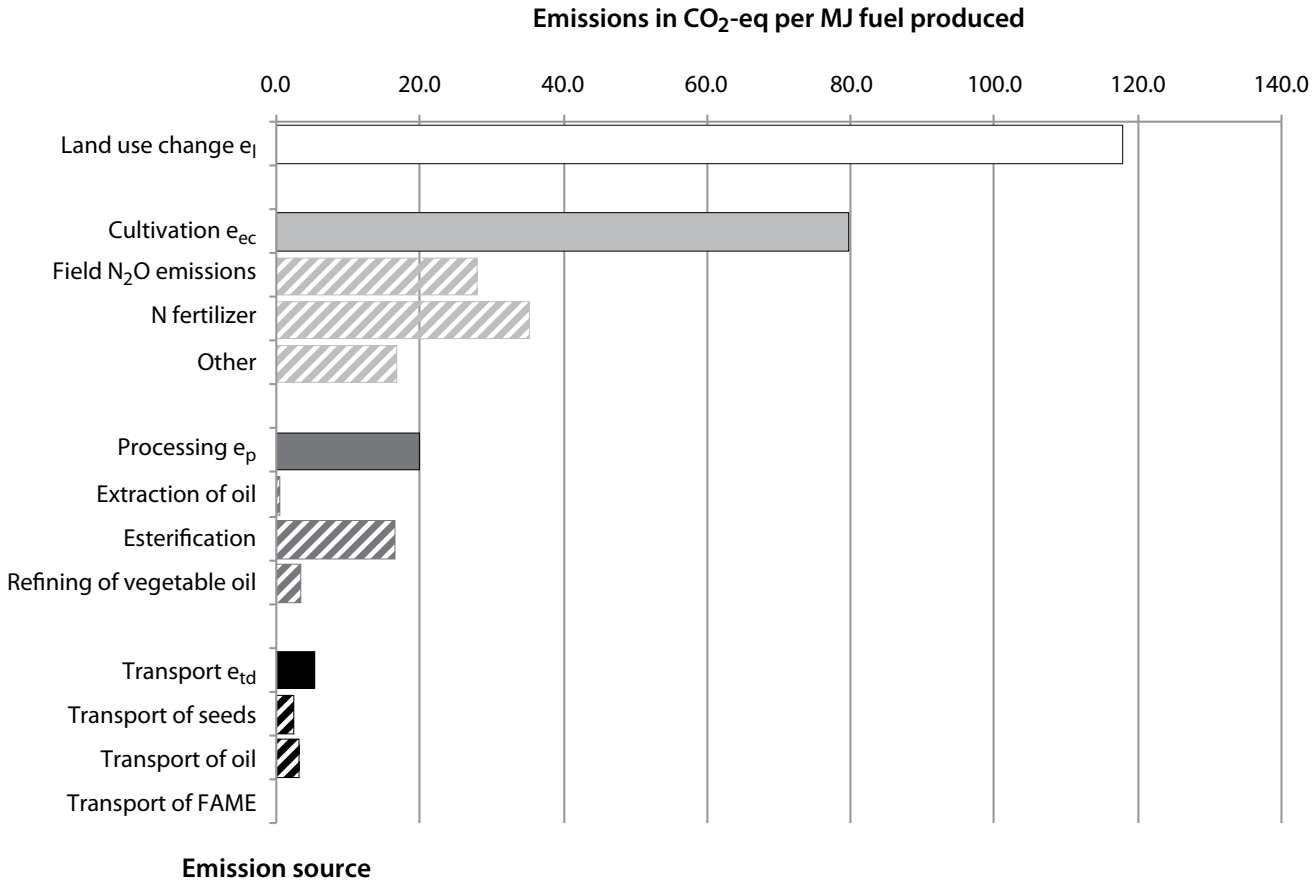


Figure 12. Emission sources for biodiesel production from jatropha, Mexico (low productivity, export of oil to EU)

FAME: fatty acid methyl ester

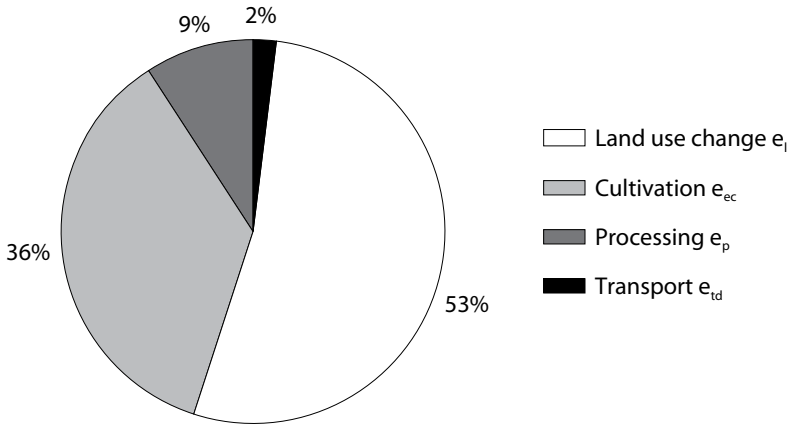


Figure 13. Proportion of emissions from each main source for biodiesel production from jatropha, Mexico (low productivity, export of oil to EU)

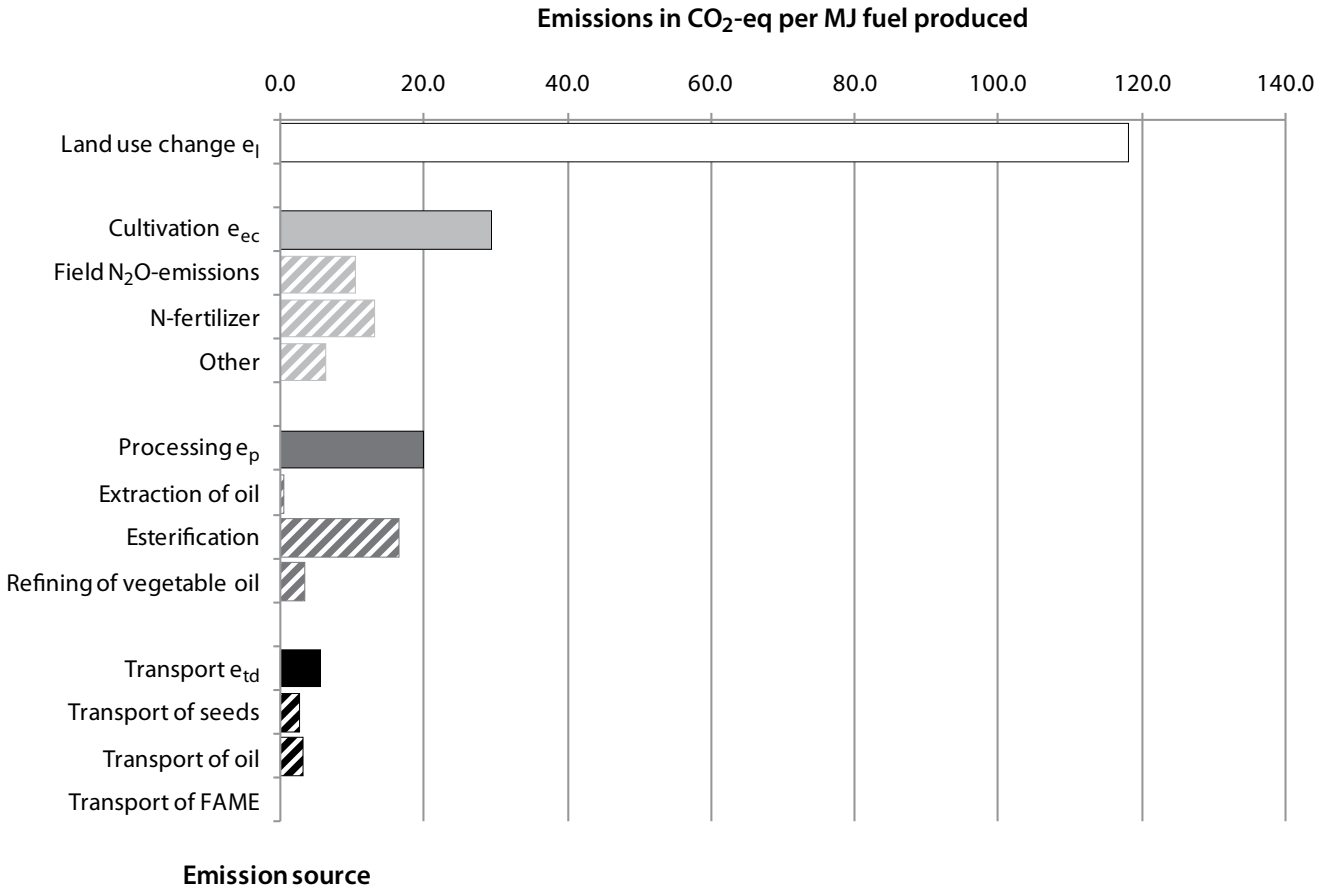


Figure 14. Emission sources for biodiesel production from jatropha, Mexico (high productivity, export of oil to EU)

FAME: fatty acid methyl ester

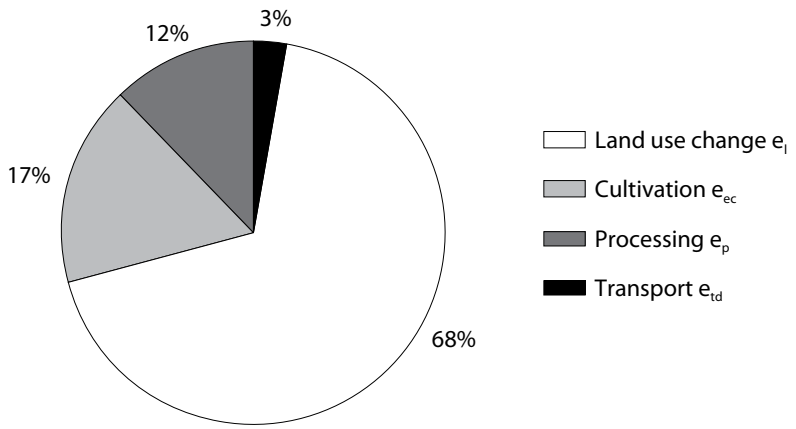


Figure 15. Proportion of emissions for each main source for biodiesel production from jatropha, Mexico (high productivity, export of oil to EU)

4.2.2 Africa

The pathways in which seedcake is used as fertiliser have much lower emissions from cultivation even though almost all cultivation emissions are allocated to the biodiesel. In these pathways, the only source of emissions in cultivation is the use of pesticides; emissions from seedcake application are omitted.

In the pathways in which artificial fertiliser is used, only 32% of cultivation emissions are allocated to the diesel, with the rest mostly allocated to exported seedcake. In the cases where artificial fertiliser is used, most emissions stem from the application of N fertiliser and the resulting field N_2O emissions. The relative amounts of cultivation emissions

Table 36. Overview of emissions due to biodiesel production from jatropha, South Africa (seedcake fertilisation, in-country consumption)

All results in g CO_2-eq / MJ_{FAME}	Non-allocated results	Allocation factor (%)	Allocated results	Total	Default values RFA
Cultivation e_{ec}				**5.7**	
Cultivation of Jatropha	5.97	95.7	5.71		
Processing e_p				**23.4**	
Extraction of oil	0.36	95.7	0.35		
Refining of vegetable oil	6.07	95.7	5.81		
Esterification	18.03	95.7	17.24		
Transport e_{td}				**2.1**	
Transport of fruits	2.22	95.7	2.13		
Transport of oil	0.00	95.7	0.00		
Transport of FAME	0.02	100.0	0.02		
Land use change e_l	**118.00**	**100.0**	**118.00**	**118.0**	
$e_{sca} + e_{ccr} + e_{ccs}$	**0.00**	**100.0**	**0.00**	**0.0**	
Totals	**150.70**			**149.3**	**31**

FAME: fatty acid methyl ester; RFA: Renewable Fuels Agency

Table 37. Overview of emissions due to biodiesel production from jatropha, South Africa (seedcake fertilisation, export of oil to EU)

All results in g CO_2-eq / MJ_{FAME}	Non-allocated results	Allocation factor (%)	Allocated results	Total	Default values RFA
Cultivation e_{ec}				**5.7**	
Cultivation of Jatropha	5.97	95.7	5.71		
Processing e_p				**23.4**	
Extraction of oil	0.36	95.7	0.35		
Refining of vegetable oil	6.07	95.7	5.81		
Esterification	18.03	95.7	17.24		
Transport e_{td}				**5.3**	
Transport of fruits	2.22	95.7	2.13		
Transport of oil	3.35	95.7	3.21		
Transport of FAME	0.00	100.0	0.00		
Land use change e_l	**118.00**	**100.0**	**118.00**	**118.0**	
$e_{sca} + e_{ccr} + e_{ccs}$	**0.00**	**100.0**	**0.00**	**0.0**	
Totals	**154.00**			**152.4**	**31**

FAME: fatty acid methyl ester; RFA: Renewable Fuels Agency

might change, however, if emissions from seedcake application are taken into account.

Emission sources other than cultivation are affected by the allocation differences between the fertilisation scenarios up to the point where seedcake is potentially exported. However, these emissions make only a small contribution to the total, and hence these differences play a minor role in total emissions.

Table 38. Overview of emissions due to biodiesel production from jatropha, South Africa (artificial fertiliser, in-country consumption)

All results in g CO_2-eq / MJ_{FAME}	Non-allocated results	Allocation factor (%)	Allocated results	Total	Default values RFA
Cultivation e_{ec}				**14.6**	
Cultivation of Jatropha	45.86	31.9	14.62		
Processing e_p				**22.5**	
Extraction of oil	0.36	31.9	0.12		
Refining of vegetable oil	6.07	95.7	5.81		
Esterification	17.29	95.7	16.54		
Transport e_{td}				**0.7**	
Transport of seeds	2.22	31.9	0.71		
Transport of oil	0.00	95.7	0.00		
Transport of FAME	0.02	100.0	0.02		
Land use change e_l	**118.00**	**100.0**	**118.00**	**118.0**	
$e_{sca} + e_{ccr} + e_{ccs}$	**0.00**	**100.0**	**0.00**	**0.0**	
Totals	**189.80**			**155.8**	**31**

FAME: fatty acid methyl ester; RFA: Renewable Fuels Agency

Table 39. Overview of emissions due to biodiesel production from jatropha, South Africa (artificial fertiliser, export to EU)

All results in g CO_2-eq / MJ_{FAME}	Non-allocated results	Allocation factor (%)	Allocated results	Total	Default values RFA
Cultivation e_{ec}				**14.6**	
Cultivation of Jatropha	45.86	31.9	14.62		
Processing e_p				**22.5**	
Extraction of oil	0.36	31.9	0.12		
Refining of vegetable oil	6.07	95.7	5.81		
Esterification	17.29	95.7	16.54		
Transport e_{td}				**3.9**	
Transport of seeds	2.22	31.9	0.71		
Transport of oil	3.35	95.7	3.21		
Transport of FAME	0.00	100.0	0.00		
Land use change e_l	**118.00**	**100.0**	**118.00**	**118.0**	
$e_{sca} + e_{ccr} + e_{ccs}$	**0.00**	**100.0**	**0.00**	**0.0**	
Totals	**193.20**			**159.0**	**31**

FAME: fatty acid methyl ester; RFA: Renewable Fuels Agency

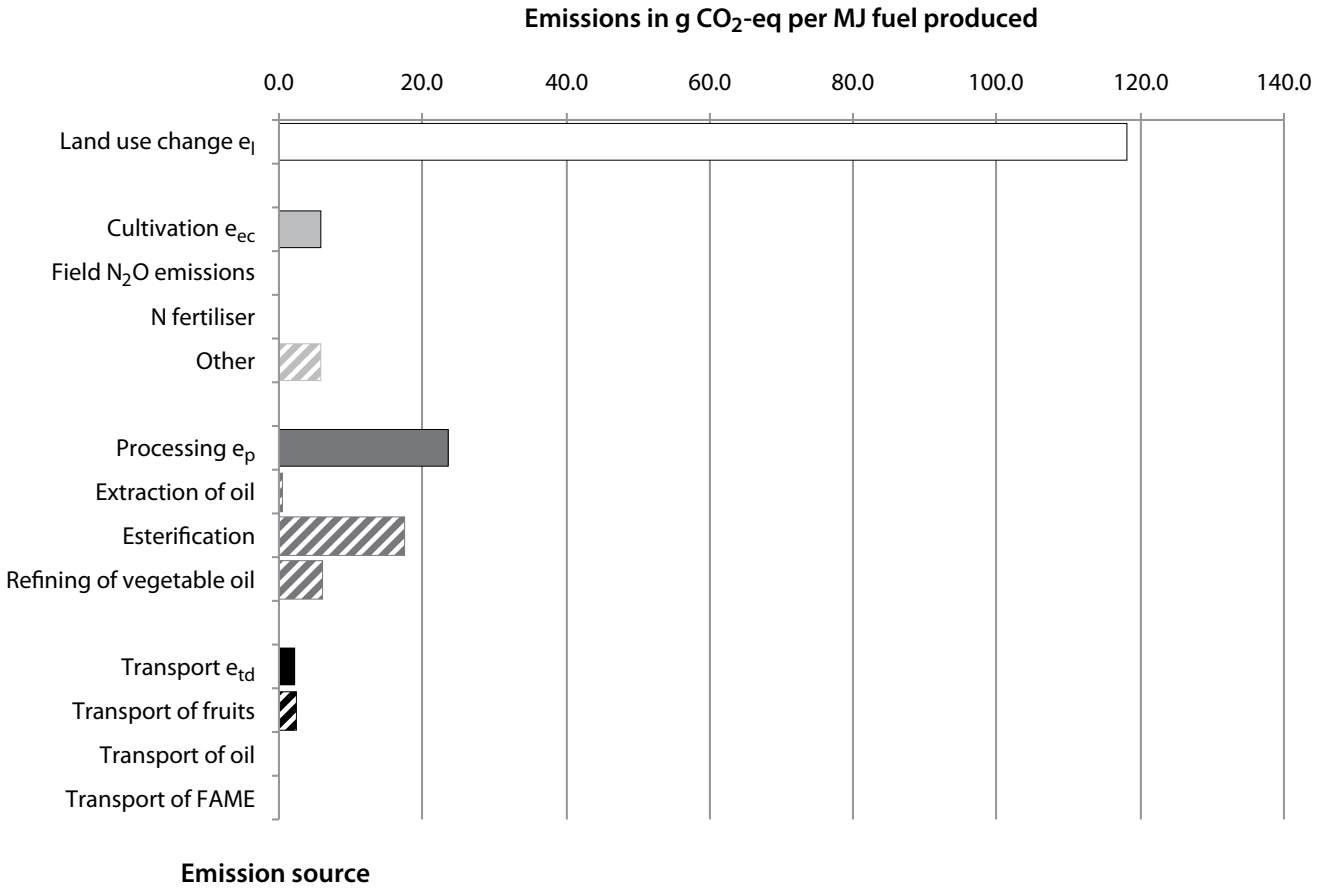


Figure 16. Emission sources for biodiesel production from jatropha, South Africa (seedcake fertilisation, in-country consumption)

FAME: fatty acid methyl ester

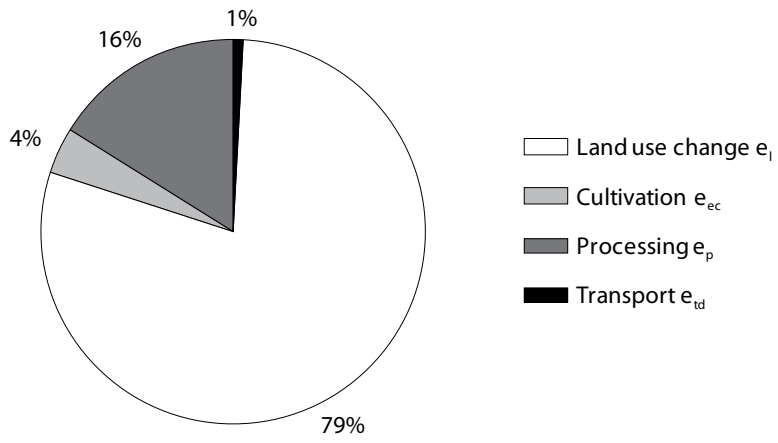


Figure 17. Proportion of emissions from each main source for biodiesel production from jatropha, South Africa (seedcake fertilisation, in-country consumption)

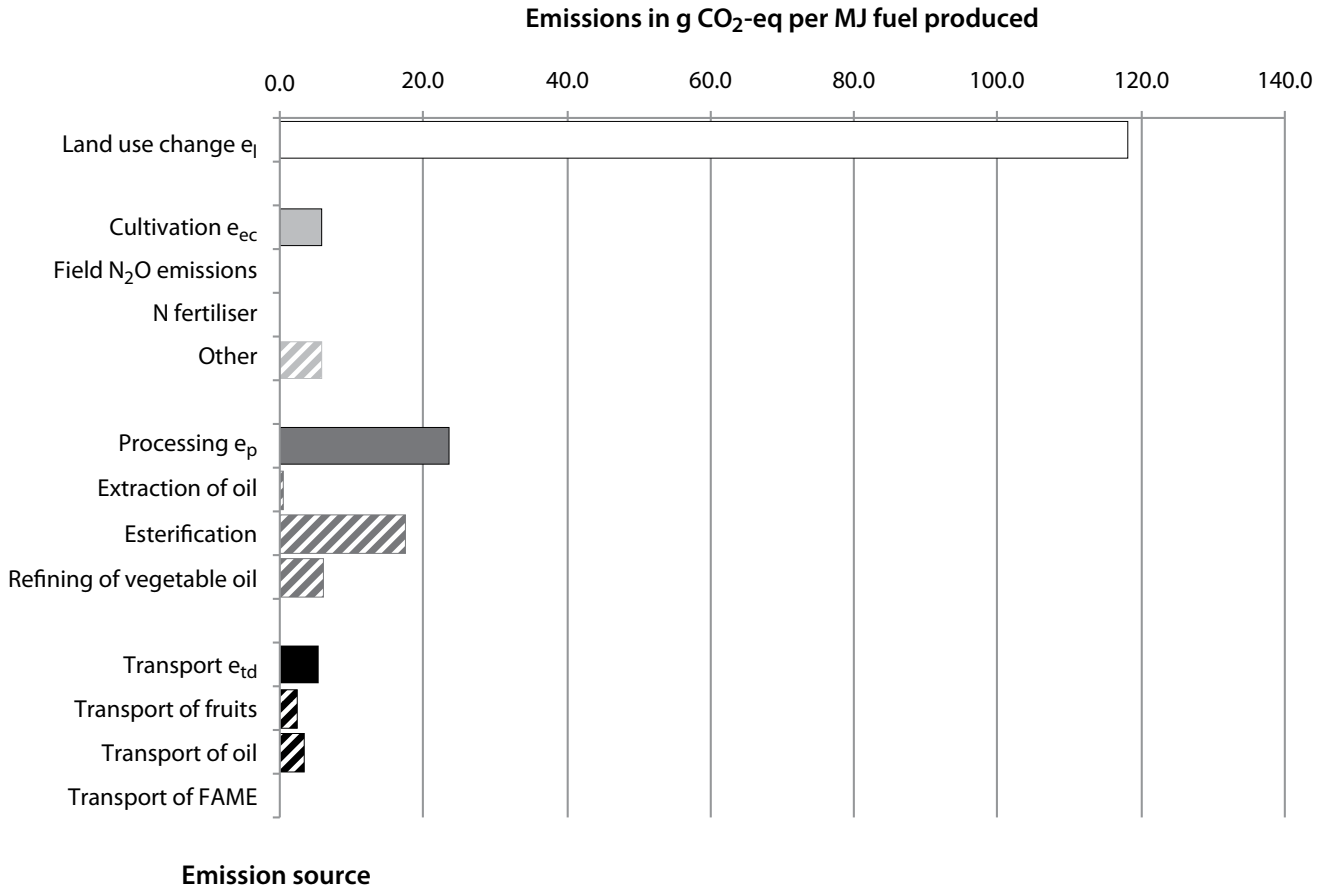


Figure 18. Emission sources for biodiesel production from jatropha, South Africa (seedcake fertilisation, export of oil to EU)

FAME: fatty acid methyl ester

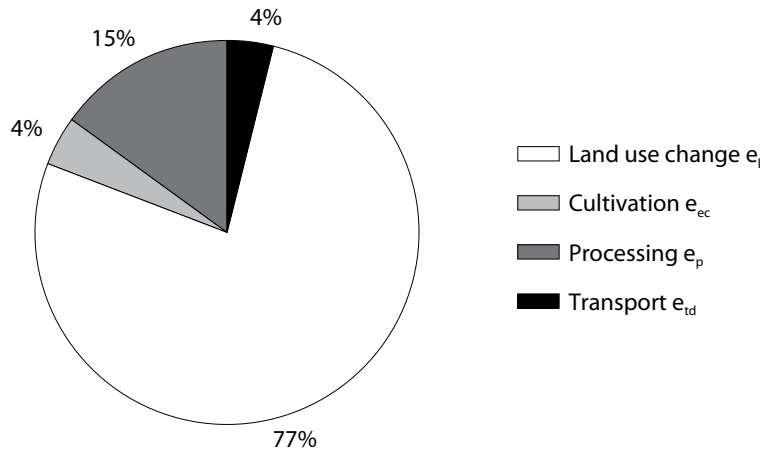


Figure 19. Proportion of emissions from each main source for biodiesel production from jatropha, South Africa (seedcake fertilisation, export of oil to EU)

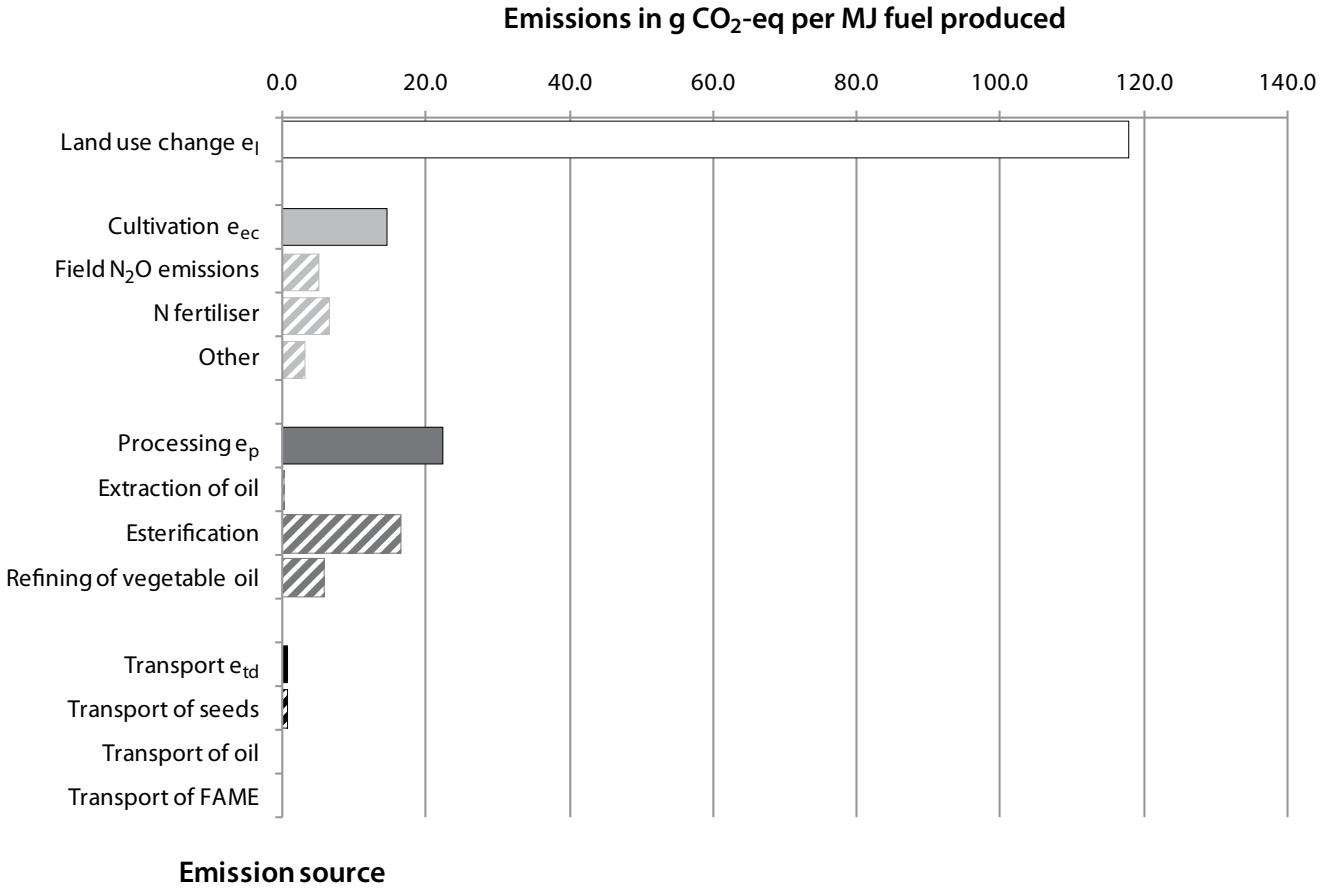


Figure 20. Emission sources for biodiesel production from jatropha, South Africa (artificial fertiliser, in-country consumption)

FAME: fatty acid methyl ester

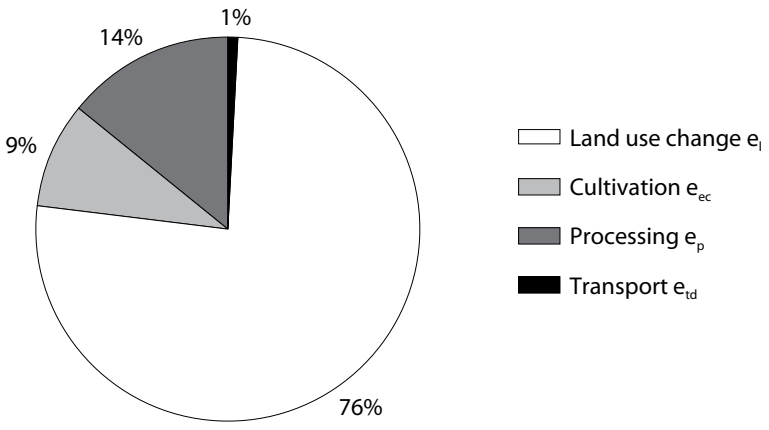


Figure 21. Proportion of emissions from each main source for biodiesel production from jatropha, South Africa (artificial fertiliser, in-country consumption)

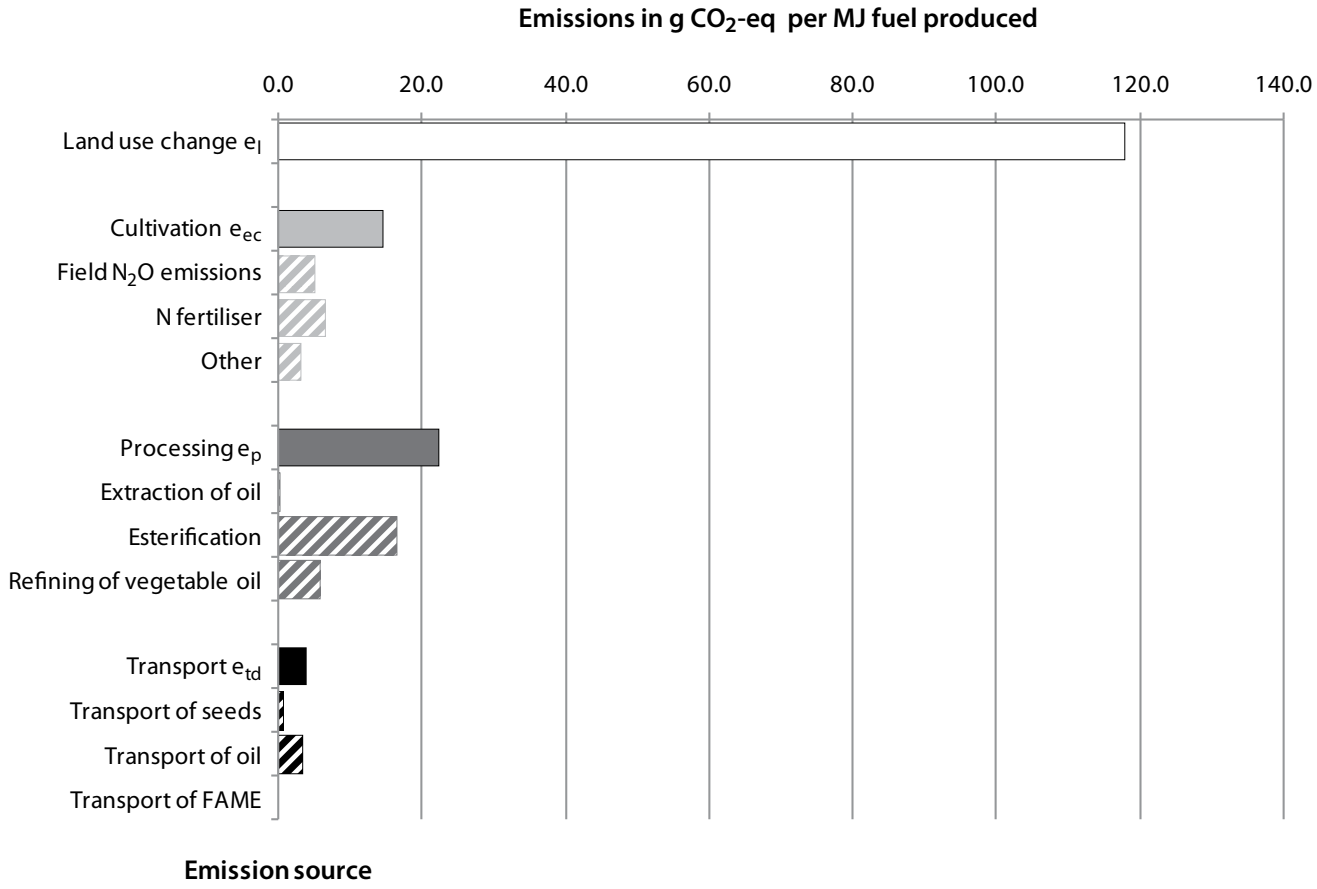


Figure 22. Emission sources for biodiesel production from jatropha, South Africa (artificial fertiliser, export of oil to EU)

FAME: fatty acid methyl ester

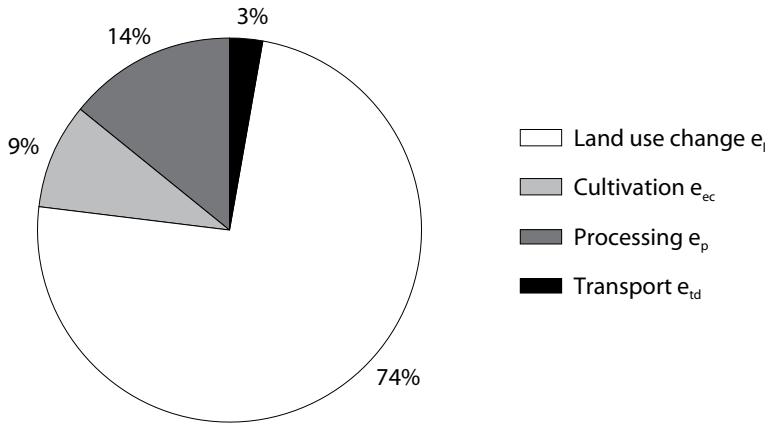


Figure 23. Proportion of emissions from each main source for biodiesel production from jatropha, South Africa (artificial fertiliser, export of oil to EU)

4.3 Bioethanol from sugarcane

As explained in Chapter 3, conversion of sugarcane to ethanol is a simple process with low inputs. Consequently, the processing step contributes the smallest proportion of the total emissions from these pathways – around 1%. The low amount of emissions from processing means other emission sources gain relative importance in relation to total emissions.

4.3.1 Africa

The second largest emission source after LUC is cultivation, which contributes about 15% of the total emissions. This is about 50% higher than the RED default value, mainly because of a higher value for N fertiliser application. Other non-LUC emission sources are comparable to the RED default values. The share of emissions from transport is 4% for in-country consumption and 8% when export of ethanol to the EU is assumed. Emissions from transport of sugarcane are higher than the default values because the transport distance of 90 km is higher than the default value of 20 km.

Table 40. Overview of emissions due to ethanol production from sugarcane, South Africa (in-country consumption)

All results in g CO_2-eq / $MJ_{Ethanol}$	Non-allocated results	Allocation factor (%)	Allocated results	Total	Default values RED Annex V.D
Cultivation e_{ec}				**21.7**	**14.00**
Cultivation of sugarcane	21.66	100	21.66		14.45
Processing e_p				**0.9**	**1.00**
Ethanol plant	0.93	100	0.93		0.84
Transport e_{td}				**6.3**	**9.00**
Transport of sugarcane	3.80	100	3.80		0.84
Transport of ethanol	2.47	100	2.47		7.70
Filling station	0.00	100	0.00		0.44
Land use change e_l	**118.00**	**100**	**118.00**	**118.0**	**0.00**
$e_{sca} + e_{ccr} + e_{ccs}$	**0.00**	**100**	**0.00**	**0.0**	**0.00**
Totals	**146.90**			**146.9**	**24.00**

Table 41. Overview of emissions due to ethanol production from sugarcane, South Africa (export to EU)

All results in g CO_2-eq / $MJ_{Ethanol}$	Non-allocated results	Allocation factor (%)	Allocated results	Total	Default values RED Annex V.D
Cultivation e_{ec}				**21.7**	**14.00**
Cultivation of sugarcane	21.66	100	21.66		14.45
Processing e_p				**0.9**	**1.00**
Ethanol plant	0.93	100	0.93		0.84
Transport e_{td}				**10.6**	**9.00**
Transport of sugarcane	3.80	100	3.80		0.84
Transport of ethanol	6.77	100	6.77		7.70
Filling station	0.00	100	0.00		0.44
Land use change e_l	**118.00**	**100**	**118.00**	**118.0**	**0.00**
$e_{sca} + e_{ccr} + e_{ccs}$	**0.00**	**100**	**0.00**	**0.0**	**0.00**
Totals	**151.20**			**151.2**	**24.00**

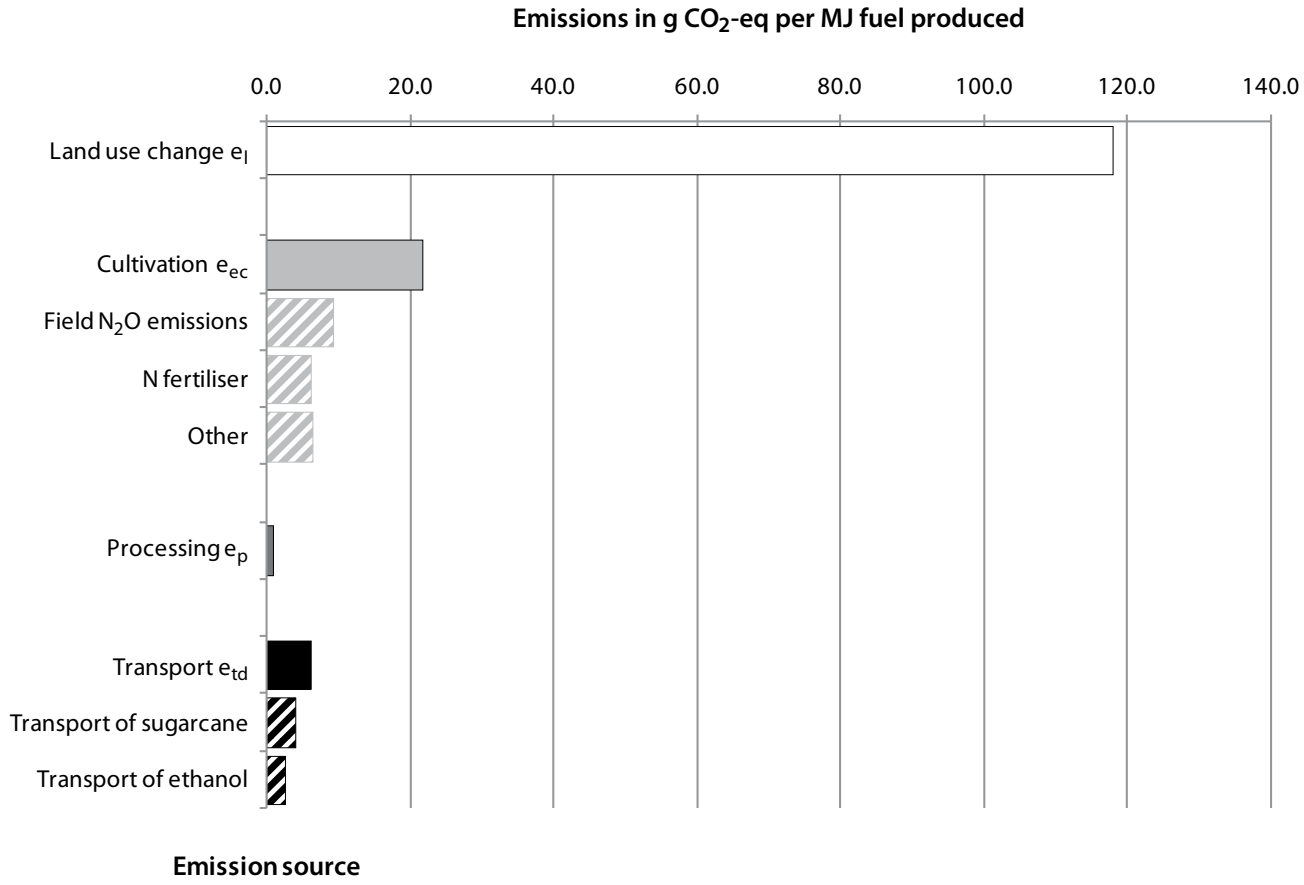


Figure 24. Emission sources for ethanol production from sugarcane, South Africa (in-country consumption)

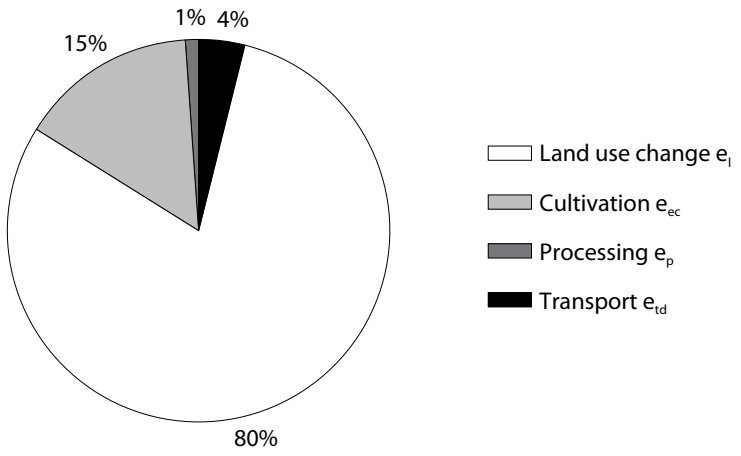


Figure 25. Proportion of emissions from each main source for ethanol production from sugarcane, South Africa (in-country consumption)

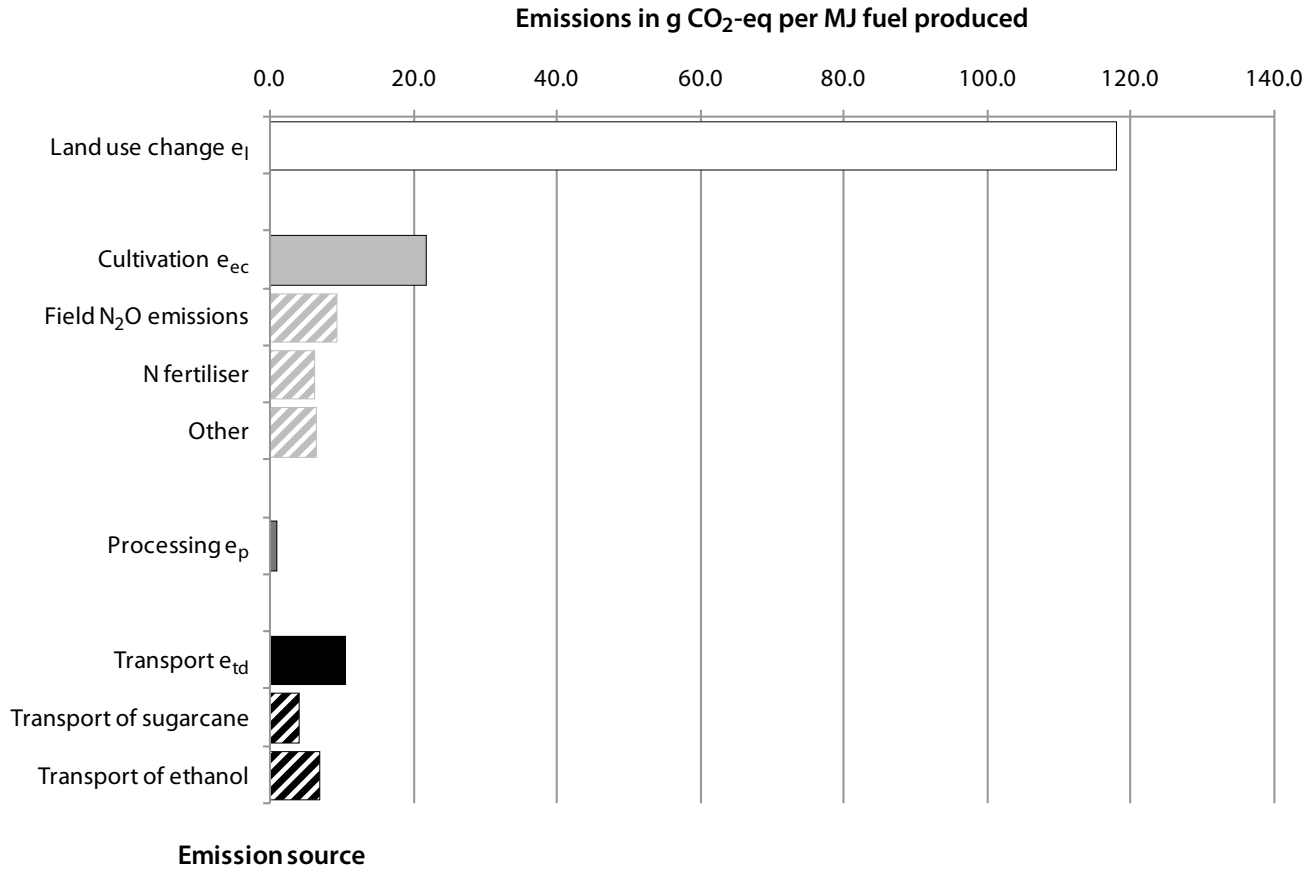


Figure 26. Emission sources for ethanol production from sugarcane, South Africa (export to EU)

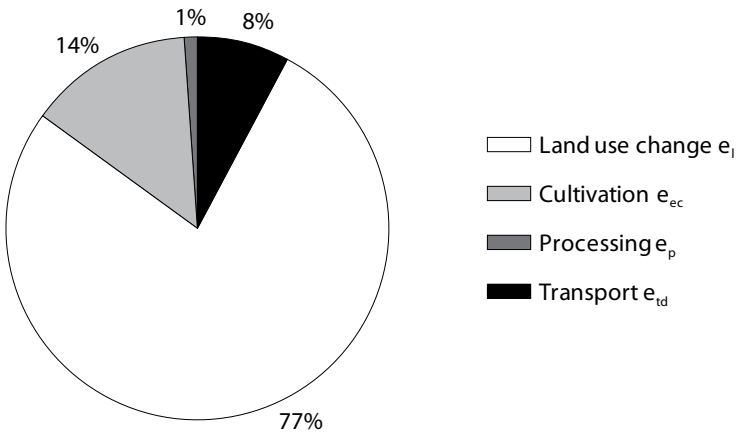


Figure 27. Proportion of emissions from each main source for ethanol production from sugarcane, South Africa (export to EU)

4.3.2 Mexico

All non-LUC figures are relatively close to the RED default values. The difference from the South African pathway in terms of emissions from cultivation arises mainly because of lower N fertiliser use in Mexico.

Table 42. Overview of emissions due to ethanol production from sugarcane, Mexico (in-country consumption)

All results in g CO_2-eq / $MJ_{Ethanol}$	Non-allocated results	Allocation factor (%)	Allocated results	Total	Default values RED Annex V.D
Cultivation e_{ec}				**13.2**	**14.00**
Cultivation of sugarcane	13.21	100	13.21		14.45
Processing e_p				**0.9**	**1.00**
Ethanol plant	0.93	100	0.93		0.84
Transport e_{td}				**2.0**	**9.00**
Transport of sugarcane	1.05	100	1.05		0.84
Transport of ethanol	0.99	100	0.99		7.70
Filling station	0.00	100	0.00		0.44
Land use change e_l	**118.00**	**100**	**118.00**	**118.0**	**0.00**
$e_{sca} + e_{ccr} + e_{ccs}$	**0.00**	**100**	**0.00**	**0.0**	**0.00**
Totals	**134.20**			**134.2**	**24.00**

Table 43. Overview of emissions due to ethanol production from sugarcane, Mexico (export to EU)

All results in g CO_2-eq / $MJ_{Ethanol}$	Non-allocated results	Allocation factor (%)	Allocated results	Total	Default values RED Annex V.D
Cultivation e_{ec}				**13.2**	**14.00**
Cultivation of sugarcane	13.21	100	13.21		14.45
Processing e_p				**0.9**	**1.00**
Ethanol plant	0.93	100	0.93		0.84
Transport e_{td}				**6.1**	**9.00**
Transport of sugarcane	1.05	100	1.05		0.84
Transport of ethanol	5.08	100	5.08		7.70
Filling station	0.00	100	0.00		0.44
Land use change e_l	**118.00**	**100**	**118.00**	**118.0**	**0.00**
$e_{sca} + e_{ccr} + e_{ccs}$	**0.00**	**100**	**0.00**	**0.0**	**0.00**
Totals	**138.30**			**138.3**	**24.00**

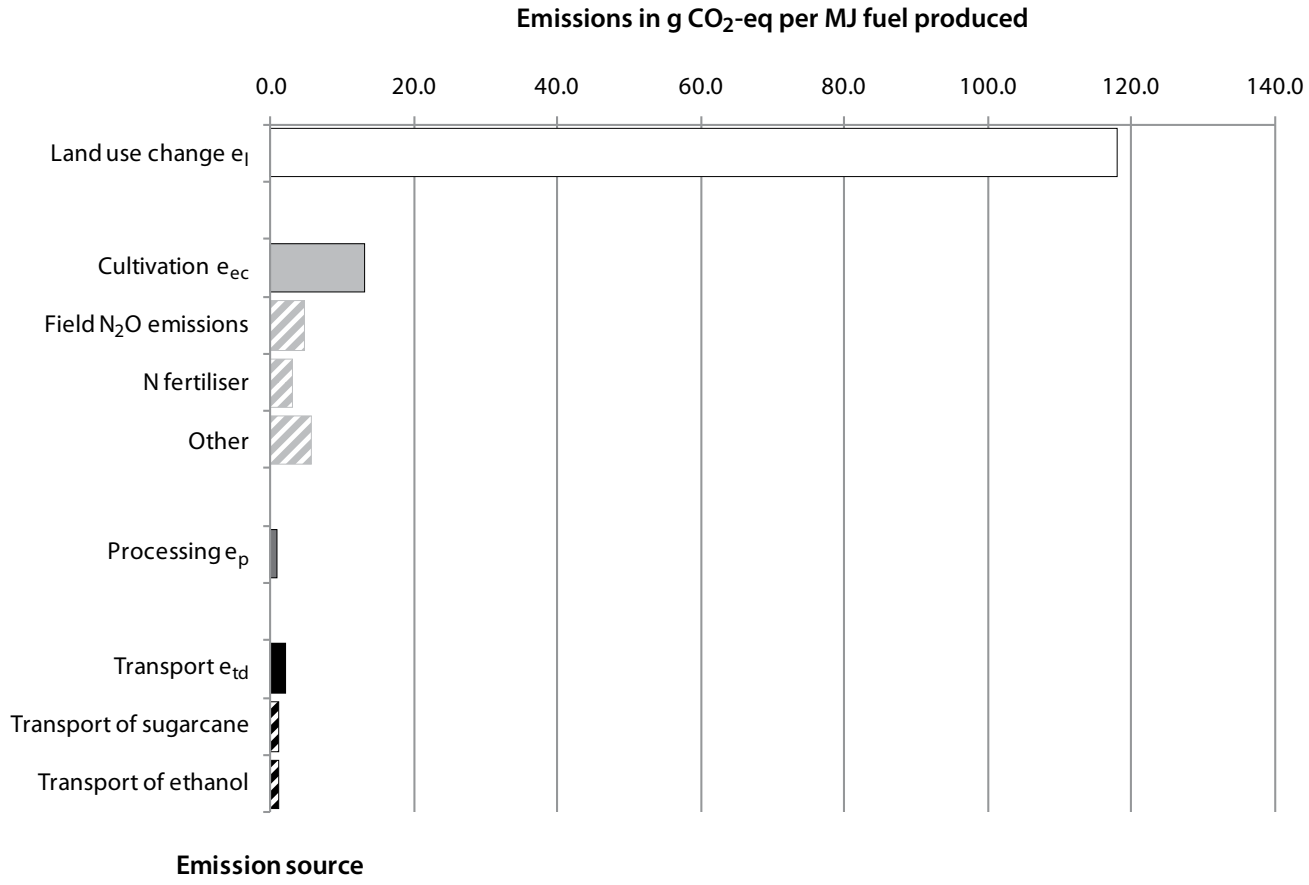


Figure 28. Emission sources for ethanol production from sugarcane, Mexico (in-country consumption)

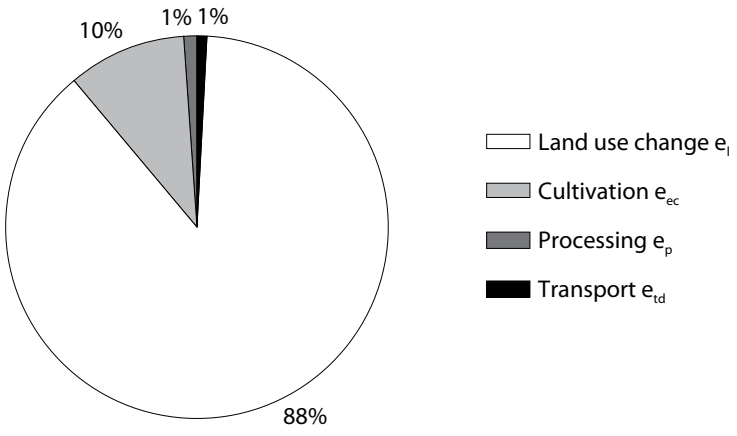


Figure 29. Proportion of emissions from each main source for ethanol production from sugarcane, Mexico (in-country consumption)

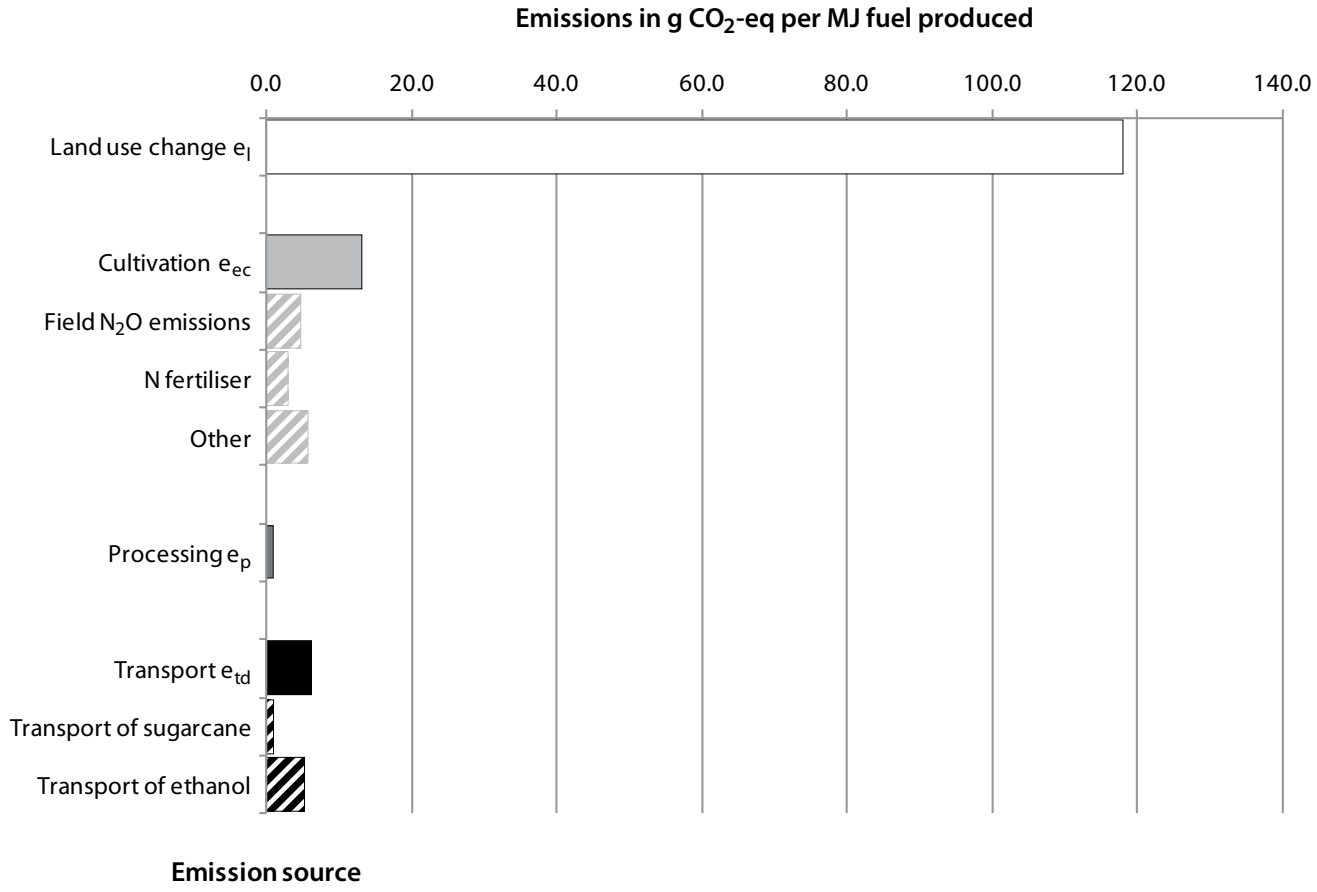


Figure 30. Emission sources for ethanol production from sugarcane, Mexico (export to EU)

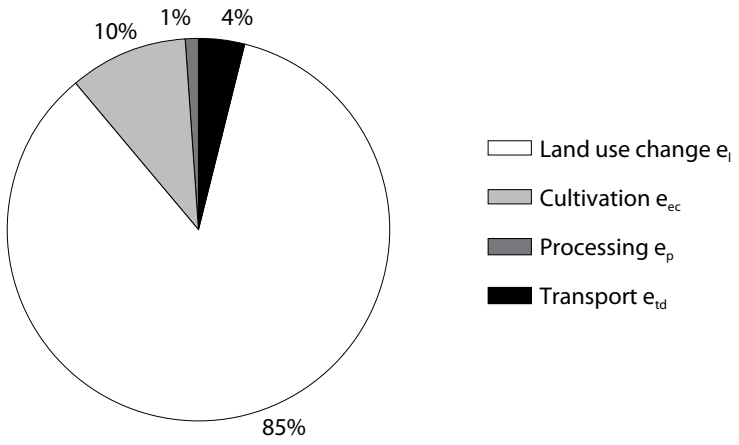


Figure 31. Proportion of emissions from each main source for ethanol production from sugarcane, Mexico (export to EU)

4.3.3 Indonesia

All non-LUC figures are relatively close to the RED default values, except for transport of sugarcane, which is more than twice as high as the default. This is because the transport distance of 50 km is higher than the default value of 20 km. The difference from the African pathway in terms of emissions from cultivation arises mainly because of lower N fertiliser use in Indonesia.

Table 44. Overview of emissions due to ethanol production from sugarcane, Indonesia (in-country consumption)

All results in g CO_2-eq / $MJ_{Ethanol}$	Non-allocated results	Allocation factor (%)	Allocated results	Total	Default values RED Annex V.D
Cultivation e_{ec}				**13.4**	**14.00**
Cultivation of sugarcane	13.43	100	13.43		14.45
Transport of vinasse and filter mud cake	0.00	100	0.00		
Processing e_p				**0.9**	**1.00**
Ethanol plant	0.93	100	0.93		0.84
Transport e_{td}				**2.8**	**9.00**
Transport of sugarcane	2.11	100	2.11		0.84
Transport of ethanol	0.66	100	0.66		7.70
Filling station	0.00	100	0.00		0.44
Land use change e_l	**118.00**	**100**	**118.00**	**118.0**	**0.00**
$e_{sca} + e_{ccr} + e_{ccs}$	**0.00**	**100**	**0.00**	**0.0**	**0.00**
Totals	**135.10**			**135.1**	**24.00**

Table 45. Overview of emissions due to ethanol production from sugarcane, Indonesia (export to EU)

All results in g CO_2-eq / $MJ_{Ethanol}$	Non-allocated results	Allocation factor (%)	Allocated results	Total	Default values RED Annex V.D
Cultivation e_{ec}				**13.4**	**14.00**
Cultivation of sugarcane	13.43	100	13.43		14.45
Transport of vinasse and filter mud cake	0.00	100	0.00		
Processing e_p				**0.9**	**1.00**
Ethanol plant	0.93	100	0.93		0.84
Transport e_{td}				**7.8**	**9.00**
Transport of sugarcane	2.11	100	2.11		0.84
Transport of ethanol	5.70	100	5.70		7.70
Filling station	0.00	100	0.00		0.44
Land use change e_l	**118.00**	**100**	**118.00**	**118.0**	**0.00**
$e_{sca} + e_{ccr} + e_{ccs}$	**0.00**	**100**	**0.00**	**0.0**	**0.00**
Totals	**140.20**			**140.2**	**24.00**

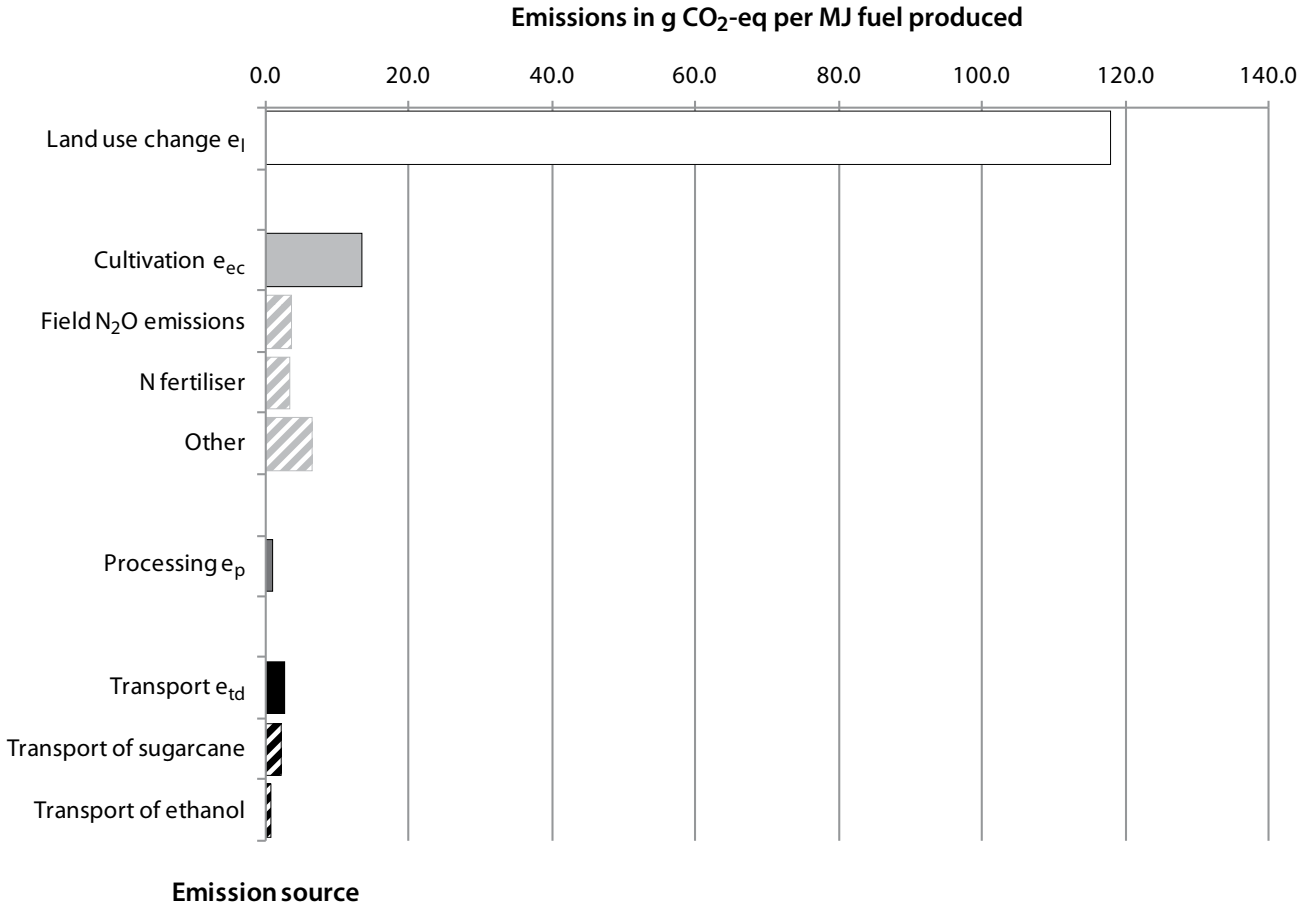


Figure 32. Emission sources for ethanol production from sugarcane, Indonesia (in-country consumption)

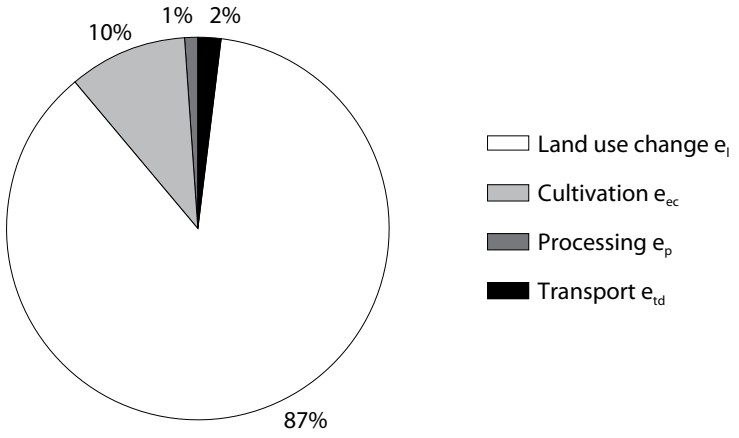


Figure 33. Proportion of emissions from each main source for ethanol production from sugarcane, Indonesia (in-country consumption)

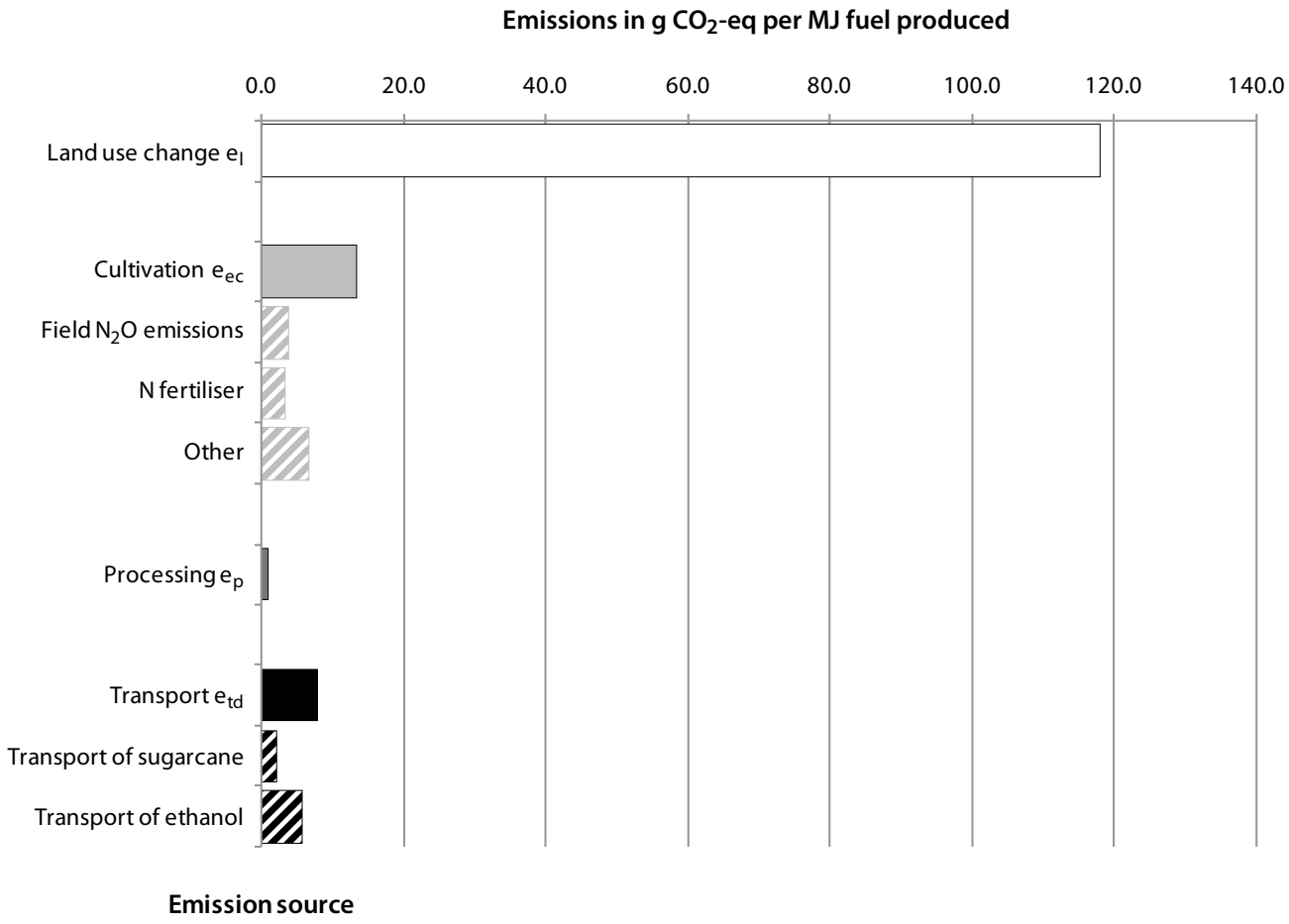


Figure 34. Emission sources for ethanol production from sugarcane, Indonesia (export to EU)

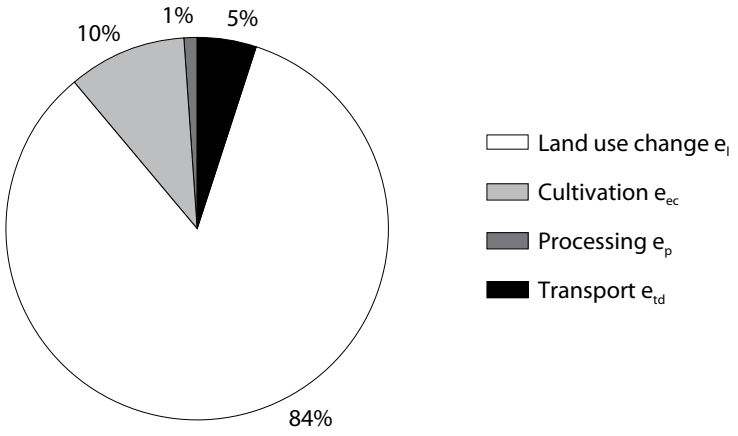


Figure 35. Proportion of emissions from each main source for ethanol production from sugarcane, Indonesia (export to EU)

4.4 Bioethanol from wood

For bioethanol from wood, only pathways including export to the EU are shown, as it is assumed that export would be the main driver for developing second-generation pathways in the study countries because of the high generation costs.

4.4.1 Mexico (woodchips)

Because the 'second generation only' scenario, which assumes that wood is taken from existing forests, is used for LUC emissions, these emissions are negative.

With the exception of the bioethanol from wood pathways in the other countries, the RED default

Table 46. Overview of emissions due to ethanol production from woodchips, Mexico (export to EU)

All results in g CO_2-eq / $MJ_{Ethanol}$	Non-allocated results	Allocation factor (%)	Allocated results	Total	Default values RED Annex V.E
Cultivation e_{ec}				**1.1**	**1**
Cultivation of wood	1.08	100	1.08		
Processing e_p				**16.6**	**17**
Ethanol plant	16.60	100	16.60		
Transport e_{td}				**5.4**	**4**
Transport of wood	0.35	100	0.35		
Transport of ethanol	5.05	100	5.05		
Land use change e_l	**-10.70**	**100**	**-10.70**	**-10.7**	**0**
$e_{sca} + e_{ccr} + e_{ccs}$	**0.00**	**100**	**0.00**	**0.0**	**0**
Totals	**12.40**			**12.4**	**22**

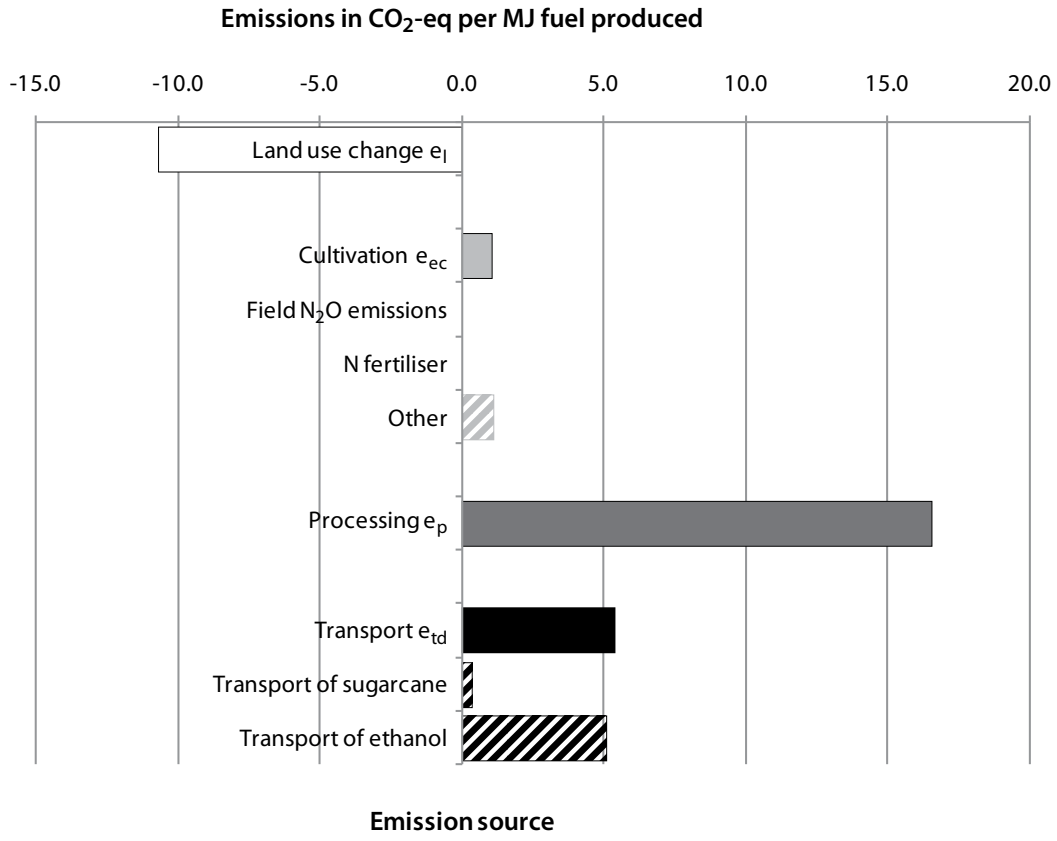


Figure 36. Emission sources for ethanol production from woodchips, Mexico (export to EU)

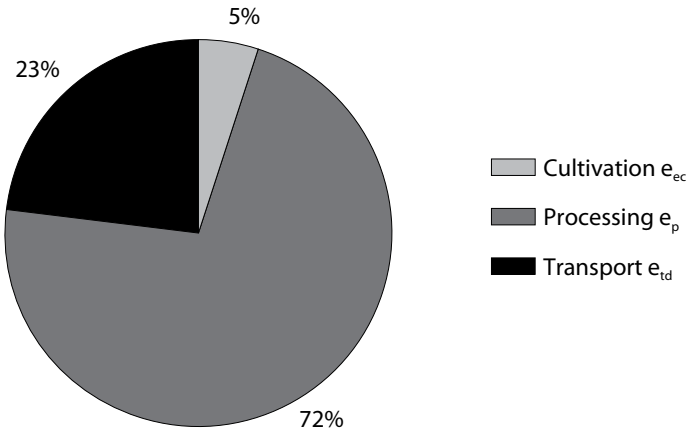


Figure 37. Proportion of emissions from each main source for ethanol production from woodchips, Mexico (export to EU)

values shown are those for ethanol from waste wood (rather than farm wood). All emission values are close to the RED default values.

4.4.2 Africa (short rotation coppice, Uganda)

Because the 'second generation only' scenario, which assumes that wood is taken from agricultural land, is used, LUC emissions are higher than those from the Mexican pathway using woodchips from existing forests. However, they contribute only a little to the total emissions. Emissions from processing and transport are comparable to the values for the Mexican pathway. Cultivation emissions are much higher than in the Mexican case but still below the RED default value.

4.5 Fischer–Tropsch diesel from wood

As with bioethanol from wood, only pathways including export to the EU are shown for FT diesel from wood, as it is assumed that export would be the main driver for developing second-generation pathways in the study countries because of the high generation costs.

For all countries, the largest emission source is processing. This is because of relatively high demand for grid electricity in the refining process and an electricity mix that leads to much higher emissions than in the EU, for example. These emissions might be reduced if power for the refining step were (partly) supplied by electricity generated during the FT

Table 47. Overview of emissions due to ethanol production from wood, South Africa (export to EU)

All results in g CO_2-eq / $MJ_{Ethanol}$	Non-allocated results	Allocation factor (%)	Allocated results	Total	Default values RED Annex V.E
Cultivation e_{ec}				**3.3**	**6**
Cultivation of wood (SRC)	3.26	100	3.26		
Processing e_p				**16.6**	**17**
Ethanol plant	16.60	100	16.60		
Transport e_{td}				**5.3**	**2**
Transport of wood	0.49	100	0.49		
Transport of ethanol	4.79	100	4.79		
Land use change el	**0.40**	**100**	**0.40**	**0.4**	**0**
$e_{sca} + e_{ccr} + e_{ccs}$	**0.00**	**100**	**0.00**	**0.0**	**0**
Totals	**25.50**			**25.5**	**25**

SRC: short rotation coppice

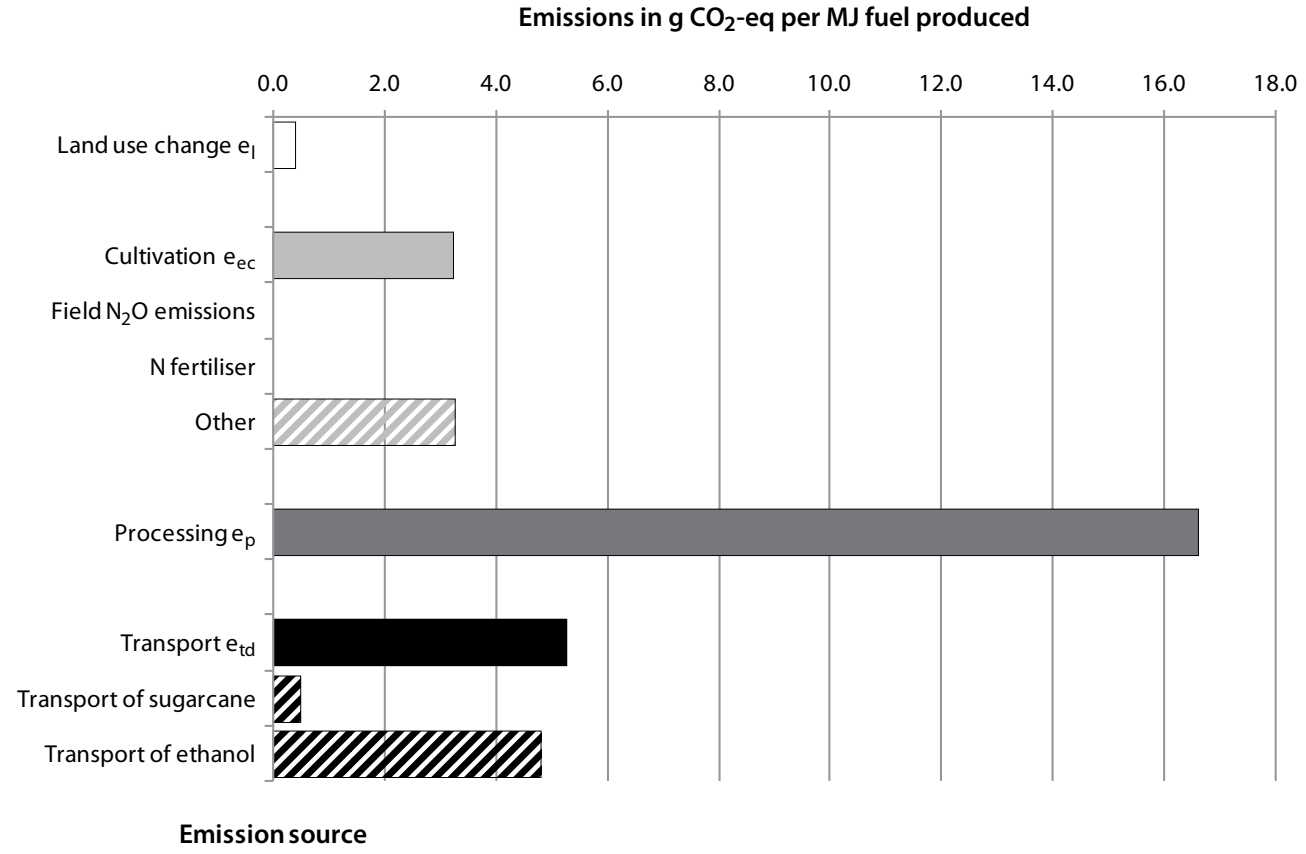


Figure 38. Emission sources for ethanol production from wood, South Africa (export to EU)

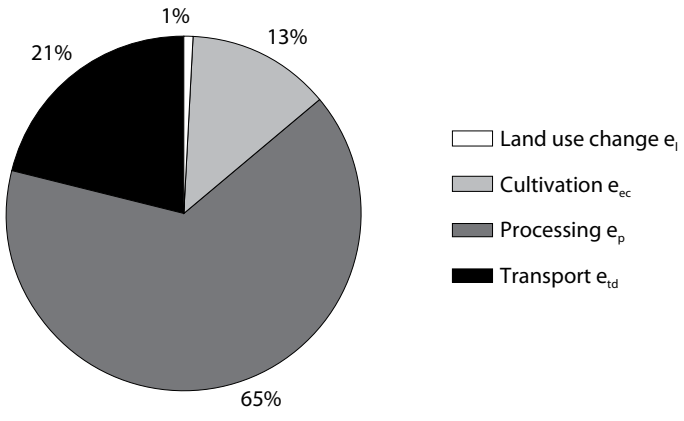


Figure 39. Proportion of emissions from each main source for ethanol production from wood, South Africa (export to EU)

process. However, increasing the electricity output from the FT process reduces the biodiesel yield. The fact that no emissions are attributed to the processing steps in the RED default values may be due to the assumption that the entire system is energy self sufficient.

4.5.1 Mexico (short rotation coppice)

Most of the pathway emissions come from refining of the FT diesel. Emissions from the short rotation cultivation are low because of low inputs. The diesel consumption for cultivation is similar to that of the

Table 48. Overview of emissions due to FT diesel production from wood, Mexico (export to EU)

All results in g CO_2-eq / MJ_{FAME}	Non-allocated results	Allocation factor (%)	Allocated results	Total	Default values RED Annex V.E
Cultivation e_{ec}				**0.9**	**4**
Cultivation of SRC	0.92	100	0.92		
Processing e_p				**20.5**	**0**
FT raw product	0.27	100	0.27		
Refining	20.19	100	20.19		
Transport e_{td}				**3.6**	**2**
Transport of wood	0.31	100	0.31		
Transport of FT diesel	3.28	100	3.28		
Land use change e_l	**0.40**	**100**	**0.40**	**0.4**	**0**
$e_{sca} + e_{ccr} + e_{ccs}$	**0.00**	**100**	**0.00**	**0.0**	**0**
Totals	**25.40**			**25.4**	**6**

SRC: short rotation coppice; FT: Fischer–Tropsch

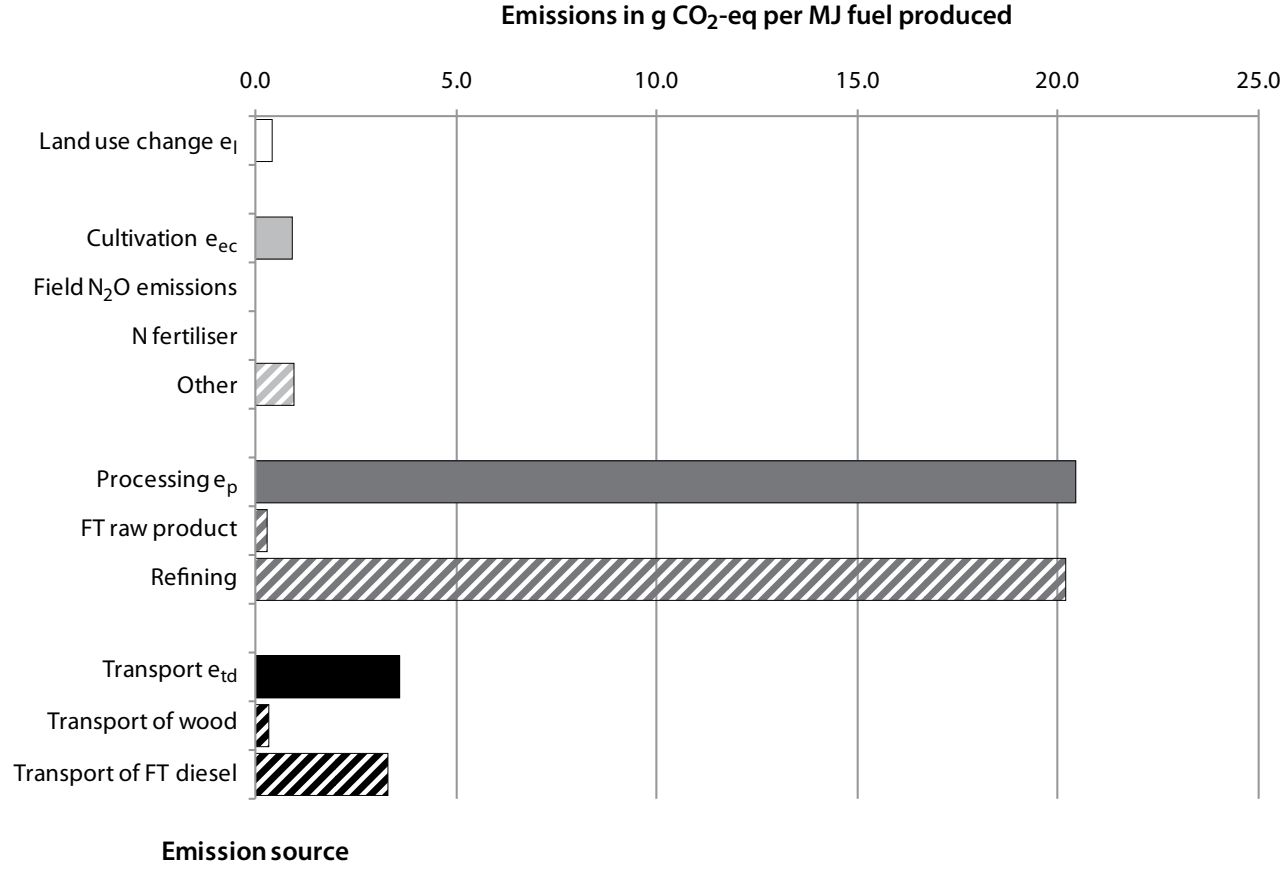


Figure 40. Emission sources for FT diesel production from wood, Mexico (export to EU)

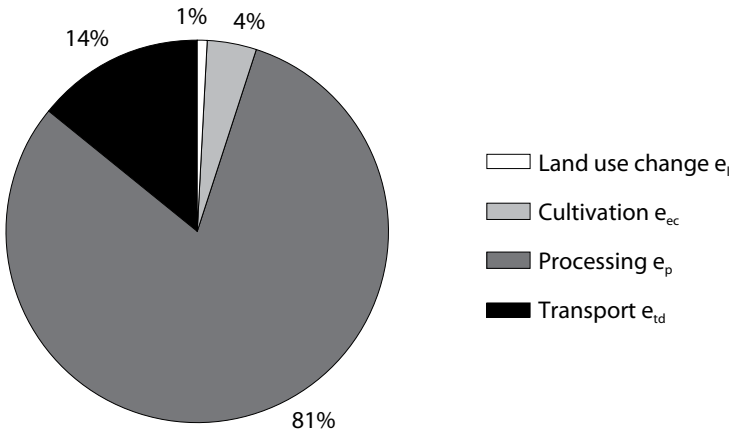


Figure 41. Proportion of emissions from each main source for FT diesel production from wood, Mexico (export to EU)

woodchip pathways for bioethanol; furthermore, only a small amount of pesticides is applied. However, much higher yields mean that cultivation emissions are lower than in the woodchip pathways for bioethanol. LUC emissions play a minor role.

4.5.2 Africa (short rotation coppice, Uganda)

Most of the pathway emissions come from refining of the FT diesel. Cultivation emissions exceed those from the Mexican short rotation coppice but still fall below the RED default values. LUC emissions play a minor role.

4.5.3 FT diesel from logging and wood residues

The main difference between this pathway and the pathways in Mexico and Africa is the use of the 'second generation only' scenario that assumes that wood is taken from existing forests for LUC emission calculations. Therefore, LUC emissions are negative. Overall emissions primarily stem from refining of the FT diesel.

Table 49. Overview of emissions due to FT diesel production from wood, South Africa (export to EU)

All results in g CO_2-eq / MJ_{FAME}	Non-allocated results	Allocation factor (%)	Allocated results	Total	Default values RED Annex V.E
Cultivation e_{ec}				**2.5**	**4**
Cultivation of SRC	2.51	100	2.51		
Processing e_p				**20.5**	**0**
FT raw product	0.27	100	0.27		
Refining	20.19	100	20.19		
Transport e_{td}				**3.7**	**2**
Transport of wood	0.43	100	0.43		
Transport of FT diesel	3.22	100	3.22		
Land use change e_l	**0.40**	**100**	**0.40**	**0.4**	**0**
$e_{sca} + e_{ccr} + e_{ccs}$	**0.00**	**100**	**0.00**	**0.0**	**0**
Totals	**27.00**			**27.0**	**6**

SRC: short rotation coppice; FT: Fischer–Tropsch

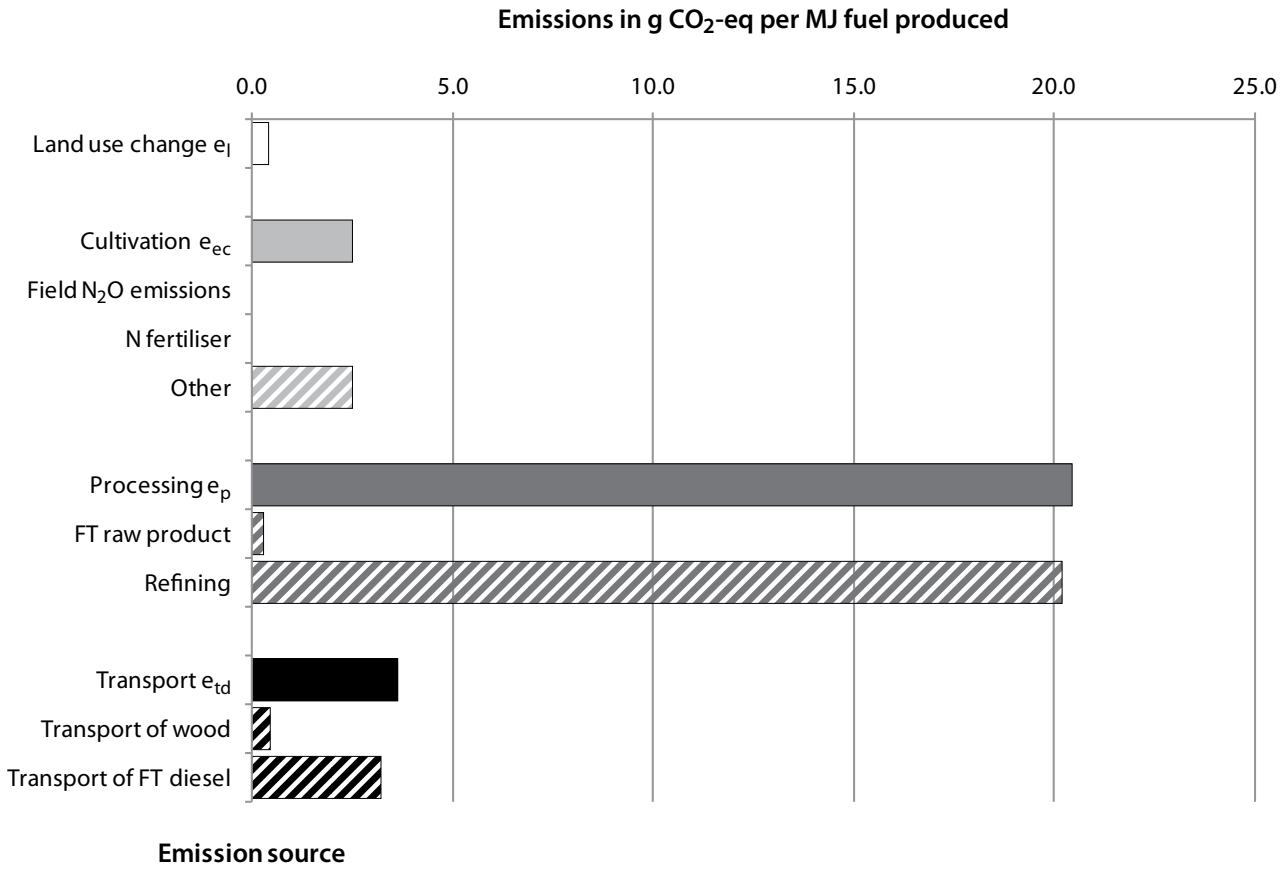


Figure 42. Emission sources for FT diesel production from wood, South Africa (export to EU)

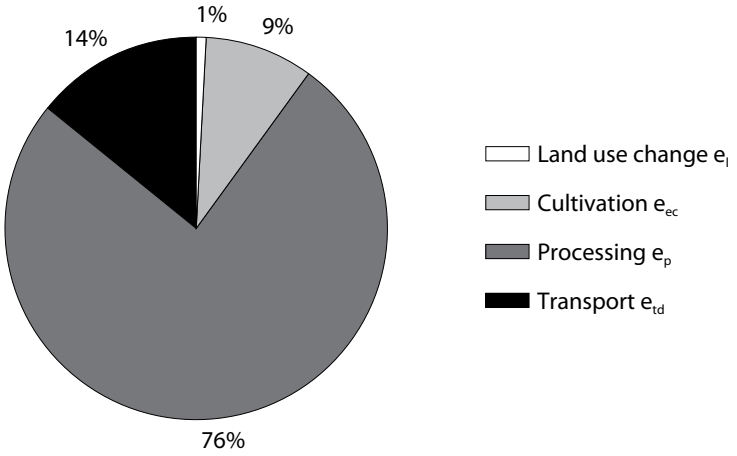


Figure 43. Proportion of emissions from each main source for FT diesel production from wood, South Africa (export to EU)

Due to the negative emissions from LUC and the omission of emissions from cultivation, the diagram illustrating the proportion of emissions from each source only shows emissions from processing and transport.

Table 50. Overview of emissions due to FT diesel production from wood residues, generic (export to EU)

All results in g CO_2-eq / MJ_{FAME}	Non-allocated results	Allocation factor (%)	Allocated results	Total	Default values RED Annex V.E
Cultivation e_{ec}				**0.0**	**4**
Cultivation	0.00	100	0.00		
Processing e_p				**20.5**	**0**
FT raw product	0.27	100	0.27		
Refining	20.19	100	20.19		
Transport e_{td}				**3.8**	**2**
Transport of wood	0.31	100	0.31		
Transport of FT diesel	3.48	100	3.48		
Land use change e_l	**-10.70**	**100**	**-10.70**	**-10.7**	**0**
$e_{sca} + e_{ccr} + e_{ccs}$	**0.00**	**100**	**0.00**	**0.0**	**0**
Totals	**13.60**			**13.6**	**6**

FAME: fatty acid methyl ester; FT: Fischer–Tropsch

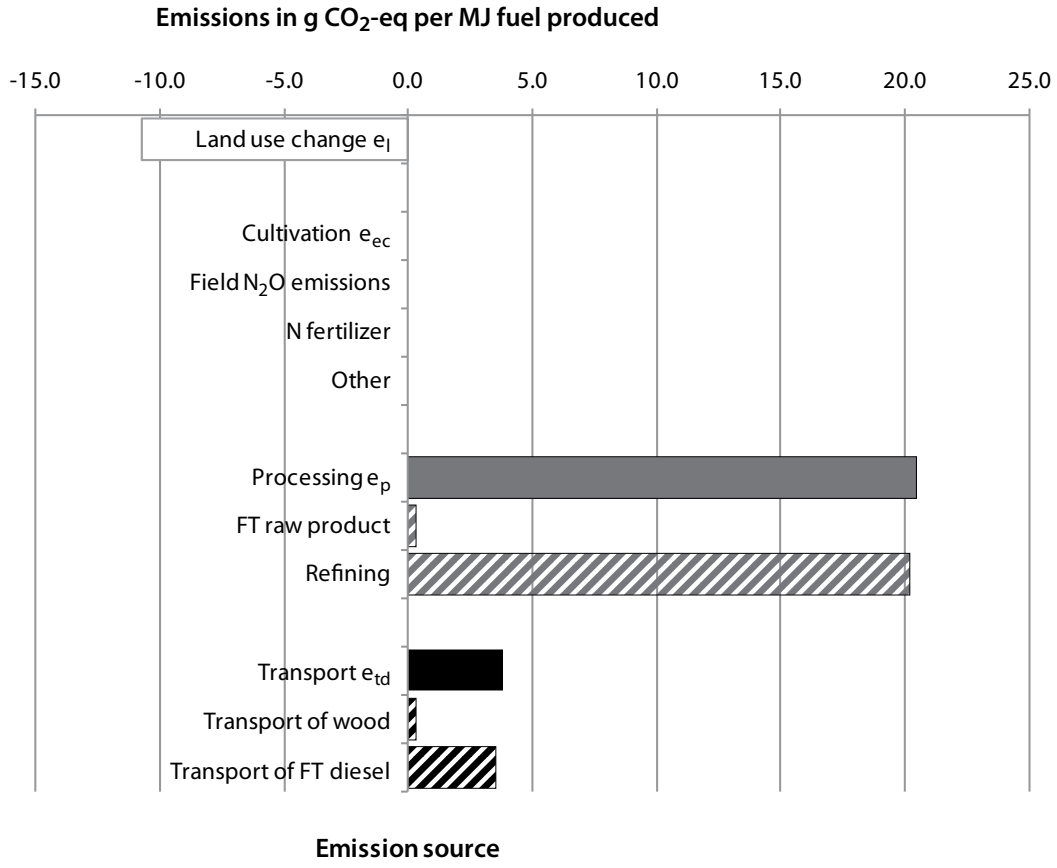


Figure 44. Emission sources for FT dieselFT diesel production from wood residues, generic (export to EU)

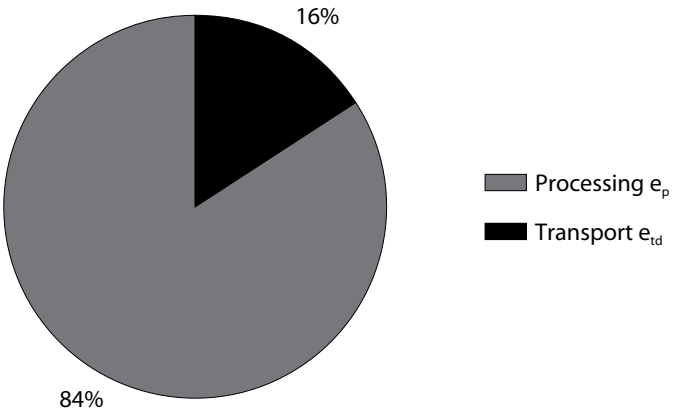


Figure 45. Proportion of emissions from each main source for FT diesel production from wood residues, generic (export to EU)

4.6 Summary of results

The following figures provide an overview of the results of all pathways analysed. Because emissions from transport do not contribute much to the total emissions from biofuel production, overviews are provided only for the pathways that include export to the EU. Figure 46 shows an overview grouped by countries; Figure 47 shows rankings by total emissions from biofuel production.

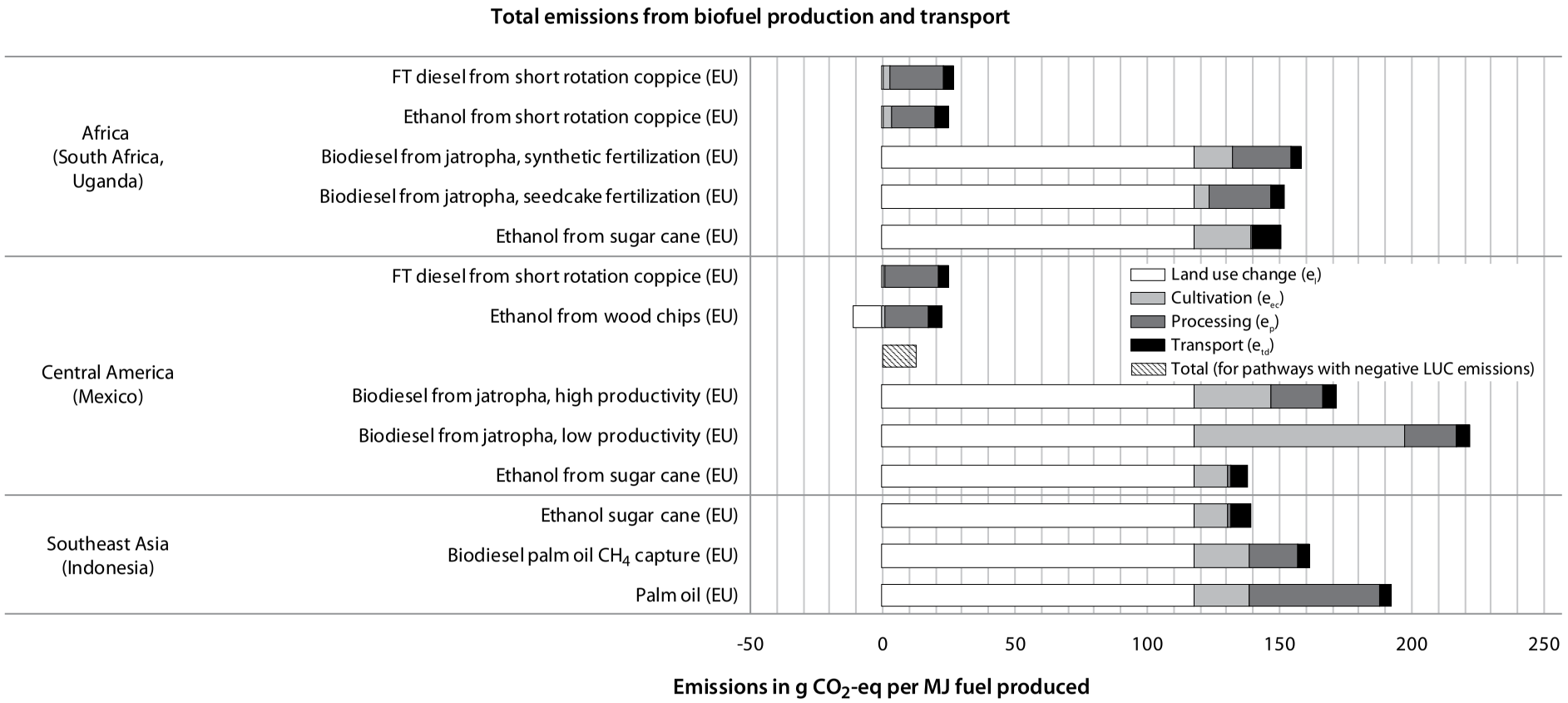


Figure 46. Overview of emissions due to biofuel production for all analysed pathways with export to EU, by region

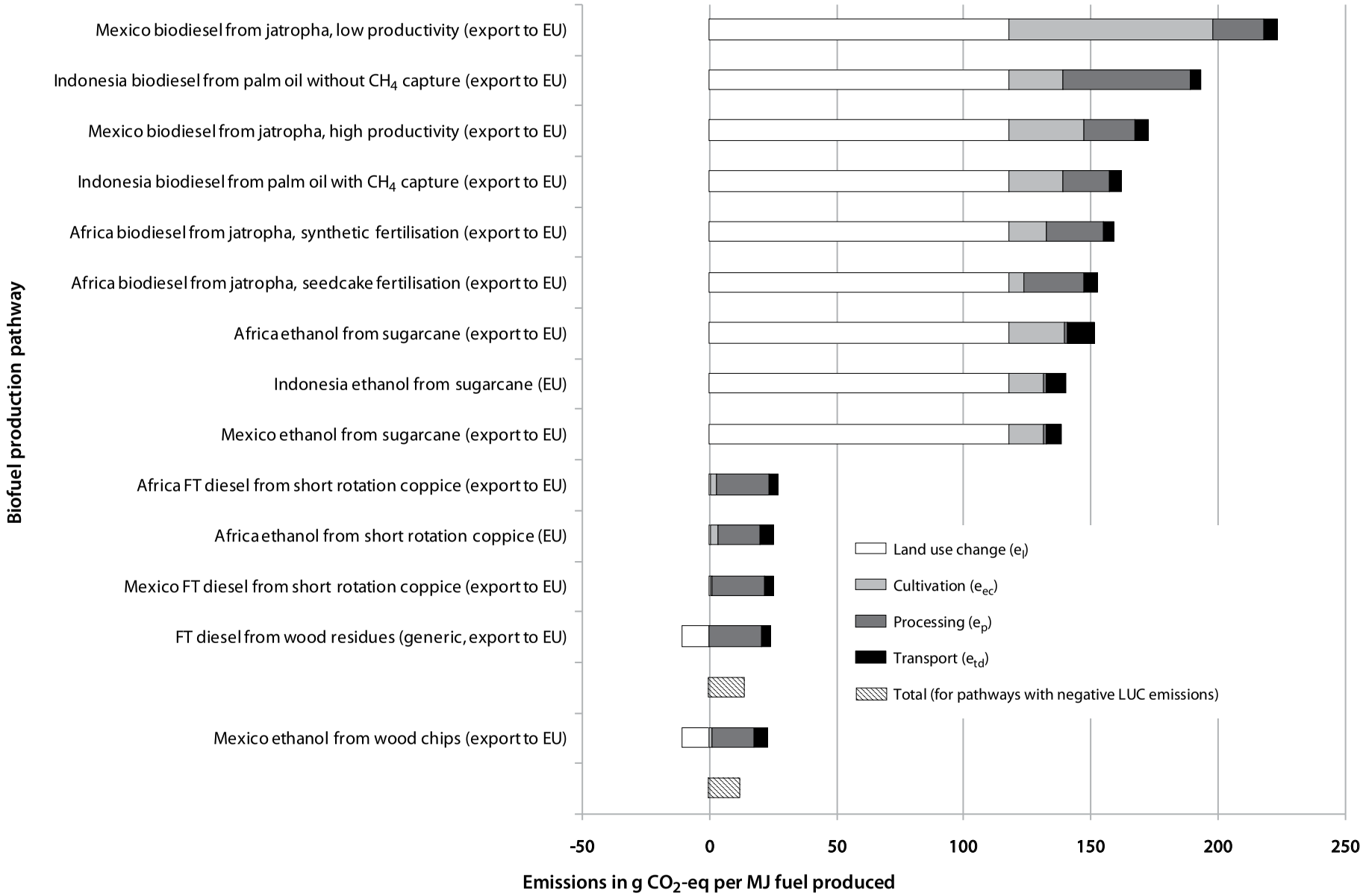


Figure 47. Overview of emissions due to biofuel production for all analysed pathways with export to EU, by total value

5. Discussion

The calculation of emissions from the non-LUC component is based on regional information, whereas that for the LUC component is based on global modelling. As a result, the LUC component is not regionally differentiated, but rather depends only on the type and origin of the feedstock (e.g. LUC is the same for all regions in the 'first generation only' scenario). Further regional differentiation was not possible with the GLOBIOM model for the following reasons.

1. The GLOBIOM model does not distinguish between direct and indirect LUC; it calculates the effects of the 2 together;
2. The GLOBIOM model does not distinguish between origins of demand; it calculates the impacts of global demand on regional land use; and
3. Although the GLOBIOM model calculates the regional production, a change in production may not lead to emissions from LUC in the given region (e.g. converting a wheat-field to a rape-field in Germany is a land management change that does not cause an emission). It may cause LUC in another region (indirect LUC).

The estimation of direct emissions due to a specific LUC is a typical *bottom-up* analysis. Although the results are useful for that specific situation, they do not provide answers to the general question of what emissions will occur in a region due to the production of bioenergy in that region, nor does a bottom-up analysis include the emissions due to indirect LUC.

The GLOBIOM model is an example of a typical *top-down* approach. As discussed above, it gives a global estimate of emissions from LUC by region because of the global demand for biofuels. The results are useful for general policy indications because they include both direct and indirect LUC. However, the results do not provide answers to the general question of what emissions will occur in a region due to the adoption of bioenergy in that region.

A GLOBIOM-type model could be used to answer this question, assuming that the region is isolated. However, this is a hypothetical situation since agricultural markets are global in nature, and the results would ignore indirect LUC.

This dichotomy is typical of *bottom-up* and *top-down* approaches and is not easily resolvable. We have used a *bottom-up* approach for the non-LUC emissions because we have confidence in these values. However, we used the *top-down* GLOBIOM estimate of emissions from LUC because we believe that it provides the best representation of the global impacts of biofuel adoption.

Bottom-up estimates are highly accurate for specific situations, but do not represent the probable reality. Top-down estimates are more representative of the average impacts of biofuels but ignore reliable specific information when it is available. The top-down GLOBIOM estimate of emissions from LUC provides a middle value in the range of possible emissions. The bottom-up specific cases can be used to estimate the maximum and minimum LUC emissions possible.

As a result, the emissions attributed to LUC only differ between the cases where biofuels are derived from agricultural crops, short rotation forests and residues from existing forests. Since indirect LUC can occur anywhere in the world, the emission value for such LUC is the same regardless of where the biofuels are produced.

In cases where wood is used as the feedstock, almost no or negative LUC emissions (i.e. sequestration) are attributed to the pathway. In cases where biofuel is derived from agricultural crops, LUC emissions largely dominate GHG emissions from other sources in the pathway. Where jatropha with a low productivity rate is used, total non-LUC emissions are almost equal to LUC emissions.

The sensitivity analysis on emissions from transportation shows that, even when biofuels are exported to the EU, transport emissions constitute only a minor share of total emissions. The relative importance of transport emissions increases particularly where LUC emissions are low, that is, pathways where wood is used as the feedstock.

The sensitivity analyses for jatropha show that emissions from cultivation are strongly influenced by the feedstock productivity. This may be an artefact of our assumption of the same amount of inputs independent of the productivity of the location. The 2 jatropha pathways in Mexico are amongst the 3 pathways with the highest total emissions. Their high emissions from cultivation are primarily due to disposal of nutshell meal, meaning that there is no allocation of emissions to the meal. The analysis on use of artificial fertilisation compared with fertilisation with the by-product seedcake in jatropha cultivation in Africa shows that using artificial fertiliser leads to much higher emissions from cultivation. Even though an important share of these emissions is allocated to the seedcake when it is exported from the system, pathway emissions remain lower if the seedcake is used for fertiliser.

Amongst the pathways examined, the pathways with the highest total GHG emissions are the production of biodiesel from jatropha in Mexico and from palm oil in Indonesia, where CH_4 emissions are not captured. Pathways that use wood as feedstock have the lowest total emissions because of the low or negative LUC associated with these options.

6. Conclusions

The production of biodiesel from jatropha in Mexico and from palm oil in Indonesia, where CH_4 emissions are not captured, have the highest GHG pathways amongst those examined. The 5 pathways with the lowest emissions all use wood as the feedstock. These low emissions result from the fact that low or negative emissions from LUC are attributed to these pathways. However, these pathways require second-generation conversion technologies. Bioethanol from sugarcane in Mexico and Indonesia have the lowest emissions from first-generation pathways.

Where the 'first generation only' value for emissions from LUC is applied, emissions from LUC dominate pathway emissions. Where 'second generation only' values for LUC are applied, these emissions contribute only a minor portion of the pathway emissions. As only 3 default values for LUC emissions were used, many biofuel pathways yield similar results.

Country-specific data were not available for many of the factors needed to run BioGrace. More country-specific data would enable better differentiation between the GHG implications of use of particular feedstock-conversion combinations in different countries. However, given the dominance of emissions from LUC for most pathways, unless it can be shown that the type or area of land that is converted depends on the nation in which the biofuels are produced, substantial differences between countries cannot clearly be identified. However, it is possible to differentiate according to the importance of particular factors such as feedstock productivity, fertiliser use, allocation of co-products, capture of CH_4 emissions or the energy needs of specific conversion technologies.

As only 3 default values for LUC emissions were used, no detailed differentiation could be made. However, we observed that, where the higher default value for first-generation biofuels is applied, this value dominates all other sources of emissions along the biofuel pathways. The low values for second-generation pathways, applied only to pathways where wood is used as feedstock, contribute only a minor share of the total emissions from these pathways. If only non-LUC emissions are included, then there is no clear differentiation in emissions between first- and second-generation pathways.

7. References

Bird, D.N., Pena, N. and Zanchi, G. 2011 Analysis of the potential of sustainable forest-based bioenergy for climate change mitigation. EuropeAid/ENV/2007/143936/TPS Bioenergy, sustainability and trade-offs: Can we avoid deforestation while promoting bioenergy? CIFOR, Bogor, Indonesia.

Borman, G.D. 2011 An assessment of the economic sustainability of Jatropha-based biodiesel initiatives: implications for labour and rural livelihoods. MSc thesis. University of the Witwatersrand, South Africa.

Disbunjatim 2010 Kletek dan pemupukan tanaman tebu tegalan [Weeding and fertilising sugarcane]. http://cybex.deptan.go.id/penyuluhan/kletek-dan-pemupukan-tanaman-tebu-tegalan [accessed 24 May 2011].

European Commission (EC) 2009 Directive 2009/28/EC of the European Parliament and of the Council of 23 April 2009 on the promotion of the use of energy from renewable sources and amending and subsequently repealing Directives 2001/77/EC and 2003/30/EC. http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2009:140:0016:0062:en:PDF [accessed 24 May 2011].

Havlík, P., Schneider, U.A., Schmid, E., Böttcher, H., Fritz, S., Skalský, R., Aoki, K., De Cara, S., Kindermann, G., Kraxner *et al.* (in press) Global land-use implications of first and second generation biofuel targets. Energy Policy. Available online 7 April 2010.

Intergovernmental Panel on Climate Change (IPCC) 2003 Good practice guidance for land use, land-use change and forestry. (Penman, J., Gytarsky, M., Hiraishi, T., Krug, T., Kruger, D., Pipatti, R. *et al.*, eds.). Institute for Global Environmental Strategies for the IPCC and IPCC National Greenhouse Gas Inventories Programme, Kanagawa, Japan.

Intergovernmental Panel on Climate Change (IPCC) 2006 IPCC guidelines for national greenhouse gas inventories. Volume 4. Agriculture, forestry and other land uses. (Prepared by the National Greenhouse Gas Inventory Programme, Eggleston, H.S., Buendia, L., Miwa, K., Ngara, T., Tanabe, K., eds.). Institute for Global Environmental Strategies, Kanagawa, Japan.

International Energy Agency (IEA) 2010 World energy outlook 2010. International Energy Agency, Paris.

Jongschaap, R.E.E., Corré, W.J., Bindraban, P.S. and Brandenburg, W.A. 2007 Claims and facts on *Jatropha curcas* L. Global *Jatropha curcas* evaluation, breeding and propagation programme. Report 158. Plant Research International B.V., Wageningen, Netherlands.

Jungmeier, G., Canella, L., Spitzer, J. and Stiglbrunner, R. 1999 Treibhausgasbilanz der Bioenergie – Vergleich der Treibhausgas-Emissionen aus Bioenergie-Systemen und fossilen Energiesystemen [Greenhouse gas balance of bioenergy – comparison of greenhouse gas emissions of bioenergy systems and fossil energy systems]. Joanneum Research, Graz, Austria.

Jungmeier, G., Hausberger, S. and Canella, L. 2002 Treibhausgas-Emissionen und Kosten von Transportsystemen mit Biomasse im Vergleich zu fossilen Treibstoffen. Joanneum Research, Graz, Austria.

Mashoko, L., Mbohwa, C. and Thomas, V.M. 2010 LCA of the South African sugar industry. Journal of Environmental Planning and Management 53: 793–807.

Nazir, N. and Setyaningsih, D. 2010 Life cycle assessment of biodiesel production from palm oil and jatropha oil in Indonesia. 7th Biomass Asia Workshop. Jakarta, Indonesia, 29 November–01 December.

Schmidt, J.H. 2007 Life cycle assessment of rapeseed oil and palm oil. Part 3: life cycle inventory of rapeseed oil and palm oil. PhD thesis. Department of Development and Planning, Aalborg University, Denmark.

Yukamgo, E. and Yuwono, N.W. 2007 Peran silikon sebagai unsur bermanfaat pada tanaman tebu [The role of silicon as a useful nutrient in sugarcane]. Jurnal Ilmu Tanah dan Lingkungan 7:103–116.

Zanchi, G., Frieden, D., Pucker, J., Bird, N., Buchholz, T. and Windhorst, K. 2011 Climate benefits of biomass plantations for energy in Uganda. Submitted to Biomass and Bioenergy, 2011 (review completed).

This report examines and compares the greenhouse gas emissions of alternative first-generation and second-generation biofuel production pathways. The emissions balance analysed include greenhouse gas emissions from cultivation, land use change, processing and transport of biofuels. The biofuel production pathways reviewed are:

- Biodiesel from palm oil in Indonesia
- Biodiesel from jatropha in South Africa and Mexico
- Bioethanol from sugar cane in South Africa, Mexico and Indonesia
- Bioethanol from wood in South Africa and Mexico
- Fischer-Tropsch diesel from wood in South Africa and Mexico

Most calculations are undertaken using a tool developed by the BioGrace project funded by the European Union. For land use change emissions, three default values based on results from the partial equilibrium Global Biomass Optimisation Model (GLOBIOM) are used. An allocation of greenhouse gas emissions to the biofuel and its co-products is done by using the energy allocation method. The results show that wherever a land use change default value for non-wood feedstocks is used, this value dominates by far all other emission sources. Default land use change emissions for pathways using wood as feedstock are minor (short rotation coppice) or negative (wood from existing forests). However, woody feedstocks require second-generation conversion technologies. The least emission intensive first-generation pathways are bioethanol from sugar cane in Mexico and Indonesia due to the high productivity of sugar cane and the simple conversion process.

Due to the limited country-specific database, a differentiation between countries or regions could not clearly be made. Differentiation can rather be done for the importance of particular factors such as feedstock productivity in conjunction with fertiliser use, allocation of co-products or the energy demand of specific conversion technologies.

www.cifor.org blog.cifor.org

JOANNEUM RESEARCH

CIFOR

Center for International Forestry Research
CIFOR advances human wellbeing, environmental conservation and equity by conducting research to inform policies and practices that affect forests in developing countries. CIFOR is one of 15 centres within the Consultative Group on International Agricultural Research (CGIAR). CIFOR's headquarters are in Bogor, Indonesia. It also has offices in Asia, Africa and South America.

CGIAR