Screening LCA of the rice and cashew value chains of GIZ's CARI and ComCashew projects

Reviewed LCA report

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Title	Screening LCA of the rice and cashew value chains of GIZ’s CARI and ComCashew projects	
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Summary

This screening LCA is carried out to gain insight into the environmental impact associated with cashew and rice value chains linked to GIZ's Competitive African Rice Initiative (CARI) and Competitive Cashew Initiative (ComCashew).

Even though West Africa is the largest cashew producing region, the vast majority of the raw cashew nuts is processed in South East Asia (Trade for Development Centre, 2018). At the same time, rice production in West Africa cannot meet domestic demand, and a large share of the rice is imported from Asia. This screening LCA provides insights into the environmental impact of the current rice and cashew chains, and compares it to the situation in which both food products would be produced and processed locally, in West Africa.

This study therefore investigates the environmental impact of enhanced localized production and processing, as well as the impact of applying climate-smart practices. The study fills an important gap that exists when it comes to LCA data for food products and value chains originating from West Africa.

The LCA focuses on Nigeria for the rice value chain, and Ghana for the cashew value chain. The scope of the LCA is cradle to distribution, and includes all steps from cultivation up to transport to the destination market. For rice, the emphasis lies on investigating the environmental impact of different production practices (e.g. rain-fed cultivation versus irrigation) and comparing the locally produced rice to imported rice from Asia. For cashew, the influence of applying good agricultural practices (GAP) was assessed, as well as the impact of processing cashew locally instead of in Vietnam.

This study is conducted in accordance with the ISO 14040 and 14044 LCA methodological standards. Data on cultivation, transport and processing in West Africa was collected from cashew and rice farmers and processors linked to the ComCashew and CARI projects (so data is not representative for average cashew or rice farming in these countries). For Vietnam, existing data on rice production practices was obtained through the Institute for Agricultural Environment (IAE).

Emissions were calculated using IPCC Guidelines (for cultivation), as well as Agri-footprint 5.0 and Ecoinvent 3.4 LCA databases (for transport, agri-inputs, energy and use of machinery). The ReCiPe 2016 environmental impact categories for climate change, fine particulate matter formation, fossil resource scarcity, water use, and land use were taken into consideration. A separate Excel tool has been developed that allows calculating and monitoring the carbon footprint for each of the value chain stages, and can help to easily identify where in the value chain climate mitigation gains can be made.

Results for rice

As shown in the figure and table below, the average rice produced by CARI farmers in Nigeria has a 47% lower carbon footprint than rice imported from Vietnam. Rainfed rice from CARI farmers has an even lower footprint, as methane emissions from anaerobic decomposition of organic material are minimal. Due to its low yield, rainfed rice does however have a higher impact for land use, ecotoxicity and fine particulate matter formation compared to irrigated rice from CARI farmers.

Imported rice from Vietnam has a higher environmental impact because of fewer aeration periods during irrigation, higher transport emissions, burning of more rice straw, and higher level of mechanization.

The solidity of these results is underpinned by an uncertainty analysis, illustrating that the impact results for climate change, fossil resource scarcity and fine particulate matter formation are significantly lower for the Nigerian rice as opposed to Vietnamese rice.

Table 1 Environmental impact category results for 1 kg of white rice, with the coloured bars showing the relative result for each category

Impact category	Unit	Irrigated rice Nigeria	Rainfed rice Nigeria	Average rice Nigeria	Average rice Vietnam
Global warming (excl. LUC)	*kg CO_2 eq*	1.487	1.215	1.375	2.601
Fine particulate matter	*kg PM2.5 eq*	0.011	0.012	0.012	0.014
Land use	*m^2a crop eq*	1.259	2.106	1.537	1.789
Fossil resource scarcity	*kg oil eq*	0.192	0.201	0.195	0.279
Water consumption	*m^3*	0.453	0.007	0.306	0.244
Water scarcity index	*m^3*	0.137	0.005	0.094	0.088

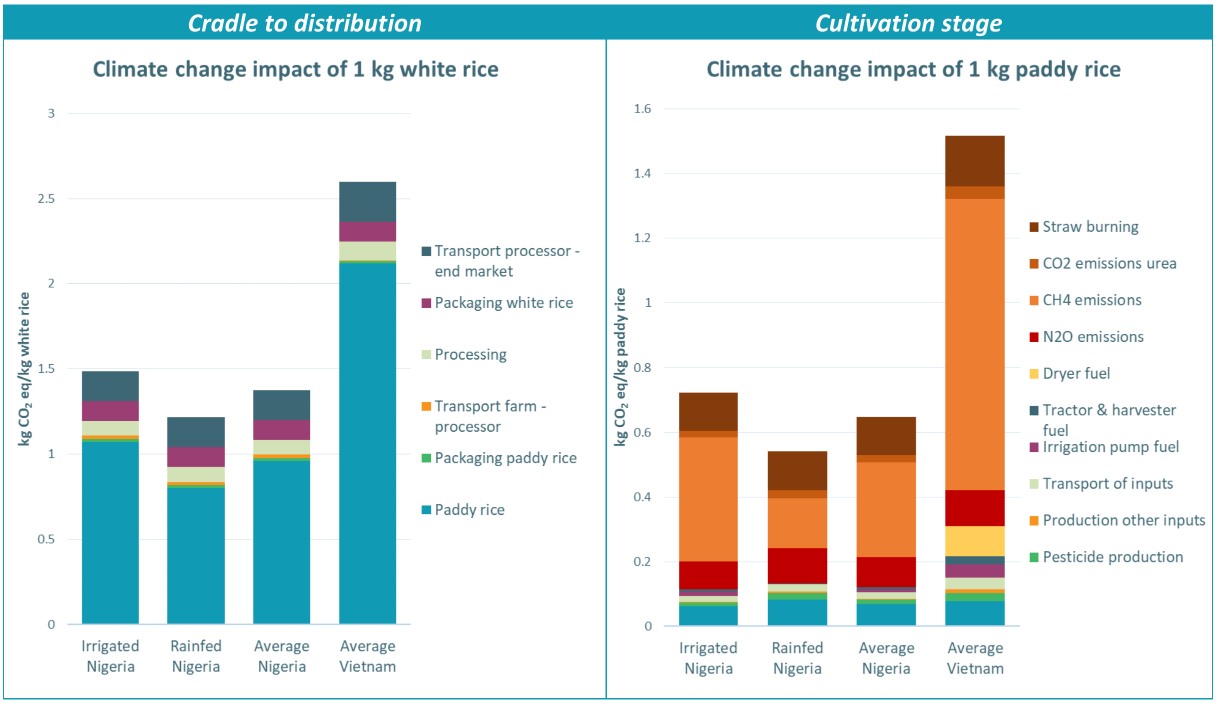

Figure 1 Climate change impact for the cradle-to-distribution stages (1 kg white rice), and cultivation stage (1 kg paddy rice) of rice

The results clearly show the environmental benefit of stimulating local production and processing of rice in Nigeria. The environmental impact could be further lowered by incorporating organic material long before cultivation, using rice straw productively (e.g. in rice processing), and by stimulating more frequent drainage periods. Results can become more accurate by carrying out actual methane measurements in rice fields, and by a more detailed study into the impact of land use change.

Results for cashew

Cashew that is grown with good agricultural practices (GAP) and processed in Ghana has the lowest impact for all environmental impact categories under consideration.

Ghanaian cashew that is processed in Vietnam results in a 43% higher carbon footprint and 66% higher use of fossil fuels, which is attributed to the long transport distance.

Table 2 Environmental impact category results for 1 kg of cashew kernel, with the coloured bars showing the relative result for each category

Impact category	Unit	GAP cashew	non GAP cashew	average cashew	Cashew processed in VN
Global warming	*kg CO_2 eq*	2.204	2.556	2.205	3.156
Fine particulate matter	*kg PM2.5 eq*	0.008	0.012	0.008	0.012
Land use	*m^2 a crop eq*	77.232	156.130	77.470	77.470
Fossil resource scarcity	*kg oil eq*	0.398	0.460	0.398	0.662
Water consumption	*m^3*	0.014	0.024	0.014	0.014

The solidity of these results is underpinned by an uncertainty analysis, illustrating that the impact results for climate change, fossil resource scarcity and fine particulate matter formation are significantly lower for cashew processed in Ghana as opposed to cashew processed in Vietnam. Even if processing in Ghana would be 50% less efficient and in Vietnam 50% more efficient, cashew processed in Ghana would still have a lower carbon footprint.

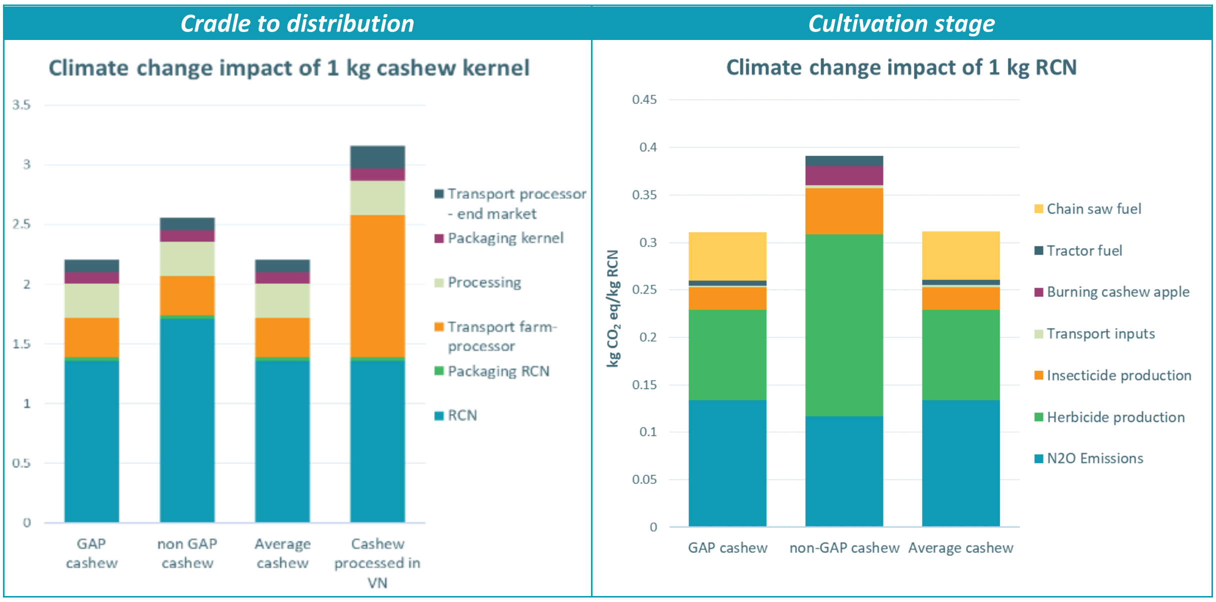

Figure 2 Climate change impact for the stages cradle to distribution (1 kg cashew kernel), and cultivation stage (1 kg RCN) of cashew

The results clearly underpin the environmental benefit of stimulating processing in Ghana instead of Vietnam, and of encouraging the application of good agricultural practices (GAP). The environmental impact could be further lowered by using the cashew apple productively, instead of letting it rot in the field. Data quality would improve through collecting primary data on cashew processing in Ghana and Vietnam. Note that the average cashew represents the average cashew cultivated in Ghana by farmers linked to ComCashew. Since the vast majority of these farmers implement GAP practices, the average is very close to the GAP farmers. This average was used for raw cashew nuts that are processed in Vietnam.

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Abbreviations

CH_4	Methane
CNSL	Cashew Nut Shell Liquid
CO_2	Carbon dioxide
GAP	Good Agricultural Practice
GH	Ghana
GHG	Greenhouse gas
IAE	Institute for Agricultural Environment (Vietnam)
ISO	International organisation for standardization
LCA	Life cycle assessment
LCI	Life cycle inventory
LCIA	Life cycle impact assessment
LUC	Land Use Change
N	Nitrogen
N_2O	Laughing gas / nitrous oxide / dinitrogen monoxide
NG	Nigeria
PEF	Product Environmental Footprint
PEFCR	Product Environmental Footprint Category Rules
RCN	Raw cashew nut
ReCiPe	*This is not an abbreviation but a name of a life cycle impact assessment method*
SRI	System of Rice Intensification
SRP	Sustainable Rice Platform
VN	Vietnam

Definitions

Allocation: A step in the inventory analysis in which the inventory model is refined and the input and output flows of multifunctional processes are partitioned to the functional flows of these processes.

Category indicator: A quantifiable representation of an impact category, e.g. infrared radioactive forcing for climate change (Guinée et al., 2002).

Category unit: Unit to express the category indicator (Guinée et al., 2002).

Characterisation factor: a factor derived from a characterisation model for expressing a particular environmental intervention in terms of a common unit of the category indicator (Guinée et al., 2002).

Characterisation method: a method for quantifying the impact of environmental interventions with respect to a particular impact category; it compromises a category indicator, a characterisation model and characterisation factors derived from the model (Guinée et al., 2002).

Characterisation unit: used to express the indicator result which is the numerical result of the characterisation step for a particular impact category, e.g. 12 kg CO_2-equivalents for climate change (Guinée et al., 2002).

Functional unit: The quantified function provided by the product system(s) under study, for use as a reference basis in an LCA

Impact category: a class representing environmental issue of concern to which environmental interventions are assigned, e.g. climate change, loss of biodiversity (Guinée et al., 2002).

Life Cycle Assessment (LCA): Compilation and evaluation of the inputs, outputs and the potential environmental impacts of a product system throughout its life cycle (ISO, 2006a).

Life Cycle Impact Assessment (LCIA): Stage of life cycle assessment aimed at understanding and evaluating the magnitude and significance of the potential environmental impacts for a product system throughout the life cycle of the product (ISO, 2006a).

Reference flow: Measure of the outputs from processes in a given product system required to fulfil the function expressed by the functional unit (ISO, 2006a).

1. Introduction

For its ComCashew and CARI projects, GIZ aims to gain an understanding of the environmental impact of the cashew and rice value chains, and how it compares to cashew and rice production and processing in Asia. Even though West Africa is the largest cashew producing region, the vast majority of processing occurs in South East Asia (Trade for Development Centre, 2018). At the same time, rice production in Africa cannot meet domestic demand, and a large share of the rice is imported from Asia (Zenna, Senthilkumar, & Sie, 2017). This screening LCA provides insights into the environmental impact of the current rice and cashew chains, and compare it to the situation in which both food products would be produced and processed locally.

The environmental impact of all steps from cradle to distribution, including cultivation, packaging, processing and transport to the destination market, are taken into consideration. For rice, the emphasis lies on investigating the environmental impact of different production practices (e.g. rain-fed cultivation versus irrigation) and comparing the locally produced rice with imported rice from Asia. For cashew, the influence of applying good agricultural practices (GAP) will be assessed, as well as the impact of processing cashew locally instead of in Vietnam.

This study is conducted in accordance with the ISO 14040 and 14044 LCA methodological standards (ISO, 2006a, 2006b), including an external critical review. This report outlines the goal, scope, LCA methodology used, data, impact assessment and interpretation. It follows the structure of an ISO-compliant report.

1.1 LCA framework and methodology

LCA is a framework that allows the quantitative analysis of the environmental burdens of a product or system throughout all the stages of its life cycle, from the extraction of raw materials, production, processing, use and end of life management. By integrating all life cycle stages, life cycle assessment provides a "holistic approach", allowing to observe interactions between stages. This can lead to identify opportunities for indirect environmental management along the whole chain, or to observe potential "burden shifting" when comparing alternative systems. Burden shifting refers to situations where solving one environmental problem in a specific stage, shifts the burden to another life cycle stage. A comparative assessment will not be complete without considering the shift of burdens to other stages of the life cycle.

This LCA is conducted according the iterative multi-step, methodology proposed in ISO 14040 (ISO, 2006a).

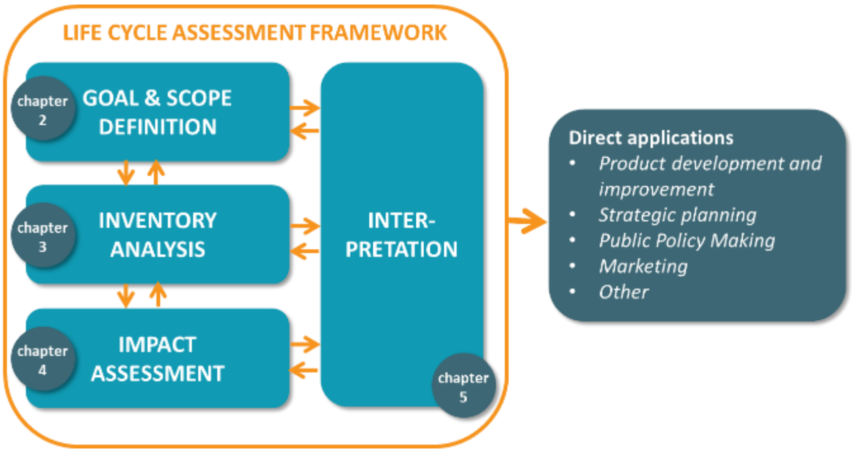


Figure 3 Methodological steps in LCA based on ISO 14040

- **Goal and scope**: This step provides a description of the product system in terms of system boundaries and functional unit.
- **Inventory analysis**: also called life cycle inventory (LCI) is a methodology for estimating the consumption of resources and the quantities of waste flows and emissions caused by or otherwise attributable to a product’s life cycle.
- **Impact assessment**: also known as life cycle impact assessment (LCIA) provides indicators and the basis for analysing the potential contributions of the resource extractions and emissions in an inventory to a number of potential impacts.
- **Interpretation**: in this phase the results of the analysis and all choices and assumptions made during the analysis are evaluated in terms of soundness and robustness. After this, overall conclusions are drawn.

2. Background on rice and cashew sectors in West Africa and South East Asia

This section provides background information on the rice and cashew value chains in West Africa and Asia, specifying key characteristics of production and processing in both regions. In the two regions, focus countries were selected for data collection. For rice, Nigeria is selected, and for cashew, Ghana is selected. Vietnam was used for the comparison of cashew processing and rice production in South East Asia, as it is the biggest processor of West African cashews (Trade for Development Centre, 2018), and also exports a large amount of rice to Africa.

Furthermore, a brief overview is given of existing LCAs conducted for these sectors.

2.1 Rice

2.1.1 Rice cultivation in West Africa

Currently, about 32 million tonnes of rice (21 million tonnes milled) is produced in Africa at an annual basis (FAO, 2018), with West Africa being the leading producer and consumer. Despite promising yield increases over the last years (108 kg/ha between 2007 and 2012), the production however can't meet demand, and about 40% of the rice consumed is imported, mainly from Asia (Zenna et al., 2017). Nigeria is the largest rice producing country in Sub-Saharan Africa, with an annual production of about 5.8 million tonnes, which supplies only half of the country's demand (Udemezue, 2018).

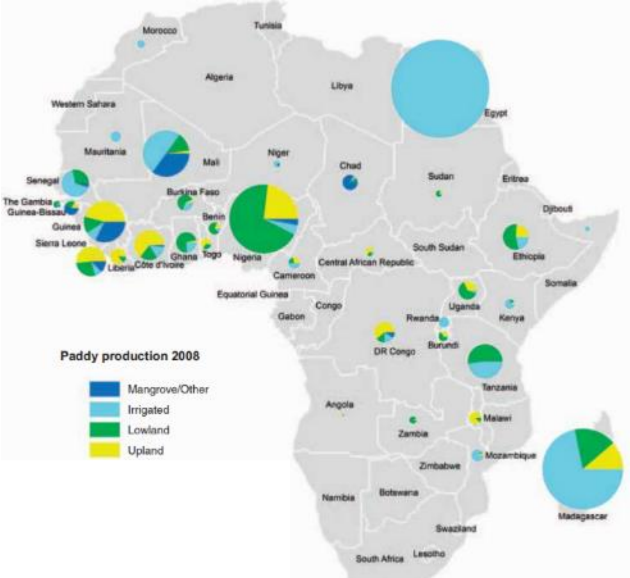


Figure 4 Type and size of rice production systems in Africa (based on Africa Rice Center (2011))

As shown in the table below and in Figure 4, the largest share of rice in Nigeria, and Africa in general, is produced under rainfed lowland conditions. The three most common rice production systems are further described in the table below (based on (Africa Rice Center (AfricaRice), 2011a; National Food Reserve Agency, 2009; Zenna et al., 2017). Figure 5 shows the focus areas of the CARI project in Nigeria.

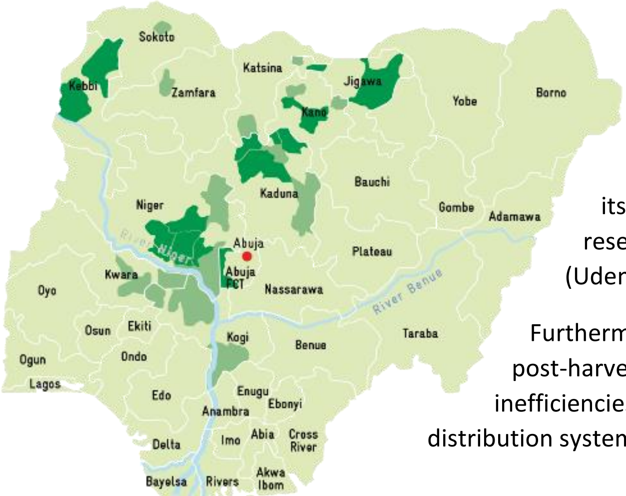


Figure 5 CARI project areas in Nigeria (source: CARI)

Generally, rice production systems in West Africa are characterised by relatively low productivity, low use of external inputs, low level of mechanisation, use of poorly yielding varieties, and inadequate crop and weed management practices. This is why the actual yield is far below its potential. In Nigeria, yields stand at 1.5 t/ha, whereas on research farms yields of up to 7 t/ha have been achieved (Udemezue, 2018).

Furthermore, production is characterised by relatively high pre- and post-harvest losses, with about 25% of the rice lost in Nigeria due to inefficiencies (Zenna et al., 2017). Furthermore, poor seed production and distribution systems hinder the widespread availability of good quality seeds.

Table 3 Characteristics of rice production systems in Africa (based on Africa Rice Center (AfricaRice), 2011; National Food Reserve Agency, 2009; Zenna et al., 2017)

Rice production system	***Share of total production***		***Average yield***	***Characteristics***	***Most common rice species (genotype)***
	Africa	***Nigeria***			
Rainfed lowland	33%	69%	1.9 t/ha	Depending on rainfall and groundwater, with hardly any water control. Often followed by vegetable cultivation (crop rotation).	O. sativa indica and O. glaberrima
Rainfed upland	30%	28%	1.2 t/ha	No flooding, low input use (thus low soil fertility), often using slash & burn. Land preparation by hand or with oxen	O. sativa tropical japonica and O. glaberrima
Irrigated	26%	3%	1.9-3.7 t/ha	Grown in bunded fields using water from dams, river diversions or wells. Sometimes only supplementary irrigation. Use of organic manure and compost for fertilization	O. sativa indica
Other (mangrove, deep water)	11%			(for Nigeria, mangrove cultivation is grouped under rainfed lowland)	

2.1.2 Rice cultivation in Vietnam

With an annual production of 650 million tons, Asia is responsible for over 90% of global rice production (IRRI). In Vietnam alone, over 40 million ton of rice is produced, of which 5 million tonnes are exported (FAOSTAT, 2017a). This makes Vietnam one of the world's largest rice exporters (Purcell, 2012a).

The vast majority of Vietnam's rice is produced in its delta regions, under irrigated conditions with 2 cropping seasons (Hai, 2012). Average yields stand at 5.5 t/ha (FAOSTAT, 2017b).

Rice production in Vietnam has benefitted from the introduction of improved rice varieties, new production models, efficient irrigation systems, multiple cropping seasons, and enhanced mechanisation of rice harvesting and drying (Hai, 2012). Only a small share, about 5%, of the (post-)harvesting activities is done manually, with the remainder using either a machine for threshing or cutting, or being fully mechanised. Drying is mostly done in the sun, but is done mechanically if rice is harvested in the rainy season.

2.1.3 Rice milling in West Africa

Rice milling in West Africa is mostly done by-small scale processing units. These often use outdated equipment leading to relatively high physical and quality losses of the grain. The few large rice mills that are present often lack access to sufficient (high-quality) rice to maintain full capacity. The use of by-products, like husk or straw, is limited due to absence of suitable technologies (Grow Africa, 2017).

In Nigeria, about 95% of the processors are small-scale using low capacity mills (National Food Reserve Agency, 2009).

The processing steps of rice milling are depicted in Figure 6 (Durlinger, Koukouna, Broekema, van Paassen, & Scholten, 2017). Even though it is not specifically for Africa, it is assumed to be applicable.

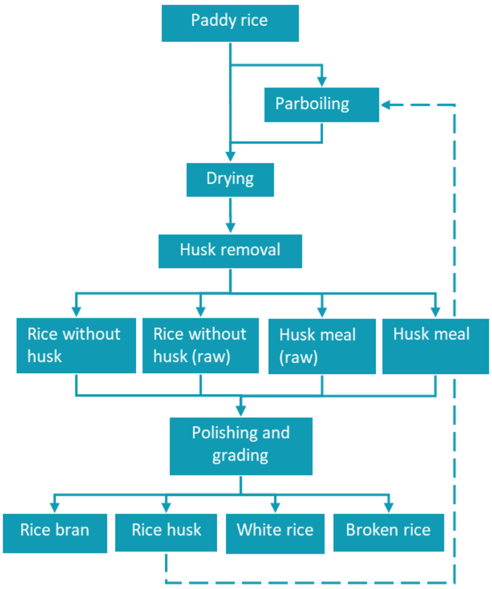


Figure 6 Schematic overview of rice milling, based on Durlinger et al. (2017)

2.1.4 Rice milling in Vietnam

The processing sector in Vietnam consists of a variety of players. There are many relatively small processing units that engage only in de-husking, after which they sell the brown rice to larger processing units for further processing (Purcell, 2012b).

2.2 Cashew

2.2.1 Cashew cultivation in West Africa

West Africa is the largest cashew producing area in the world, responsible for 59% of the world supply (1,795,000 tons) (Ton, Hinnou, Yao, & Adingra, 2018). In contrast, only 5% of the cashew is processed locally (African Cashew Alliance, 2018).

Figure 7 shows the largest cashew producing countries in West Africa (Monteiro et al., 2015), and Figure 8 details the areas which the ComCashew project focuses on.

Cashew production is dominated by smallholder farmers and has gained growing popularity as cash crop in recent decades. The trees can be part of a plantation, but are often integrated into existing farms, and thus combined with other crops. Yields are relatively low as a result of poor agronomical practices related to fertilization, weeding and pruning, and limited access to improved varieties (Monteiro et al., 2017; Ton et al., 2018).

Cashew is usually harvested when the raw cashew nuts fall on the ground, after which the apple and nut are separated and the apple is mostly left to rot in the field. The raw nuts are dried and sold to middlemen.

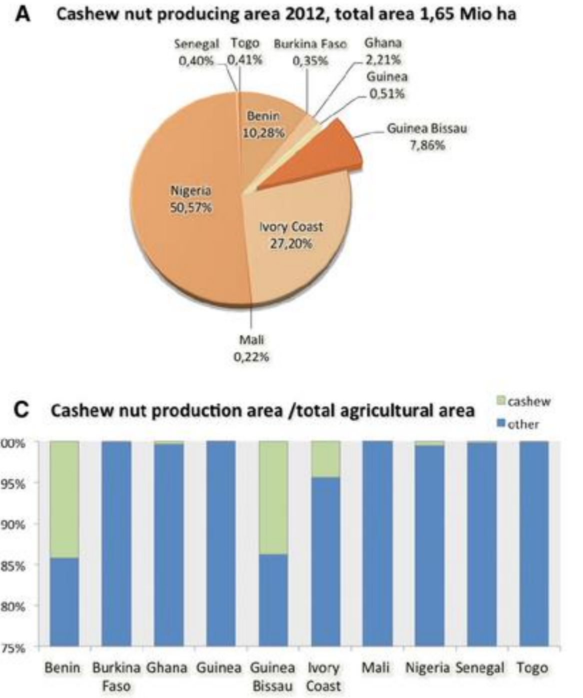


Figure 7 Cashew nut production statistics for West Africa, based on Monteiro et al. (2015)

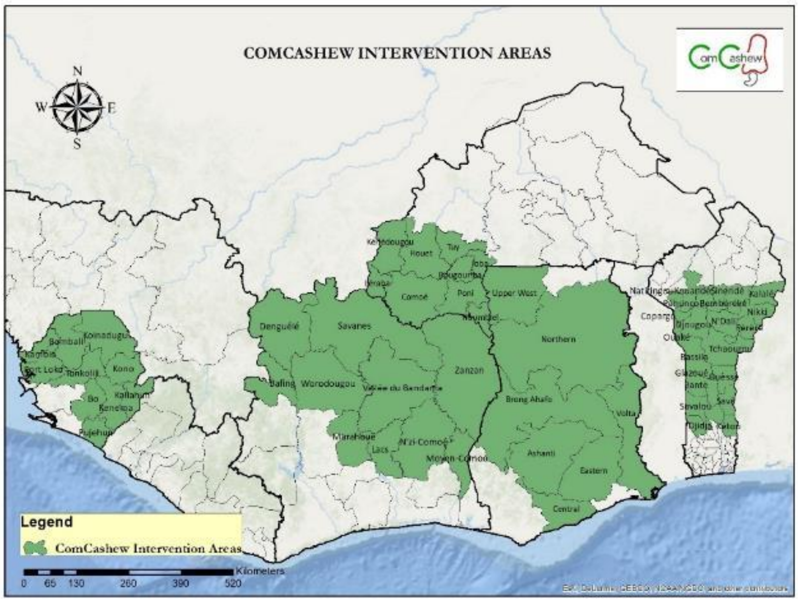


Figure 8 ComCashew project areas in West Africa (source: ComCashew)

2.2.2 Cashew processing in West Africa

The little processing of cashew that takes place in West Africa involves a large share of manual labour, although in the last decade more processing units have been established. Processing units include small units with shelling machines that can process 500-1,500 tons a year, semi-automated units with 3,000-5,000 tons a year, and large-scale units producing 10,000-30,000 tons a year. Machines for the processing industry are generally imported from Vietnam and India.

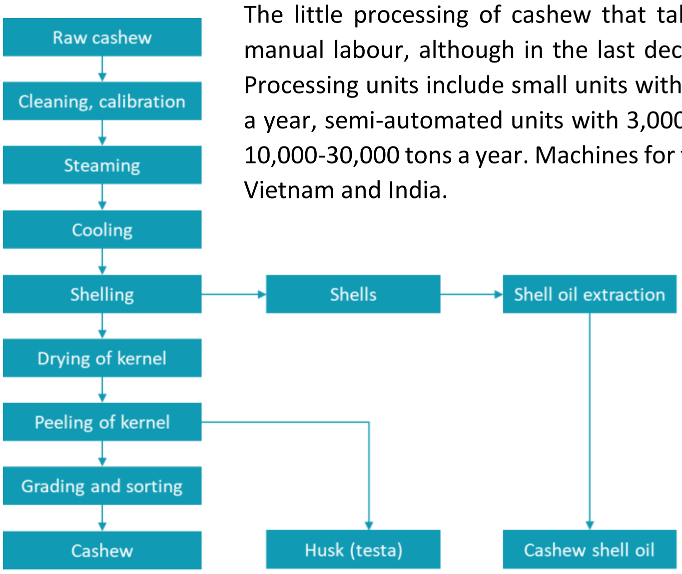


Figure 9 Schematic overview of cashew processing (based on Mohod et al., 2011)

Processing steps of the raw nut include calibration, steaming and drying in order for the shells to crack. Another round of steaming and drying is required to remove the peel from the kernel. The resulting raw cashew kernel can be steamed once again to increase moisture level (to prevent breakage). Often wood is used for the cooking, heating and steaming. After sorting, the kernels are conditioned using nitrogen and carbon dioxide, packed in industrial plastic bags, and shipped to the final destination (e.g. Europe) in cartons. In Europe, further processing takes place such as roasting, salting or coating. The processing steps are depicted in Figure 9 (based on (Mohod, Jain, & Powar, 2011))

The cashew shell, which constitutes 80% of the weight of the raw cashew nut, is toxic in nature and can be burned to produce steam, but is also simply burned as waste. Further processing of the shell, such as to generate oil, energy or charcoal, is hardly practiced (Ton et al., 2018).

2.2.3 Cashew processing in Vietnam

Vietnam is the largest exporter of processed cashew nuts. Its cashew processing capacity is three to four times the size of its actual local cashew production, and therefore relies on imports from African and other Asian countries (Ton et al., 2018).

About 60-70% of the processing sites concern small-sized processors that often supply to bigger exporting companies, 25-30% concerns medium-sized companies and the remainder are big exporting companies that sell directly to retailers in export markets.

Processing steps are similar to those described above, however are characterised by higher levels of mechanisation and automatization, hence higher efficiency.

2.3 Existing LCA studies for rice and cashew

2.3.1 Rice

The GHG emissions from rice cultivation are largely determined by methane emissions linked to crop management practices like flooding and use of organic amendments. For the calculation of these emissions, it is vital to review current available data in order to identify baseline emission factors that can help in calculating GHG emissions for the African context.

Literature review points out that currently there is a serious lack of available research on GHG emissions from rice in Sub-Saharan Africa, as also confirmed by for example (Boateng, Obeng, & Mensah, 2017) and (Kim, Thomas, Pelster, Rosenstock, & Sanz-cobena, 2016). Most studies that have been carried out are based on modelling efforts, that estimate emissions as a function of production activities (mostly based on IPCC guidelines), rather than measurements in the field. Without empirical observations from the field, it is however hard to verify the accuracy and correctness of such modelling outcomes.

The two studies that have actually measured greenhouse gases in the field (the first two in below list), have been used to calculate an adjusted emission factor for Africa, as further explained in section 4.6.2.1.

For Nigeria, the only available information on GHG emissions originates from national GHG inventory reports, which are also based on IPCC methods to calculate GHG emissions at the national level.

Box 1. Studies on GHG emissions from rice in Africa

Studies that have measured GHG emissions from rice

- Nyamadzawo, Wuta, Chirinda, Mujuru, & Smith (2014) have measured methane and nitrous oxide emissions in intermittently flooded rice planted in seasonal wetlands in Zimbabwe, accounting for the effect of different tillage and mulching practices.
- Tyler, Zimmerman, Greenberg, Westberg, & Darlington (1988) measured methane emissions from rice paddies in Kenya
- MacCarthy et al. (2018) have carried out actual measurements in Ghana, however only of CO_2, and not methane or nitrous oxide (which are more abundant in rice).

Studies that have modelled GHG emissions from rice

- Eshun, Apori, & Wereko (2013) have calculated greenhouse gas emissions for rice production in Ghana using activity data (input use, land preparation, planting, energy requirements) and (old) IPCC emission factors. It is however unclear what type of rice system and water management system is considered. No measurements of emissions.
- Boateng et al., (2017) provides an overview of available research on GHG emissions for rice in Africa. He emphasizes the lack of available primary research and the gap that therefore exists in knowledge on factors that influence GHG emissions from African rice production systems.
- Rwejumura, Kibassa, & Chacha (2018) have carried out an LCA of rice production in Tanzania, which is however incomplete as it only quantified the environmental impact of inputs used and ignored methane and nitrous oxide emissions. Diesel from farm machinery resulted in the highest impact, which is rather unusual for rice.
- Farag, Radwan, Abdrabbo, Heggi, & McCarl (2013) have estimated the carbon footprint of paddy rice production in Egypt based on modelling efforts, which included emissions related to methane, field burning, fertilizer application, and fuel combustion.

Unlike for Africa, for Asia a lot of literature is available on GHG emissions from rice paddies. Instead of looking for literature for a whole continent, the literature search could therefore focus on Vietnam only. Some studies are summarised below.

Box 2. Studies on GHG emissions from rice in Vietnam

- Sandin (2005) has done measurements of methane in Northern Vietnam, from rice paddies with different water regimes, such as high-water level and intermittent irrigation.
- Tran, Hoang, Tokida, & Tirol-padre (2018) have carried out a 3-year-long study to measure methane and nitrous oxide emissions throughout two rice cropping seasons and comparing different water management practices: continuous flooding, alternate wetting and drying and site-specific alternate wetting and drying.
- Trang, Thi, Huong, & Trinh (2019) have calculated the carbon footprint of rice by combining data on farming activities with modelling guidelines by the IPCC. Emission factors were based on actual measurements, not on default values.
- Tariq et al. (2017) studied the effectiveness of different drainage patterns (such as early, mid and late season drainage) and residue management practices (full and reduced residue incorporation), on methane and nitrous oxide emissions.

2.4 Cashew

Even though there is quite some information available on cultivation and processing stages, only little research has been carried out on GHG emissions related to cashew cultivation and processing, and none of them relate to Ghana or Vietnam. Below a summary is given of the few studies that are available.

Box 3. Studies on GHG emissions from cashew

- Figueirêdo et al. (2015) have carried out a detailed LCA of a low and high input cashew production systems in Brazil. It only considers the cultivation stage, not processing.
- Flysjo & Ohlsson (2006) have carried out basic LCA analyses for the production of cashew nuts in El Salvadaor and Guatemala, as part of a bigger study on the environmental impacts of different agro-food chains in Central America.
- Jekayinfa & Bamgboye (2006) have estimated energy requirements for small, medium and large scale cashew processors in Nigeria
- Callado (2008) has not measured greenhouse gas emissions, but has looked at litter fall and biomass measurements of cashew species in Brazil.

3. Goal

The overall goal of this screening LCA is to quantify the environmental impact of all stages of the rice value chain in Nigeria and cashew value chain in Ghana (linked to the CARI and ComCashew projects), and to compare this to rice imported from and cashew processed in Vietnam.

3.1 Intended application, audience and type and format of the study

The results of this LCA will be used by the CARI and ComCashew projects and its partners to gain insight into what environmental impact is associated with cashew and rice value chains in the project countries, and how this impact compares to cashew and rice produced or processed in South East Asia. It can be used in external communication towards relevant stakeholders, such as public partners (Ministry of Agriculture, African Cashew Alliance) and private partners (e.g. processing sector within Africa and in importing countries), and is backed up by an ISO-compliant external review.

The study consists of three parts:

- An easy-to-use **Excel tool** that enables quantification of greenhouse gases along the value chain for both cashew and rice (so two tools). This provides insight into the relative contribution of the different stages and (farming) practices towards the overall carbon footprint.
- This **report** that elaborates the methodology, and provides detailed results for all environmental impact categories, as well as the relative contribution of the value chain stages to these categories.
- **Training** (in Ghana): during a 2-day workshop the results of the study were presented to key project staff and stakeholders. The workshop enhanced the participants' understanding of the concept of LCA, and included practical exercises using the excel tools.

3.2 Tools and methods

The LCA methodology is used for this screening LCA. It is regarded as fitting to the aim of this study, as an LCA considers life cycle stages of the production of rice and cashew, and is able to quantify the environmental impact of all relevant processes at each of these stages. Appendix I contains a detailed explanation of the LCA methodology.

The study includes a contribution analysis, meaning that the contribution of the stages in the lifecycle are analysed and reported. This provides insight into where in the value chain 'hotspots' occur. Relevant sensitivity analyses, including an uncertainty analysis,are also carried out.

This study is conducted in accordance with the ISO 14040 and 14044 LCA methodological standards (ISO, 2006a, 2006b). Furthermore, the Product Environmental Footprint Category Rules (PEFCR) from the European Commission (European Commission, 2018) are used as supporting guidance in the decision-making process of methodological choices related to agricultural modelling only. This comprehensive set of guidelines is developed to ensure consistent approach in the calculation of the environmental impact of products.

The LCA is performed in the LCA software SimaPro 9.0 using LCIA method ReCiPe 2016 (M. Huijbregts et al., 2016). The ReCiPe impact assessment method was chosen as it has a global applicability (in contrast to other methods, like the PEF method, which has a European focus). Relevant parts of the model are integrated in the two Excel tools.

4. Scope

4.1 System boundaries

For both rice and cashew, the system under consideration extends from crop cultivation (cradle) up to transport to the end market. Consecutive steps, such as further processing (e.g. flavouring and consumer packaging), retail, distribution and consumption, are out of scope.

This section describes the processes that are part of the systems, as well as the different scenarios considered.

4.2 Functional units

To describe the qualitative and quantitative aspects of the systems under study as well as the basis on which the comparison between the systems is made, the following functional units have been defined:

- Cashew: the provision of 1 kg of processed cashew nuts to the European market
- Rice: the provision of 1 kg of white rice to the Nigerian market

The following section provides the different scenarios how these functional units are fulfilled.

4.2.1 Rice

For rice, the following scenarios are included:

A. Irrigated rice produced and processed in Nigeria
B. Rainfed rice produced and processed in Nigeria
C. Rice produced and processed in Vietnam, transported to Nigeria

The system boundaries of the scenarios are depicted in the figure below. As end market, Nigeria's largest city, Lagos, is considered.

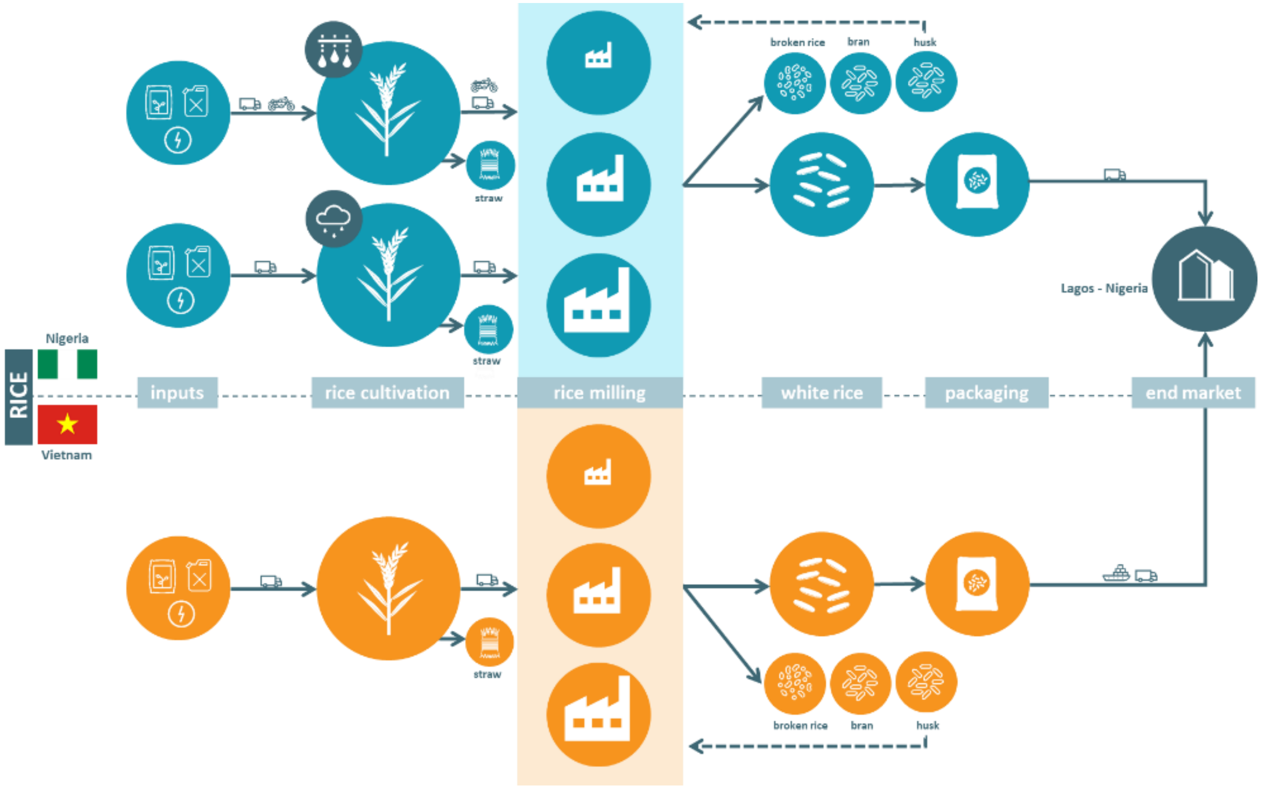


Figure 10. Schematic overview of the two rice scenarios.

Further processing in the country of destination and distribution to the consumer is excluded. This means that only transport from the processing location to the end market is considered.

4.2.2 Cashew

For the cashew value chain, the following two scenarios are included, as also depicted in the figure below:

- **A.** Cashew produced and processed in Ghana then transported to Europe
- **B.** Cashew produced in Ghana, processed in Vietnam, then transported to Europe

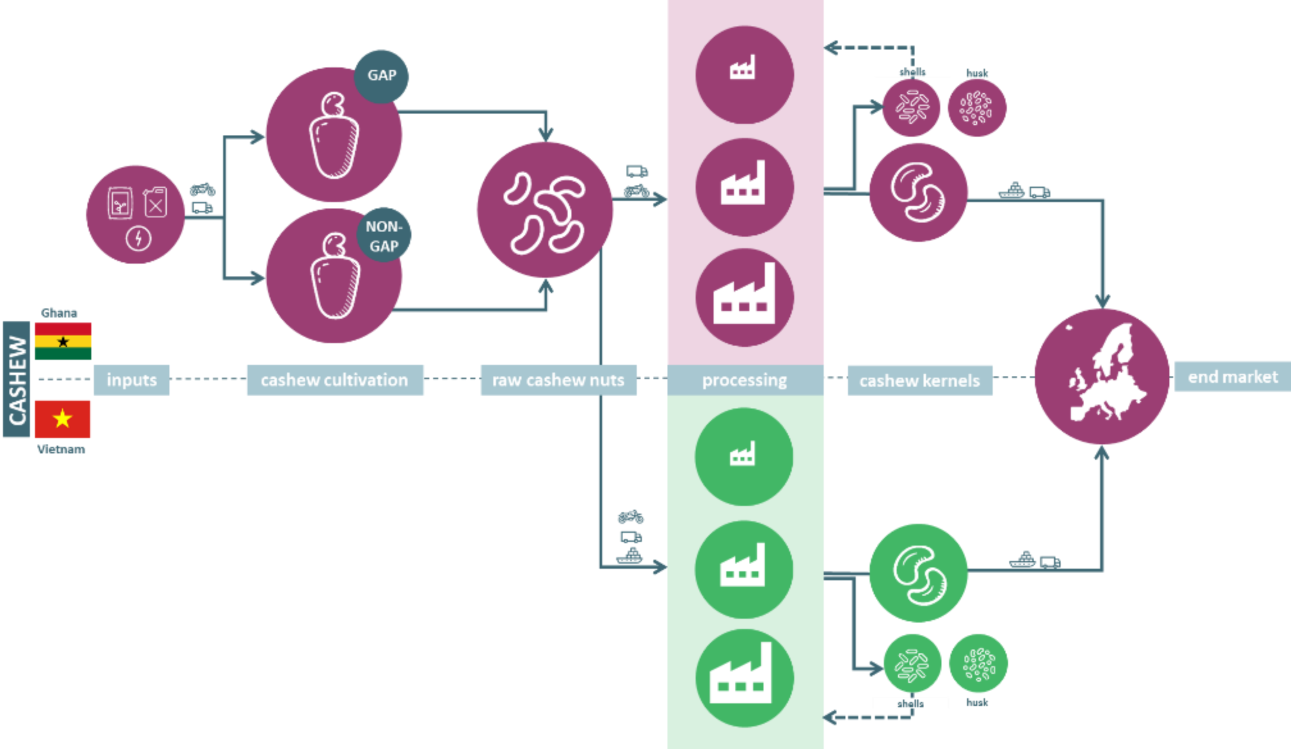


Figure 11 Schematic overview of the two cashew scenarios.

Only transport to the end market, which can be e.g. a harbour in Europe, is considered. As the Dutch company Intersnack is the largest importer of African cashew nuts (Ton et al., 2018), the harbour of Rotterdam is considered as the end point of analysis. Further processing (roasting, salting etc), packaging and distribution in Europe is not considered.

Note that not all value chain actors are included, e.g. sales in Africa often happen through middlemen. As here no further processing steps take place, these are left out, and only the transport from the farmer to the processing plant is considered.

4.3 Environmental impact categories

The environmental impact of the rice and cashew value chain is evaluated with the following environmental impact categories from ReCiPe 2016 (M. A. J. Huijbregts, Steinmann, Elshout, & Stam, 2016). As rice is a crop that generally consumes a lot of water, one additional indicator has been added: the water scarcity indicator from (Pfister, Koehler, & Hellweg, 2009).

Table 4 Overview of the most relevant environmental impact categories and related indicators

Impact category	Characterization Factor	Unit
Climate change (including land use change)	Global warming potential (GWP)	kg CO_2-eq to air
Fine particulate matter formation	Particulate matter formation potential (PMFP)	kg PM2.5-eq to air
Terrestrial ecotoxicity	Terrestrial ecotoxicity potential (TETP)	species/yr
Land use	Agricultural land occupation potential (LOP)	m^2 × yr annual crop land
Fossil resource scarcity	Fossil fuel potential (FFP)	kg Oil-eq
Water use	Water consumption potential (WCP)	m^3 water-eq consumed
Water scarcity	Water scarcity indicator (WSI)	m^3 derived/ m^3 consumed

The indicators and impact models of the ReCiPe LCIA method are generally accepted (a large volume of journal papers utilise this LCIA method in their assessments) and reflect the goal of this study. Furthermore, it is one of the few impact assessment methods that is applicable at a global level (in contrast to e.g. the European Environmental Footprint method). The impact categories most relevant to local conditions of agriculture were selected, hence the inclusion of fine particulate matter formation (due to burning of crop residues), yet the exclusion of eutrophication (as fertilizer use is low in African countries). The impacts can be aggregated to endpoints as shown in below figure.

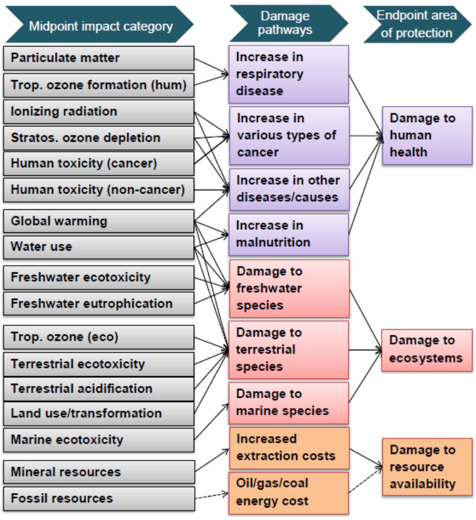


Figure 12 Overview of the impact categories that are covered in the ReCiPe2016 methodology and their relation to the areas of protection

For climate change the most relevant Global Warming Potentials (GWPs) in ReCiPe 2016, based on the 5th IPCC assessment report are;

- 1 kg fossil CO_2 = 1 kg CO_2-eq.
- 1 kg biogenic CH_4 = 34 kg CO_2-eq.
- 1 kg N_2O = 298 kg CO_2-eq.

4.4 Limitations

The following limitations should be observed when it comes to data gaps and data quality:

- Data for processing has only been derived from a limited number of processors. For rice, data was derived from small, medium and large processors. For cashew, only one small processor was interviewed. This data has been supplemented with data from a study that investigates energy needs of small, medium and large cashew processors in Nigeria (Jekayinfa & Bamgboye, 2006), assuming that conditions in both countries are similar.
- When it comes to pesticides, for cashew no information on the active ingredients was available, and hence it was decided to work with the general Agri-footprint processes on herbicides, insecticides and fungicides for their carbon footprint (no assessment of ecotoxicity was done for cashew). These are based on common pesticide manufacturing processes. For rice, active ingredients were provided by CARI. These were compared to Vietnam based on active ingredients found in literature sources. Assumptions had to be made on the concentration of the active ingredients. The ecotoxicity analysis has been included as a sensitivity analysis. See also Appendix II: Background data
- To best meet the African reality, as much as possible LCA processes have been used that represent African conditions. For electricity, national datasets were available for Ghana, Nigeria and Vietnam from Ecoinvent. For materials, like packaging, Ecoinvent processes with a global scope have been used. Transportation in Africa is similar to that in other countries, but to reflect a possible older age of vehicles, euro 3 has been chosen.
- No data could be collected on how much water is exactly used for irrigation and processing. Values on blue water consumption from literature (Mekonnen & Hoekstra, 2011), combined with Blonk Consultants' energy model have been used to calculate country-level average water consumption for rice and associated energy needs for irrigation. Energy for irrigation is calculated with the "Energy model for crop cultivation" (Blonk Consultants, 2019), which uses country-specific values for pumping efficiency and average pump depth (based on the water table).
- For both cashew and rice processing in Vietnam, no data was available (and primary data collection among processors in Vietnam was out of the scope of this study). For rice processing, data has been collected from rice processing in other Asian countries (see Appendix II). For cashew processing, the same data has been used as for Ghana (based on Jekayinfa & Bamgboye, 2006).
- The comparison takes place on the mass of the final product (1kg of rice and cashew), which means that potential differences in quality or nutritional content (which could e.g. be attributed to the variety), are not taken into account.

4.5 Allocation procedures

Allocation helps to define how the environmental burden of a production process can be divided in case it has several co-products. When planks are produced in a sawmill for example, the co-products will be planks, saw dust and wood chips. Planks are the main products, with saw dust and wood chips being by-products that however can still be used for other purposes. The environmental burden between the different co-products can be divided based on their mass, but most commonly their economic value is used. This is to avoid that a large part of the environmental impact is allocated to the wood chips/sawdust, whereas these are just by-products.

Also for the case of cashew and rice economic allocation is regarded as appropriate. For cashew for example, mass allocation would lead to the largest environmental burden being allocated to the cashew apple (as its weight is 8-10 times that of the raw cashew nut), whereas this is a by-product that has a much lower economic value than the raw cashew nut.

As can also be derived from the system diagrams, allocation has to be determined for the co-products mentioned in the table below. This means the use and economic value of each of the co-products is determined. The prices used to calculate the allocation percentages are mentioned in the life cycle inventory.

Table 5 Co-products in the cashew and rice value chains

Cashew	Rice
Cultivation	
Cashew apple Raw cashew	Rice Straw
Processing	
Processed cashew nut Cashew shell (which can be processed into cashew shell oil) Husk	White rice Broken rice Rice husk Rice bran

4.6 Specific methodological considerations

This section describes some specific methodological considerations which are relevant for rice and cashew. A detailed description of the applied method for cultivation can be found in the background reports of Agri-footprint (Blonk Consultants, 2019).

4.6.1 Generic

4.6.1.1 Land Use Change (LUC)

GHG emissions arise when land is transformed from one use to another. The most well-known example of this is deforestation for the cultivation of crops. Land use change is responsible for as much as 8% of global carbon dioxide emissions (Blonk Consultants, 2018).

A big challenge for practitioners of Life Cycle Assessments (LCA) is to translate this impact of land use change to specific crops from specific countries while little primary data is available. Blonk Consultants' 'Direct Land Use Change Assessment Tool', based on the PAS2050:2012-1 method (BSI, 2012), can be used to calculate greenhouse gas emissions from land use change. It is based on the following principles:

- <u>Did the total forest area in a country contract over the last 20 years?</u> If the total forest area in a country did not reduce compared to 20 years ago, the emissions factors due to direct land use change will generally be low.
- <u>Did the total area for crop cultivation increase in a country?</u> If there is no increase in the total area used for crop cultivation, it can be assumed that this means that any contractions of forest or grass land is not caused by cropland. Therefore, the emissions factors for that country will generally be low.
- <u>Did the total area harvested for the crop under investigation expand?</u> If the area harvested for a crop under investigation did not increase over a period of 20 years, there is no land use change. If there is an increase, the emissions due to land use change will be mainly driven by the factors mentioned above. For crops that are rapidly expanding, this can result in large changes in emission factors between the chosen 20-year interval. For instance, the emissions from groundnuts in Myanmar increased significantly, because they doubled cultivation in the in the past year and did not cultivate groundnuts 20 years ago, the expansion over 20 years has increased enormously.

The land use change tool provides the following values for cashew and rice for CARI's and ComCashew's project countries.

Table 6 Land use change emissions for project countries based on Direct Land Use Change Assessment Tool

Country	LUC (tonne CO_2-eq/ha*year^{-1}))
Cashew	
Benin	6.98
Burkina Faso	8.18
Côte d'Ivoire	0.00
Ghana	**0.00**
Mozambique	1.78
Sierra Leone	(not available)
Rice	
Burkina Faso	5.95
Ghana	0.00
Nigeria	**6.75**
United Republic of Tanzania	12.51
Vietnam	**0.00**

Instead of using these numbers, primary data from the field, satellite data or other literature sources could be used in the future. With this data, it would have to be demonstrated what kind of land use change (if any) has taken place in the past 20 years on the farming area in question. Primary data collection can lead to a more accurate outcome.

4.6.1.2 Nitrous oxide emissions

Direct and indirect nitrous oxide (N_2O) emissions from cultivation are calculated using IPCC guidelines.

Direct emissions consist of:

- **N_2O from synthetic and organic N application to the soil**. Multiplies kg N applied per year with an emission factor, EF_1. This factor is determined as follows:
    - Upland rice and other crops: synthetic fertilizers in wet climates: 0.016; organic inputs in wet climates: 0.006; all N inputs in dry climates: 0.005
    - Continuously flooded rice: 0.003
    - Rice with single and multiple drainage: 0.005
- **N_2O from urine/dung deposited by grazing animals**. Amount of urine/dung deposited multiplied by EF_3, which can have the following values:
    - Cattle, poultry and pigs in wet climates: 0.006
    - Cattle, poultry and pigs in dry climates: 0.002
    - Other animals: 0.003

Indirect N_2O emissions concern atmospheric deposition of nitrogen volatilized from managed soils. These emissions are mainly relevant for rice cultivation that has no significant flooding. It consists of:

- **N_2O from atmospheric deposition**, which is calculated by multiplying the fraction of synthetic and organic fertilizers that volatizes as NH_3 and NO_x by an emission factor (EF_4, which is 0.014 for wet and 0.005 for dry climates)
- **N_2O from leaching/runoff from managed soils**, which is calculated by multiplying the fraction of leached N in synthetic and organic fertilizers by emission factor EF_5 (0.011 for all climates).

4.6.2 Rice

4.6.2.1 Methane (CH_4) emissions of rice cultivation

Flooded rice production systems are responsible for a large amount of greenhouse gas emissions. Under the anaerobic conditions that are caused by flooding, the decomposition of organic material leads to emissions of methane, a harmful greenhouse gas (e.g. 1 kg CH_4 equals 34 kg CO_2). At a global level, rice cultivation is responsible for about 10% of emissions in the agriculture sector. Rice even contributes to 19% of all anthropogenic methane emissions and 11% of nitrous oxide emissions (Islam et al., 2018).

Flooding is unique to rice production and requires special modelling efforts. Practices like intermittent flooding, pre-season flooding and integration of straw have a big influence on emissions and therefore need to be included in modelling efforts.

With help of the IPCC guidelines (2019 refinement) (IPCC, 2019), emissions for rice can be estimated as a function of different parameters linked to production activities. The formula to calculate the daily emission factor is mentioned below (equation 2). This emission factor needs to be multiplied by the cultivation period and harvested area to obtain the total annual methane emissions (equation 1).

Equation 1. $\text{Annual } CH_4 \text{ emission} = EF \times \text{cultivation period} \times \text{harvested area}$

Equation 2. $EF = EF_{baseline} \times SF_{water\ regime\ cultivation} \times SF_{water\ regime\ pre\text{-}season} \times SF_{organic\ amendments}$

To calculate the emission factor (EF), a baseline emission factor ($EF_{baseline}$) is needed, which is multiplied by scaling factors that account for management practices related to flooding and use of organic amendments.

As emissions also depend on local climate and agro-ecological conditions, preferably country-specific emission factors should be used. If these are not available, the tier 1 approach provides regional emission factors. However, for Africa, the IPCC uses the global estimate, due to a lack of data.

This study also points out that there is a lack of emission inventory data based on field measurements in Africa. Only two studies could be identified that have conducted methane measurements in the field. To obtain a more accurate value for the baseline emission factor, that better represent African conditions, these two studies were used to 'reverse calculate' the baseline emission factor. This means that the IPCC scaling factors that represent the applied management practices were used to derive the baseline emission factor.

Thus, using equation 2, the baseline emission factor can be calculated as follows:

$$EF_{baseline} = \frac{EF_{measured}}{SF_{water\ regime\ cultivation} \times SF_{water\ regime\ pre-season} \times SF_{organic\ amendments}}$$

This was applied as follows for the two available studies:

- The Zimbabwean study (Nyamadzawo et al., 2014), which measures GHG emissions from rice planted in seasonal wetlands, corresponds to drought prone conditions (as water level only partially and briefly reaches the surface, and never reaches 50 cm), and no pre-season flooding for more than 6 months (as it is planted at the end of the dry season). They measured methane emissions of 12.5 kg/ha during a growing season that lasted 150 days, corresponding to 0.0833 kg /ha/day. Applying the scaling factors that match the practices described above, this resulted in a baseline emission factor of 0.0833/(0.16 x 0.89 x 1) =0.59 kg CH_4/ha/day
- The Kenyan case (Tyler et al., 1988) concerns rice fields with standing water (SF_w = 1) that were flooded before the season (SF_p = 2.41) and in which residues of the previous crop were incorporated into the soil. It was assumed that it concerned 5 tons of residues/ha (average value reported by (Hung, Hughes, Keck, & Sauer, 2019)), which were incorporated more than a month before cultivation started, leading to a value of SF_O of 1.48. The measured emissions were 3.55 kg CH_4/ha/day. The resulting baseline emission factor was consequently 3.55/(1 x 2.41 x 1.48) = 0.99 kg CH_4/ha/day

Based on these two calculations, an average baseline emission factor of 0.79 kg CH_4/ha/day can be assumed. This value is lower than the global average (1.19) and closer to values for North America (0.65) and South Asia (0.85). East and Southeast Asia have higher baseline emissions, of 1.32 and 1.22 respectively. It is assumed that the EF of 0.79 is more accurate than the global average.

For Vietnam, a lot more literature is available, including field measurements. However, to ensure consistency and comparability to Africa, the same IPCC Tier 1 methodology is applied, using baseline emission factor for South

East Asia ($EF_{baseline}$= 1.22 kg CH_4/ha/day), and average activity data. This activity data is based on literature research. The resulting values will be compared to measured values from the field.

Also soil type and cultivar have impact on GHG emissions. However, as these are not considered in the Tier 1 approach, and only little data is available on the influence of both factors on emissions in Africa, these will not be considered for the calculations.

4.6.2.2 Rice straw burning

Even though the carbon dioxide that is released by the burning of crop residues is biogenic, the combustion also releases methane and nitrous oxide, two gases that have a significant global warming potential. Emission data for the combustion of rice husk and rice straw has been compiled based on several studies. A more detailed overview can be found in the Appendix II.

Table 7 Emissions for burning rice husk and rice straw

	CO_2 (biogenic)	CO	CH_4	N_2O	NO_x	SO_2	PM2.5	PM10	Black carbon	Organic carbon	NO_2	NO
Rice straw	1324.20	87.68	5.77	0.34	2.66	0.89	11.96	4.10	0.61	5.35		
Rice husk	1079.06	35.29	6.20	0.26	2.30	0.11	11.96	13.23	0.61	5.35	0.19	1.38

4.6.3 Cashew

4.6.3.1 Intercropping

In Ghana, farmers do not apply any fertilizers for their cashew trees. As the cashew trees are often intercropped, it could however be that they benefit from the fertilizers applied on these ‘intercrops’. This scenario is added as a sensitivity analysis.

In LCA, there is no fixed methodology on how to deal with intercropping. Goglio, Brankatschk, Knudsen, Williams, & Nemecek (2018) have reviewed different methodologies, such as the cropping systems approach, allocation approaches, crop-by-crop approach, and a combination of these.

Due to lack of data availability, it was decided to take a simpler approach, namely considering that 10% of the fertilizers applied on the intercrop will be attributed to cashew. This 10% was selected in consultation with the ComCashew team, as there was a lack of literature available from which more precise values could be obtained. This is further elaborated in the sensitivity analysis.

4.6.3.2 Nursery phase

As shown in below figure, the cashew tree has to grow approximately 5 years before it will provide cashew. After these 5 years the production period is approximately 50 years. The non-productivity phase is currently excluded in this LCA. It is assumed that this will not influence the results a lot, as the young cashew trees hardly require any inputs.

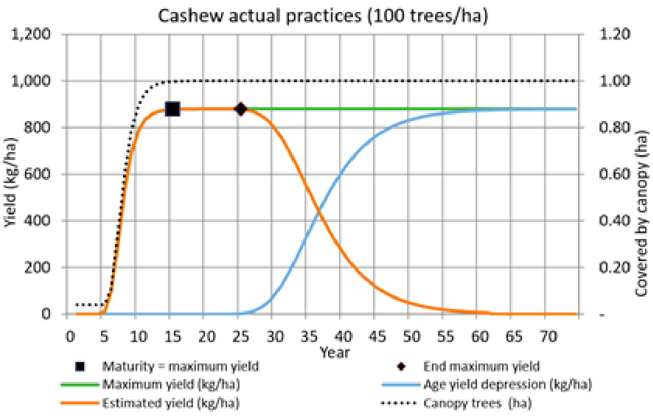


Figure 13 Cashew growth characteristics, from Groothuis (2016)

4.7 Critical review

This report has been externally reviewed according to ISO 14040/14044 standards.

5. Life Cycle Inventory (LCI)

This section explains how data was collected and how data gaps were tackled in the development of the life cycle inventory for each life cycle stage.

The data is linked to background processes (such as from the Agri-footprint and Ecoinvent databases) in order to calculate the environmental impact as reported in section 6 and interpreted in section 7. The complete inventory data can be found in appendix II, and can also be found in the carbon footprint models.

5.1 Data collection strategy

Below an overview is provided of the type of data that has been collected for each of the value chain stages, and the subsequent modelling steps that have been applied to each of these.

Table 8 Overview of data requirements and modelling actions

	Inputs	**Transport of inputs**	**Smallholder cultivation**	**Transport to processing**	**Processing**	**Transport to end market**
Data collected	• (Organic) fertilizer type and quantity • Organic inputs • Pesticides • Herbicides • Others (lime etc)	• Transport distance • Type of transport and inputs needed	• Yield • Crop & water management practices • Use of machinery • Land use change	• Transport distance • Type of transport and inputs needed	• Quantity of (sub)product per processing step • Energy inputs • Packaging material • Inputs of water, and others	• Transport distance • Type of transport and inputs needed
Data modeled	Emissions related to production of fertilizers and other inputs, derived from Agri-footprint 5.0	Emissions related to fuel combustion of vehicles, derived from Agri-footprint 5.0	Emissions related to: • application of agro-inputs, • water management (rice), • residue burning • fuel combustion of machinery	Emissions related to fuel combustion of vehicles, derived from Agri-footprint 5.0	Emissions related to • Energy use (electricity generation, fuel combustion) • Production of packaging material Derived from Ecoinvent	Emissions related to fuel combustion of vehicles, derived from Agri-footprint 5.0

In order to make an equal comparison between production systems in Asia and Africa, efforts have been undertaken to collect similar type of data for both regions. In this way, the environmental impact categories are determined in a similar way, which leads to more accurate results than if one would only calculate the impact for one country, and compare it to a value from literature for the other country. The calculations that underly the carbon footprint tool are further elaborated in the following sections.

Data for rice and cashew in Nigeria and Ghana has been derived from the CARI and ComCashew projects. For the rice from Vietnam, an expert from the Vietnamese Institute for Agricultural Environment has been consulted. This institute also has experts on cashew, however these did not have relevant information available on cashew processing. The table below provides more detail on how the data has been obtained.

Table 9 Overview of data collection for cashew and rice

	Inputs	**Transport of inputs**	**Smallholder cultivation**	**Transport to processing**	**Processing**	**Transport to end market**
			Cashew			
Ghana	Data from ComCashew project	Data from ComCashew project	Data from ComCashew project, distinguishing between GAP and non-GAP farmers	Transport modes and distances based on global transport routes	Data collected for small processor, supplemented with literature for medium and large processors.	Transport modes and distances based on global transport routes
Vietnam	n/a	n/a	n/a	Transport modes and distances based on global transport routes	Data from literature, including different Asian countries	Transport modes and distances based on global transport routes
			Rice			
Nigeria	Data from CARI project	Data from CARI project	Data from CARI project	Data from CARI project	Data from CARI project	Data from CARI project
Vietnam	Data from Vietnam's IAE	Data from Vietnam's IAE	Data from Vietnam's IAE	Data from Vietnam's IAE	Based on processing in other Asian countries.	Transport modes and distances based on global transport routes

5.2 Rice

5.2.1 Cultivation

Table 10 provides the key data that was used to model the cultivation stage (including inputs). The data for Nigeria was provided by the CARI programme, and the data for Vietnam by the Institute for Agricultural Environment (IAE). The latter concerns average data for Vietnam. As only average data could be provided for rice production in Vietnam's main rice producing regions (Mekong River Delta and Red River Delta), no differentiation could be made between rainfed and irrigated rice. Below data can also be found in the Excel tool.

Table 10 Life cycle inventory for cultivation stage of rice

	Unit	Nigeria Irrigation	Nigeria Rainfed	Nigeria Irrigation & Rain	Nigeria All farmers	Vietnam Average	Comments
Number of farmers		10724	10369	12196	33289		
Yield	*kg/ha*	6235	3725	5094	5104	5250	
Fertilizers							
NPK compound (NPK 15-15-15)	*kg/ha*	259	215	239	239	75	
Urea, as 100% CO(NH2)2 (NPK 46.6-0-0)	*kg/ha*	185	136	163	163	187	
Potassium chloride (NPK 0-0-60)	*kg/ha*	0	0	0	0	106	
Di ammonium phosphate, as 100% (NH3)2HPO4 (NPK 22-57-0)	*kg/ha*	0	0	0	0	173	
Pesticides							
Fungicide	*kg/ha*					3.945	See Annex II for more information
Herbicide	*kg/ha*	3.76	3.76	3.76	3.76	1.27	
Insecticide	*kg/ha*	0.94	0.94	0.94	0.94	3.805	
Other inputs							
Seeds	*Kg/ha*	30	30	30.00	30.00	148.40	
Lime fertilizer	*Kg/ha*	0	0	0.00	0.00	185.00	

Organic amendments							
Straw	*kg dm/ha*	555	331	453	454	1061	Based on yield straw (is equal to yield rice), multiplied by percentage of straw left on field.
Animal manure, applied by farmer	*kg fresh/ha*	10	15	12	12	33	
Animal manure, from grazing	*kg fresh/ha*	10	15	12	12	0	
Machine use							
Tractor: percentage of area on which tractor is used (%)		44%	3%	25.4%	25.5%	100.0%	Uses 25 l/ha (GIZ data)
Combine harvester: percentage of area on which harvester is used (%)		30%	10%	20.9%	21.0%	95.0%	Uses 14 l/ha (GIZ data)
Mechanical dryer: percentage of rice for which mechanical dryer is used (%)						70%	Uses 145 kg coal/ha and 21.7 kWh electricity (IEA data)
Percentage of area on which diesel-driven water pump is used (%)		75%	0%	40.9%	41.2%		Uses 31 l/ha (based on energy model)
Percentage of area on which electrical pump is used						85.0%	Uses 585.5 kWh/ha (based on IEA data)
Water regime							
Irrigated - Continuously flooded (can be dry at harvest)		10%	0%	5%	5%	20%	
Irrigated - Intermittent flooding: single drainage period		20%	0%	11%	11%	51%	
Irrigated - Intermittent flooding: multiple drainage periods		70%	0%	38%	38%	15%	
Rainfed upland: no significant flooding		0%	45%	21%	20%	3%	
Rainfed regular (lowland): water level may rise up to 50 cm		0%	27%	12%	12%	5%	
Rainfed - drought prone (lowland): dry periods during cropping season		0%	18%	8%	8%	5%	
Rainfed - deep water (lowland): floodwater rises to more than 50cm during significant time of cropping season		0%	9%	4%	4%	2%	
Pre-season flooding							
No flooding within < 6 months before cultivation		100%	100%	100%	100%	100%	
Use of straw							
Straw incorporated shortly (<30 days) before cultivation		5%	5%	5%	5%	25%	
Straw incorporated long (>30 days) before cultivation		5%	5%	5%	5%		
Fed to animals		45%	45%	45%	45%	10%	
Burned		45%	45%	45%	45%	60%	
Other uses						5%	

The table below summarises the prices (in dollars) for the main product and co-product.

Table 11 Prices of rice and straw in Nigeria and Vietnam

	Nigeria	Vietnam
Selling price paddy rice ($/ton rice)	389.50	635.00
Value of straw ($/ton straw)	7.84	28.00
Economic allocation of rice vs straw	98.03%	95.78%

5.2.2 Processing

The processing data was provided by the CARI project, which differentiated between small, medium and large processors in Nigeria. The classification of small (yearly capacity of up to 10,000 tons of rice), medium (10,000 to 50,000 tons of rice) and large processors (>50,000 tons) is based on data from the CARI team.

For Vietnam, information was only available for the mass balance and prices of rice and its co-products (provided by the Institute for Agricultural Environment). As no literature on energy needs of rice processing was available for Vietnam, data was derived from other Asian countries. Data could be found for Bangladesh, India, and Sri Lanka, from 6 different literature sources (Ahiduzzaman & Sadrul Islam, 2009; Ariyarathna, Siriwardhana, & Danthurebandara, 2016; Kamalakkannan & Kulatunga, 2018; Kapur, Kandpal, & Garg, 1996; Roomi, Namal, & Jayasinghe, 2007; Roy, Shimizu, Okadome, Shiina, & Kimura, 2007). An average was taken from this data, which is shown in the table below. No differentiation is made for small, medium and large processors.

Water use for processing was estimated to be 1 liter per kg rice by the workshop participants, which resembles the range of 0.3-3 liters/kg rice as found in two literature sources (Ariyarathna et al., 2016; Kamalakkannan & Kulatunga, 2018).

Table 12 Life cycle inventory for the processing stage of rice

		Nigeria Small processors	Nigeria Medium processors	Nigeria Large processors	Asia Average	Comments
Number of processors		2	1	6	-	
Yearly production per processor group (ton)		8000	34000	64000	-	
Efficiency	*kg white rice/kg paddy rice*	0.58	0.6	0.64	0.6	
Economic allocation to white rice	*%*	89.4%	91.5%	94.6%	83.7%	Based on prices and mass of white rice, broken rice, bran and husk
Energy inputs						
Electricity	*kWh/kg paddy rice*	0.000	0.007	0.019	0.067	
Diesel	*liter/kg paddy rice*	0.010	0.006	0.003	0.001	
Rice husk	*kg/kg paddy rice*	0.08	0.09	0.09	0.130	
Water	*liter/kg paddy rice*	1.0	1.0	1.0	1.0	Estimation based on inputs from workshop participants and literature

5.2.3 Transport and packaging

The transport distances for Nigeria were provided by the CARI project. For Vietnam, data was partly provided by the Institute for Agricultural Environment and partly by estimating shipping distances from the main rice producing areas to the harbour (HCM), and from there to Lagos.

Transport

Table 13 Life cycle inventory for the transport stages for rice

		Nigeria	Vietnam	Comments
Transport of inputs				
Transport by big truck (>10t)	km	1000	1500	
Transport by small truck (<10t)	km	10		
Transport by motorcycle/tricycle	km	20	5	New process has been modelled, see appendix II.
Transport farm - processor				
Transport by big truck (>10t)	km	40	15	
Transport by motorcycle/tricycle	km	10		New process has been modelled, see appendix II.
Transport by barge ship	km		15	
Transport processor – end market				
Transport by big truck (>10t)	km	1000	520	
Transport by sea ship	km		17400	A 35000 deadweight tonnage (DWT) sea ship was selected, as deep-sea port (which will be able to handle ships of over 45000 DWT) is yet to be constructed in Nigeria.

Packaging

Table 14 Life cycle inventory for packaging of rice

	Unit	Material	Quantity	Comments
Packaging paddy rice	Kg/kg paddy rice	Polypropylene	0.003	Equals 10% of weight bag (0.03 kg), as it is assumed that 10% gets replaced each year
Packaging white rice	Kg/kg white rice	Polypropylene	0.03	No recycling assumed

5.3 Cashew

5.3.1 Cultivation

ComCashew provided the processing data that is listed in the table below.

Table 15 Life cycle inventory of cultivation stage for cashew

	Unit	Ghana GAP	Ghana non-GAP	Ghana All	Comments
General					
Number of farmers		459	15	474	
Yield RCN	*kg/ha*	520	257	518	
Organic amendments					
Cashew apple (fresh weight)	*kg/ha*	4209.8	1676.9	4192.0	Yield of cashew apple (=9* yield RCN) multiplied by percentage of apples left on the ground (90% for GAP, 73% for non-GAP)
Animal manure, applied by farmer	*kg/ha*	83	83	83	500 kg applied in the first 5 years
Inputs					
Herbicide	*kg/ha*	3.0	3.0	3.0	
Insecticide	*kg/ha*	1.0	1.0	1.0	
Petrol use by chainsaw	*liter/ha*	10	0.0	9.9	Applied by 60% of GAP farmers, except for the first 10 year (so 20 out of 30 years)
Diesel use by tractor		0.88	0.88	0.88	Only applied in first year (=1/30 of time), and by 65% of farmers.
Use of cashew apple					
Left on ground below trees		90%	72.5%	90%	
Sold		1%	1%	1%	
Fed to animals		2%	2%	2%	
Consumed		7%	7%	7%	
Burned (e.g. due to bush fires)		0%	17.5%	0%	Non-GAP farmers do not apply fire barriers. It is assumed that 15-20% of their farms are affected by bushfires.

The following data (from ComCashew project) was used to calculate the allocation between raw cashew nut and cashew apple:

Data point	Value
Selling RCN (GHC/kg RCN)	4.60
Percentage of cashew apple that is sold/used	10%
Value of cashew apple (GHC/kg cashew apple)	0.46
Economic allocation of cashew vs cashew apple	91.74%

5.3.2 Processing

One small processor was interviewed by the ComCashew programme. This data has been supplemented with data from a study that investigates energy needs of small, medium and large cashew processors in Nigeria (Jekayinfa & Bamgboye, 2006), assuming that conditions in both countries are similar. This classification was made based on the yearly capacity of processors, with small scale processors processing <1000 tons of RCN per year, medium scale processors 1000-10,000 tons per year, and large scale processors >10,000 tons per years (provided by ComCashew team). This data is also used for cashew processing in Vietnam, as no alternative literature source could be found. Even though Chi, Nhung, & Hung (2018) report the share of small, medium and large processors in Vietnam, they don't mention the production capacity of these processors, and hence the same data was used as for Ghana. In the sensitivity analysis it is explored what the influence would be of higher and lower processing efficiency.

Table 16 Life cycle inventory of processing for cashew

		Small processors	Medium processors	Large processors	Comments
Number of processors		6	1	1	
Yearly production per processor group	*ton RCN/year*	240	241	10000	With a yearly capacity of 500, 7000 and 35000 ton RCN for small, medium and large processors
Efficiency	*kg kernel/kg RCN*	0.20	0.20	0.20	Assumed the same for all processors
Inputs					
Electricity	*kWh/kg RCN*	0.050	0.003	0.001	
Diesel	*liter/kg RCN*	0.030	0.010	0.005	
Cashew shells	*kg fresh/kg RCN*	0.185	0.185	0.185	
Soap	*kg/kg RCN*	0.002	0.002	0.002	
Wood	*kg/kg RCN*	0.015	0.000	0.000	
Water	*liter/kg RCN*	0.001	0.001	0.001	

5.3.3 Transport and packaging

Transport

Transport data for Ghana was provided by the ComCashew project. For Vietnam, Transport 2 includes both transport within Ghana (from farm to Accra) as well as transport to and within Vietnam (to the main cashew processing areas Quy Nhom and Dong Xoai). For both scenarios, transport 3 concerns the distance from the processing locations to the harbour in Rotterdam.

Table 17 Life cycle inventory of transport stages for cashew

	Unit	Ghana	Vietnam
Transport 1			
Transport by big truck (>10t)	km	400	n/a
Transport by motorcycle/tricycle	km	30	n/a
Transport 2			
Transport by big truck (>10t)	km	330	630
Transport by motorcycle/tricycle	km	30	30
Transport by sea ship	km		17400
Transport 3			
Transport by big truck (>10t)	km	225	300
Transport by sea ship	km	7700	16700

Packaging

Table 18 Life cycle inventory of packaging for cashew

	Unit	Material	Quantity	Comments
Packaging RCN	Kg/kg RCN	Jute bags (kg)	0.00125	Equals 10% of weight bag (0.0125 kg), as it is assumed that 10% gets replaced each year
Packaging cashew kernel	Kg/kg cashew kernel	Polyethylene (kg)	0.02	No recycling assumed

6. Life Cycle Impact Assessment (LCIA)

In this section the environmental impact results for the cashew and rice value chains are presented. The LCA software SimaPro 9.0 and the LCIA method ReCiPe 2016 Midpoint have been used to determine the impact for the five selected environmental impact categories: global warming, terrestrial ecotoxicity, land use, fossil resource scarcity and water consumption. As explained in more detailed in Appendix I, midpoints allow to calculate in a relative way what the environmental impact of a certain stressor is, such as its global warming potential.

6.1 Rice

Table 19 and Figure 14 show the absolute and relative results for the selected environmental impact categories.

Table 19 Environmental impact category results for the 5 rice scenarios, for 1kg of white rice. Please note that the average is the weighted average of CARI farmers.

Impact category	*Unit*	*Irrigated*	*Rainfed*	*Irrigated & Rainfed*	*Average CARI*	*Vietnam*
Global warming (excl. LUC)	*kg CO_2 eq*	1.487	1.215	1.374	1.375	2.601
Fine particulate matter	*kg PM2.5 eq*	0.011	0.012	0.012	0.012	0.014
Land use	*m^2a crop eq*	1.259	2.106	1.540	1.537	1.789
Fossil resource scarcity	*kg oil eq*	0.192	0.201	0.195	0.195	0.279
Water consumption	*m^3*	0.453	0.007	0.305	0.306	0.244
Water scarcity index	*m^3*	0.137	0.005	0.093	0.094	0.088

The results show that when it comes to climate change impact, rainfed rice in Nigeria has a lower impact than irrigated rice. The impact of the farmers that combine rainfed & irrigated production, lies in between these two. The average group is similar to those farmers that apply both irrigated and rainfed production, as there are almost an equal amount of farmers that apply only irrigation or only rainfed production (see life cycle inventory). The rice produced in Vietnam has the highest climate change impact. In the contribution analyses it will be examined to what life cycle stage these differences can be attributed.

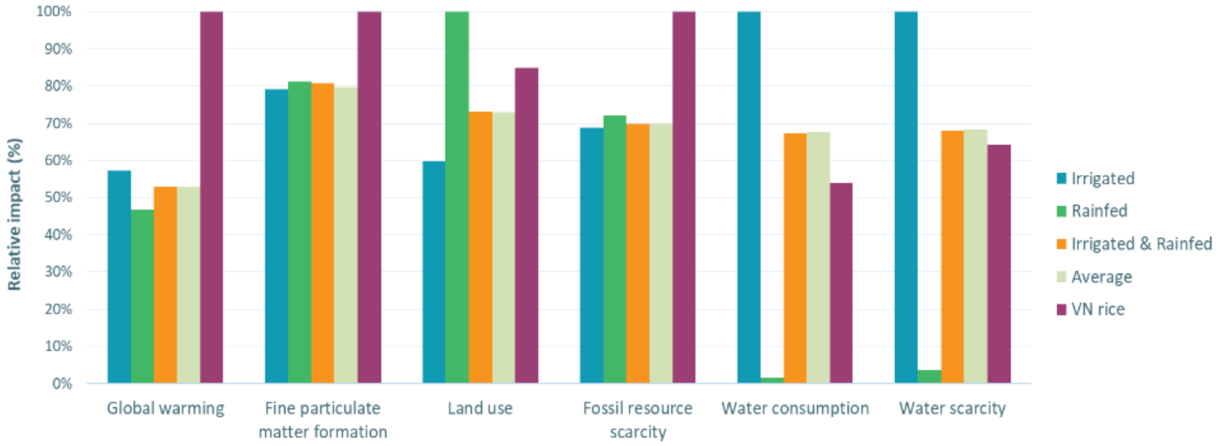


Figure 14 Relative impact category results for the 5 rice groups. Please note that the average is the weighted average of CARI farmers.

According to the ISO/TS 14067 (ISO, 2013) and the latest PEF guidance of the European Commission (Commission, 2018) the carbon emissions due to land use change should be reported separately. Land use change is covered in the sensitivity analysis, section 7.2.2. Ecotoxicity is also discussed in the sensitivity analysis, where several different toxicity-related impact categories are compared.

6.2 Cashew

The results of the environmental impact indicators for cashew are shown in Table 20 and Figure 15.

Table 20 Environmental impact category results for the 4 cashew scenarios. Please note that the average is the weighted average of GAP and non-GAP farmers.

Impact category	*Unit*	*GAP*	*non GAP*	*average*	*VN processing*
Global warming	*kg CO_2 eq*	2.204	2.556	2.205	3.156
Fine particulate matter	*kg PM2.5 eq*	0.008	0.012	0.008	0.012
Land use	*m^2a crop eq*	77.232	156.130	77.470	77.470
Fossil resource scarcity	*kg oil eq*	0.398	0.460	0.398	0.662
Water consumption	*m^3*	0.014	0.024	0.014	0.014

Overall, the cashew that is grown with good agricultural practices (GAP) has the lowest impact for all environmental impact categories. The average group is very close to this as it consists of 459 farmers, whereas only 15 farmers are included in the non-GAP group.

The cashew that is processed in Vietnam has the highest impact in the global warming and fossil resource scarcity impact categories. The non-GAP group has highest impact in terrestrial ecotoxicity and land use impact categories as a result of low yields.

Since the land use change tool indicated there is zero LUC emissions associated to cashew in Ghana, this has been left out from above table.

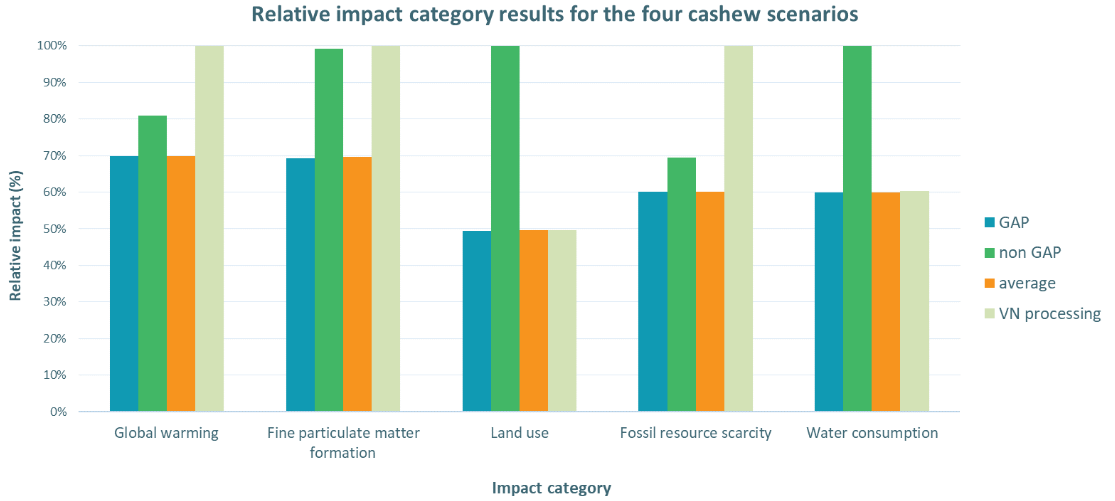


Figure 15 Relative impact category results for the four cashew scenarios. Please note that the average is the weighted average of GAP and non-GAP farmers.

Ecotoxicity has not been included as no information was available on the type of active ingredients, and the same amount and type of pesticides are applied for all cashew scenarios, so a comparison is not very relevant. However, it should be noted that, like with other impact categories, non-GAP cashew has a higher impact for ecotoxicity because of the lower yield.

Water consumption is almost negligible, and is mostly related to the production of inputs (and thus could not actively be reduced by the project). As water scarcity is closely linked to water consumption, and will also be very low, it has been left out of the analysis. It should be noted that also no irrigation is applied to crops that are grown in between the cashew trees, it only concerns rainfed agriculture.

7. Interpretation

In this section the impact results are interpreted by assessing what elements of the cashew and rice value chains contribute most to the outcome (contribution analysis), and how sensitive the outcome is (sensitivity analysis).

7.1 Consistency & completeness check

As noted earlier, in order to guarantee an equal comparison between production systems in Asia and Africa, the same type of data was collected for both regions. In this way, the environmental impact categories are determined in the same way, which leads to more accurate results than if one would only calculate the environmental impact for one country based on primary data, and compare it to a value from literature for the other country.

For rice production in Vietnam for example, a lot of literature is available including field measurements of methane emissions during rice cultivation. However, to ensure consistency and comparability to Africa, the same IPCC Tier 1 methodology is applied, using baseline emission factor for South East Asia, combined with average activity data on irrigation types. The resulting impact for Vietnam were compared to the actual field measurements from literature, and proofed to be comparable.

Furthermore, it should be noted that LCA studies and methodologies mostly originate from developed countries. To best meet the conditions of African and Asian countries, as much as possible LCA processes have been used that represent their specific conditions. For electricity, national datasets were available for Ghana, Nigeria and Vietnam from Ecoinvent. For materials, like packaging, Ecoinvent processes with a global scope have been used. Transport in Africa is similar to that in other countries, but to reflect a possible older age of vehicles, euro 3 has been selected.

Assumptions, methods and models in the elaboration of this LCA are as much as possible in line with the goal and scope formulated. To showcase important aspects to be considered regarding the consistency in this report, all data has been checked based on the following criteria:

Table 21 Consistency & completeness check

	Rice	Cashew
Data sources	For Nigeria, primary data is provided by the CARI project For Vietnam, data is provided by the IAE based on their internal knowledge/ statistics on rice production combined with literature (rice production in Asian countries is well-researched). Water use during cultivation was for both countries based on the same database. It was ensured that exactly the same data points were collected to ensure an equitable comparison and emission calculations.	Data for cultivation in Ghana was based on available data from CARI's monitoring & evaluation system. Due to lack of data availability on cashew processing in Ghana, this is supplemented by literature sources (from Nigeria), which were also used for cashew processing in Vietnam. The uncertainty associated with this is assessed in the sensitivity analysis.
Data coverage	For both Nigeria and Vietnam, collected data covers all relevant stages associated with the cradle-to-distribution scope. For both countries, the same data points were collected: • Cultivation: input use (agrochemicals, organic inputs), energy use, cultivation and water management practices, rice straw burning • Transport to processing	For both Ghana and Vietnam, collected data covers all relevant stages associated with the cradle-to-distribution scope. For both countries, the same data points were collected: • Cultivation (only Ghana): input use (agrochemicals, organic inputs), energy use, cultivation and water management practices, bush burning

	- Processing: mass balance, prices of co-products, energy use, rice straw burning, material and water use - Packaging material - Transport to market	- Transport to processing - Processing: mass balance, prices of co-products, energy use, material and water use - Packaging material - Transport to market
Sample size	Nigeria: for cultivation, data is available for a large number (>1000) of farmers through CARI's monitoring & evaluation system. For processing, data was collected for 9 processors. Vietnam: IAE provided detailed cultivation data. For processing, however, no data was available and this was obtained from literature from multiple surrounding rice-producing countries (6 literature sources).	Ghana: for cultivation, data was available for a large number (>1000) of farmers through ComCashew's monitoring & evaluation system. For processing, only 1 processor was interviewed, and data was supplemented with values from literature (from Nigeria) Vietnam: since no data on cashew processing was available, this was based on the same literature source. The uncertainty associated with this is analysed in the sensitivity analysis.
Temporal representativeness	For both Nigeria and Vietnam, data is less than 5 years old, with the exception of rice processing data for Vietnam, which is based on an average of several literature sources that are between 3-15 years old.	Cultivation data originates from 2018/2019. Data on processing is largely based on a publication that originates from 2006.
Geographical representativeness	For cultivation, the collected data represents average conditions in both countries very well. For processing in Vietnam, literature from surrounding countries was used, which have similar conditions as Vietnam.	For processing, no or little data was available for both Ghana and Vietnam, and the only literature source available relates to Nigeria. The uncertainty associated with this is analysed in the sensitivity analysuis.

7.2 Rice

7.2.1 Contribution analysis

A contribution analysis allows observing the influence of the different processes on the impact results. In this case, it helps to understand what the relative contribution of value chain stages is in relation to the overall environmental impact of the value chain. This allows to pinpoint 'hotspots', that are responsible for a large share of the overall impact.

As land use and ecotoxicity are for over 95% determined by the cultivation stage, these are excluded from the contribution analysis for both cashew and rice value chains. For rice, this applies for water as well.

Climate change

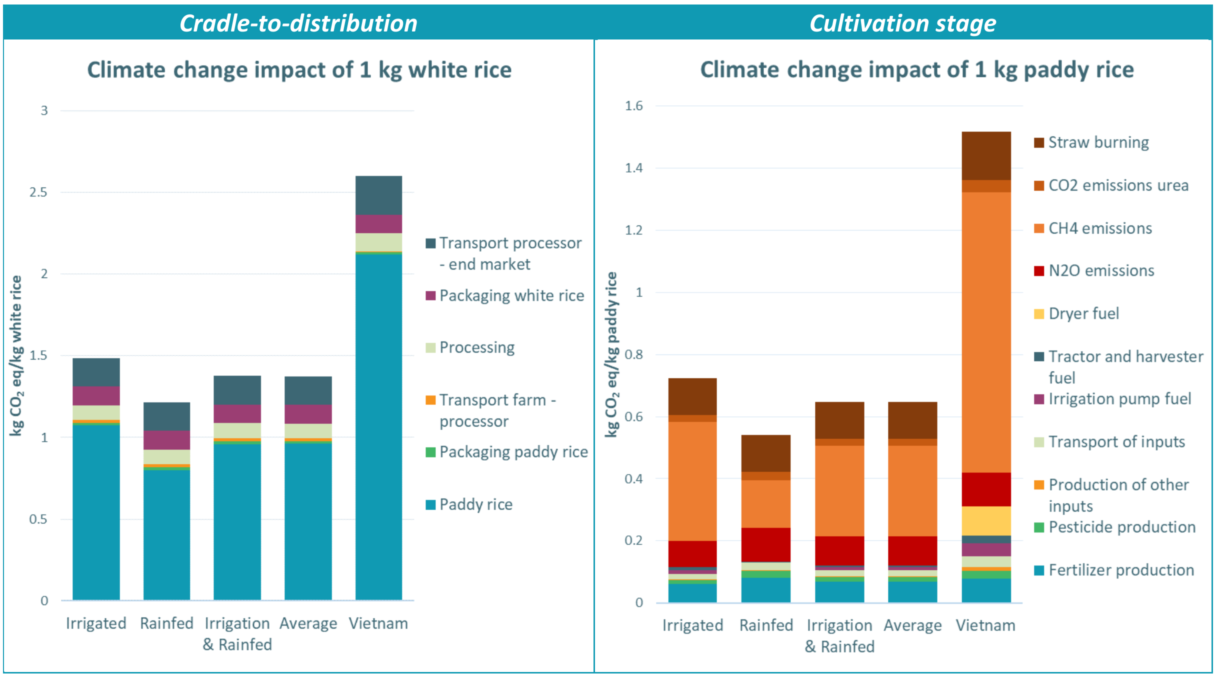


Figure 16 Climate change impact for cradle-to-distribution stages (1 kg white rice), and cultivation stage (1 kg paddy rice) of rice

The figure above differentiates between the climate change impact for the whole rice value chain (expressed as 1 kg white rice), and for the cultivation stage only (expressed as 1 kg paddy rice). The graphs show that the cultivation stage is responsible for the largest share of the impact, and this is mainly caused by methane emissions. The methane emissions are influenced by the water regime and local climate conditions, with rainfed rice in Nigeria having lowest emissions, and the irrigated rice in Vietnam having highest emissions. The largest share of rice in Vietnam (about 85%) is irrigated, and 83% of the irrigated rice is characterised by continuous flooding and single drainage, which contribute to higher emissions. In Nigeria on the other hand, 70% of the irrigated rice is produced using multiple drainage, which significantly lowers methane emissions.

After methane, straw burning results in highest emissions. Even though the carbon dioxide emissions are biogenic, the combustion of straw also results in methane and dinitrogen oxide emissions, which contribute to the relatively high impact.

When it comes to the processing stage, a differentiation can be made between, small, medium and large processors. As the large processors process the majority of all rice, the average value for processing is largely determined by this group of processors. The burning of rice husk, either for heating, or as waste, is responsible for the largest share of the carbon footprint at processing level.

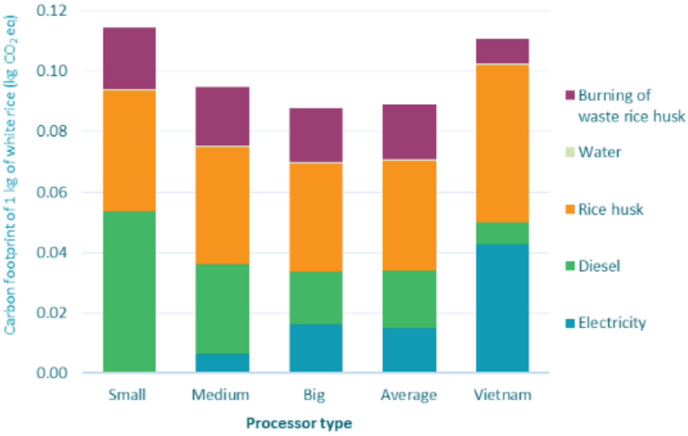


Figure 17 Climate change impact for the different processing types

Fossil resource scarcity

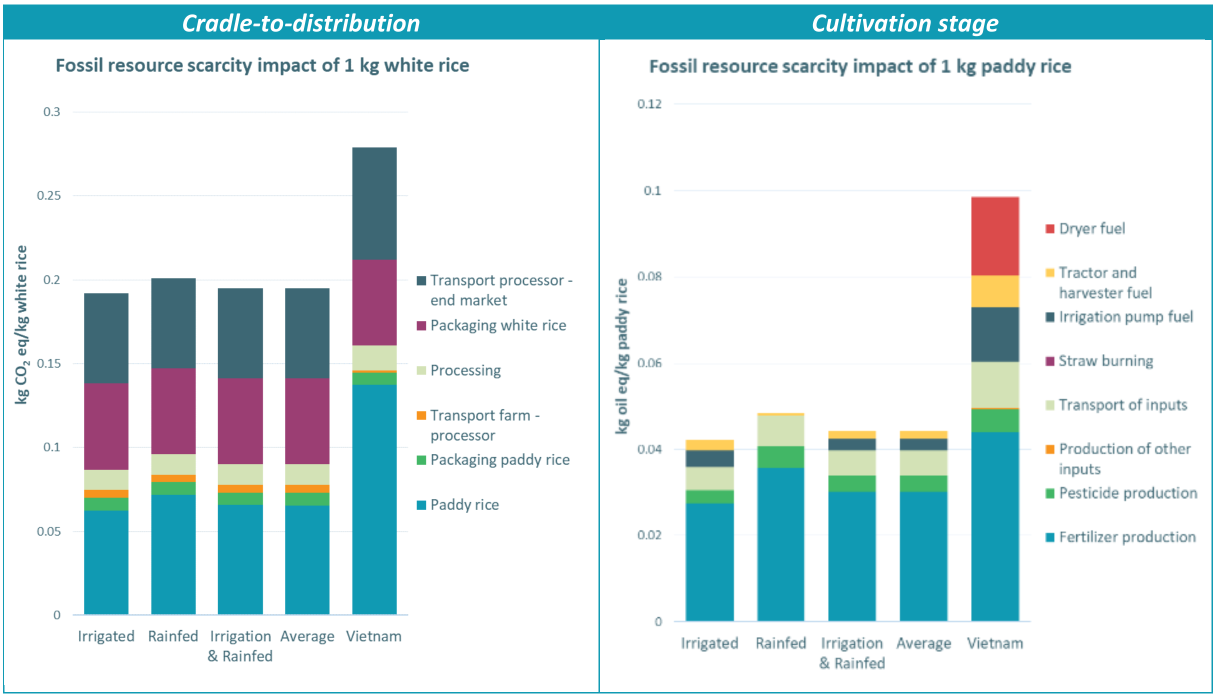


Figure 18 Fossil resource impact for cradle to distribution stages (1 kg white rice), and cultivation stage (1 kg paddy rice) of rice

Also for fossil resource scarcity, the cultivation stage is responsible for the largest share of the impact. This is mainly caused by the production of fertilizers. The dryer that is used in Vietnam to dry the grains after harvest, uses coal (along with electricity), which contributes to a relatively high impact. The plastic that is used to pack the rice, as well as the transport to the final destination (Lagos), also uses up a significant amount of fossil resources.

Fine particulate matter formation

As can be seen in the two figures below, fine particulate matter formation is mainly caused by straw burning during the cultivation stage, and to a lesser extent by the burning of rice husk during processing.

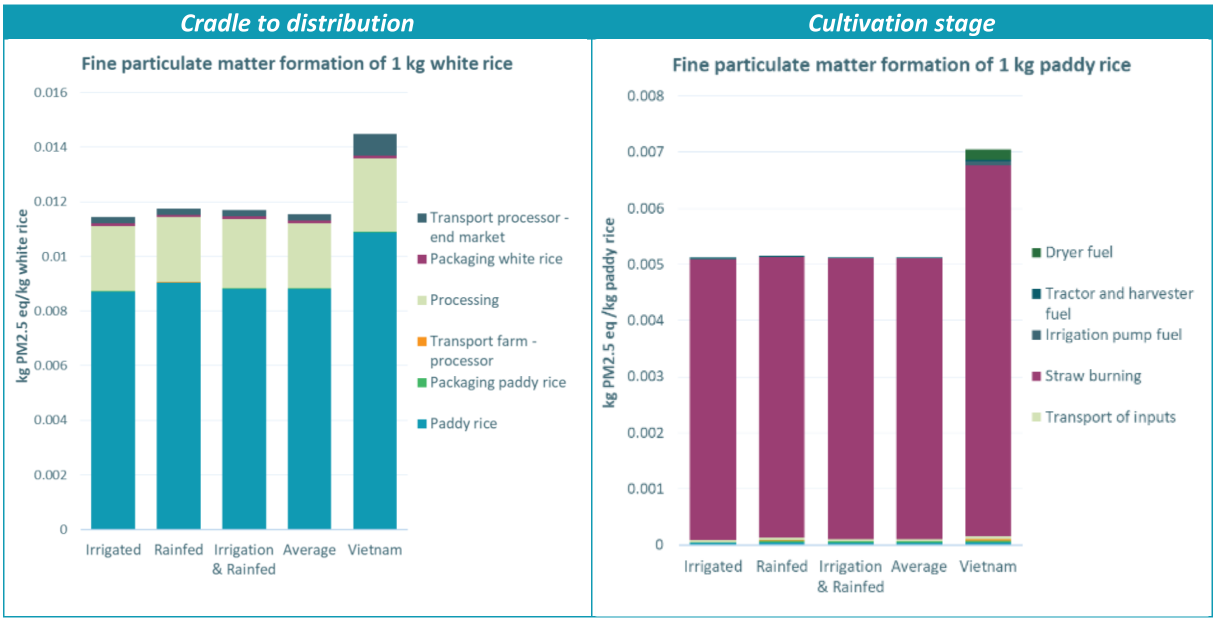


Figure 19 Fine particulate matter formation impact for cradle to distribution stages (1 kg white rice), and cultivation stage (1 kg paddy rice) of rice

7.2.2 Sensitivity check

7.2.2.1 Uncertainty analysis

An uncertainty analysis was carried out with SimaPro, focusing on those datapoints that are most sensitive to year-to-year fluctuations and/or that were based on literature:

- Yields
- Prices
- Water use

The SimaPro pedigree function was used to assess the uncertainty value, which is calculated based on whether the data concerns an estimate, whether it is representative (geographical and temporal), what the sample size is etc. Yields and prices (and related allocation) were based on primary data, but can have high year-to-year fluctuations. Water use was based on literature, which used hydrological models, and could deviate significantly from field data (which was not available). This is why relatively high uncertainty values were assigned to yields, prices and water use. Also data on processing in Vietnam received relatively high uncertainty values as it was based on literature from surrounding countries.

For all other activity data (and emissions) the basic uncertainty value was used, to reflect generic uncertainties in activity data as well as background datasets.

The outcome for the 5 key indicators is depicted in the figures below. The error bars represent the 95% confidence interval. For global warming, fine particulate matter formation and fossil resource scarcity, the error bars of the average CARI rice and the Vietnamese rice don’t overlap, which means that the results are significantly different.

For land use however, there is a small chance that Vietnamese rice has a lower impact than the Nigerian rice. For water consumption, there is even an 80% chance that the Vietnamese rice has a lower environmental impact than the rice from CARI farmers. This can be derived from Figure 21.

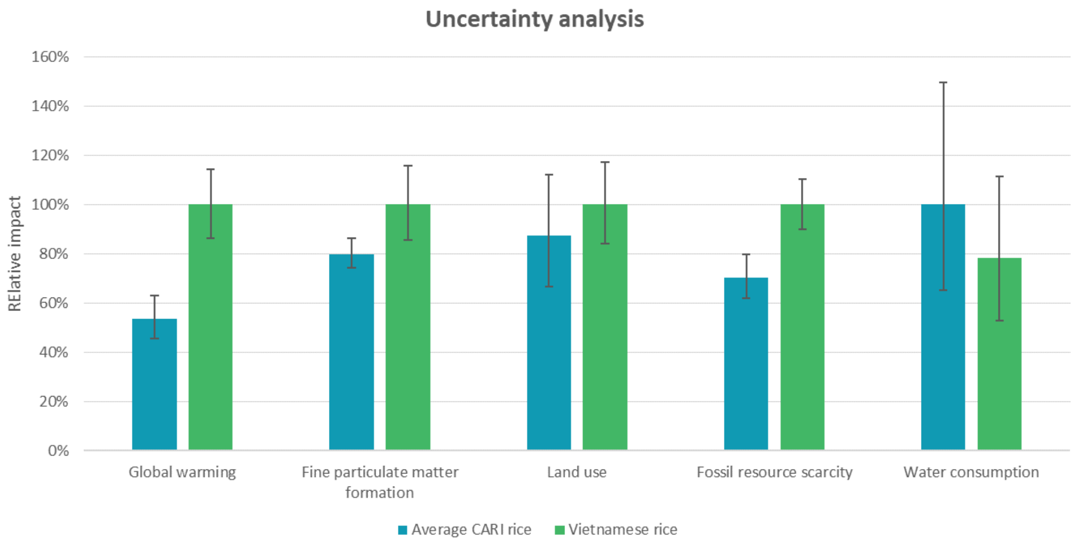


Figure 20 Uncertainty analysis for average Nigerian rice from CARI farmers, and the average Vietnamese rice. Error bars represent the 95% confidence interval.

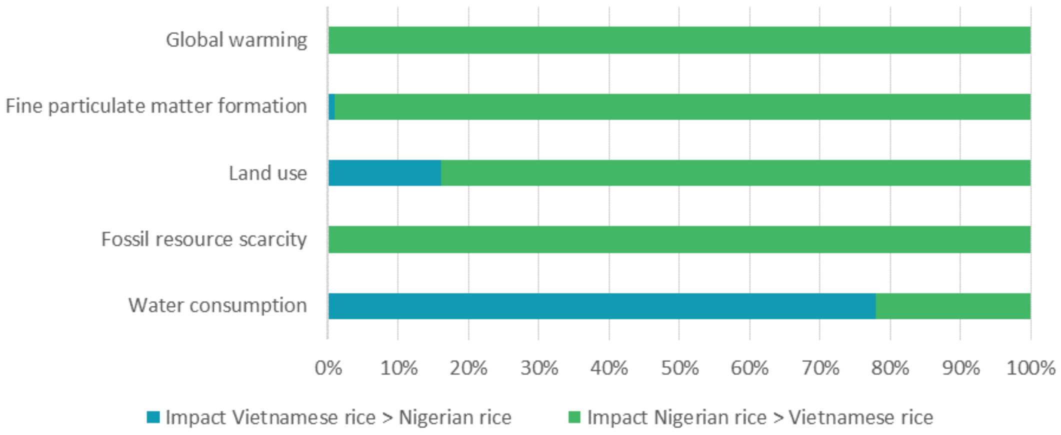


Figure 21 Uncertainty analysis, representing the Vietnamese rice minus the Nigerian rice. The percentages show the chance that one has a higher impact than the other.

7.2.2.2 Sensitivity analysis - Land use change

According to the Direct Land Use Change Assessment Tool (Blonk Consultants, 2018), land use change in Nigeria is considerable, with an average impact of 6750 kg CO_2 eq/ha. When considering the impact per kg rice, the LUC impact varies with the yield, but is in all cases higher than the footprint of the rice itself, see Table 22 and Figure 22Figure 22 Carbon footprint of 1 kg white rice, including land use change (LUC). For Vietnam, the land use change associated with rice is zero according to the same tool.

Table 22 Climate change impact of rice, with and without land use change (LUC)

Impact category	*Unit*	*Irrigated*	*Rainfed*	*Irrigated & Rainfed*	*Average CARI*	*Vietnam*
Global warming (excl. LUC)	*kg CO_2 eq*	1.487	1.215	1.374	1.375	2.601
Global warming (LUC only)	*kg CO_2 eq*	1.573	2.633	1.925	1.922	0
Global warming (incl. LUC)	*kg CO_2 eq*	**3.060**	**3.848**	**3.299**	**3.297**	**2.601**

For irrigated rice, adding up the LUC impact leads to a doubling of the carbon footprint, and for rainfed rice, to a threefold increase. It should be taken into consideration, that the LUC as derived from the tool is not sensitive to site-specific conditions, as it uses country-level averages for the expansion of deforested areas and rice areas. In Nigeria, deforestation is mostly occurring in tropical forests in southern Nigeria, whereas in northern Nigeria, where the rice is cultivated, the natural vegetation concerns savanna. Even if the sparsely vegetated savanna is deforested, this would result in a much lower release of carbon than deforestation of tropical rainforest.

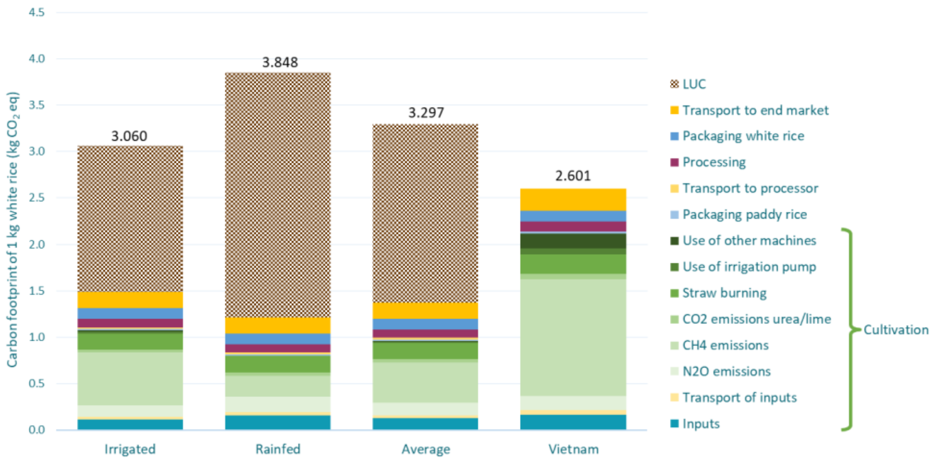


Figure 22 Carbon footprint of 1 kg white rice, including land use change (LUC)

7.2.2.3 Sensitivity analysis - Ecotoxicity

Ecotoxicity has been investigated for freshwater, terrestrial and marine compartments. Figure 23 shows the impact for these three categories. When compared to average Nigerian rice, rice from Vietnam has a higher impact for all categories. Rainfed rice however, has a higher impact when it comes to terrestrial and marine ecotoxicity, as a result of lower yields.

The figures clearly show the effect of the different active ingredients from pesticides. Cypermethrin and Lambda-cyhalothrin, two insecticides belonging to the class pyrethroids, contribute to most of the impact for freshwater and marine ecotoxicity in Nigeria.

The insecticide chlorpyrifos, only used in Vietnam, has a relatively high impact for all ecotoxicity impact categories.

For terrestrial ecotoxicity, vanadium has a relatively high impact, and is mainly released by open burning of plastic bags (packaging of rice). It was assumed that half of the bags is burned, and the remainder is going to a dump or landfill.

The herbicide glyphosate, which is in terms of quantity the most applied pesticide in Nigeria, has a relatively low impact in all categories.

It should be kept in mind that some assumptions and estimations were necessary to obtain pesticide types and quantities (see also Appendix II), which means that the results are not very accurate, and just an approximation of ecotoxicity levels.

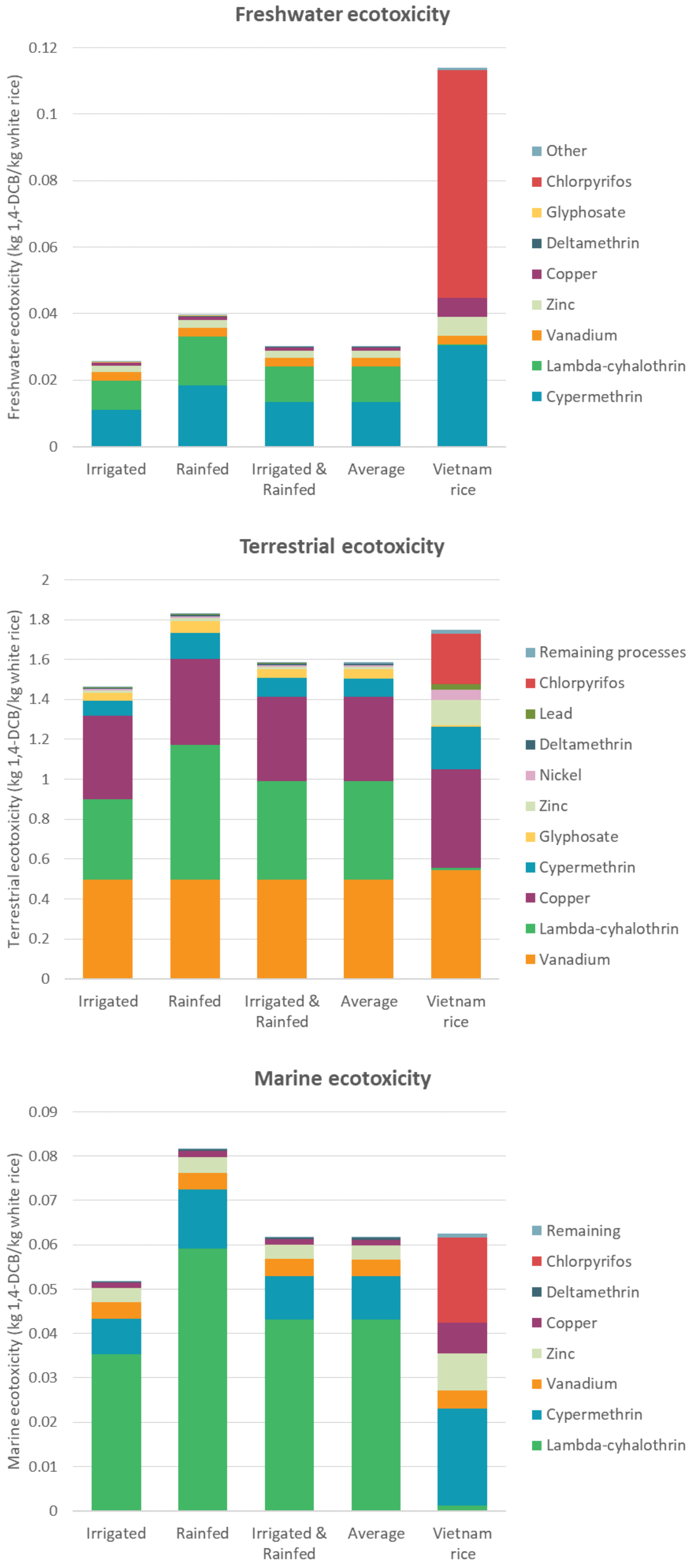


Figure 23 Ecotoxicity impact categories

7.2.2.4 Sensitivity analysis - Burning of diesel vs rice husk

Rice husk serves as an alternative to diesel as fuel for the machinery used in rice processing. To assess the environmental impact of both fuel types, they are compared based on the amount of diesel and rice husk necessary to provide 1 MJ of energy.

1 kg of rice husk has an average energy content (or heating value) of 14.5 MJ/kg (IRRI, 2020; Mhilu, 2014; Quispe, Navia, & Kahhat, 2017), which means that 0.0656 kg of rice husk is needed to generate 1 MJ of energy. Diesel on the other hand, has an energy content of 45 MJ/kg (based on Ecoinvent process), which means that only 0.0222 kg is needed to produce 1 MJ.

With these data, the environmental impact is calculated of combusting diesel and rice husk. The table and graph below show that using rice husk as fuel has an 88% lower carbon footprint than using diesel. Fine particulate matter formation, however, is 88% higher for rice husk. The fossil resource scarcity impact for rice husk is negligible when compared to diesel.

Table 23 Impact results for combustion of diesel and rice husk

Impact category	*Unit*	*1 MJ Diesel*	*1 MJ rice husk*
Global warming	kg CO2 eq	0.19090	0.02352
Fine particulate matter formation	kg PM2.5 eq	0.00046	0.00087
Fossil resource scarcity	kg oil eq	0.05230	0.00038

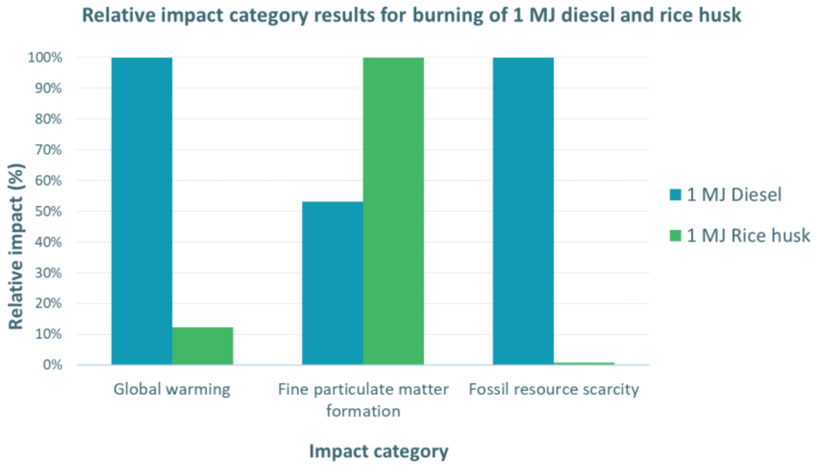


Figure 24 Relative impact category results for combustion of diesel and rice husk

7.2.2.5 Sensitivity analysis - Different applications of straw

The use of rice straw has a significant impact on methane emissions. To see what the effect would be of different rice straw management practices, four scenarios where investigated: 1) incorporating the straw into the soil long (>30 days) before the start of cultivation, incorporating the straw short (<30 days) before the start of cultivation, burning all the rice straw, or removing it entirely from the field. The average rice producer was taken as starting point, and it was assumed that all of the rice straw was used.

As shown in the figure below, incorporating straw into the soil short before cultivation leads to a 38% higher carbon footprint of white rice than incorporating it long before cultivation. The scenario in which all straw is incorporated long before cultivation has a similar footprint to the average rice producer. The average rice producer incorporates straw partly long and partly short before cultivation, however incorporates a smaller quantity (5% long, 5% short), burns a large share (45%) and feeds a large share to animals (45%).

Removing the straw from the field (and using it for other purposes), leads to the lowest emissions. Note that what happens with the straw elsewhere is not considered. It is also not considered that less nutrients are provided to the soil when removing the straw, which could lead to lower yields – and thus a higher footprint.

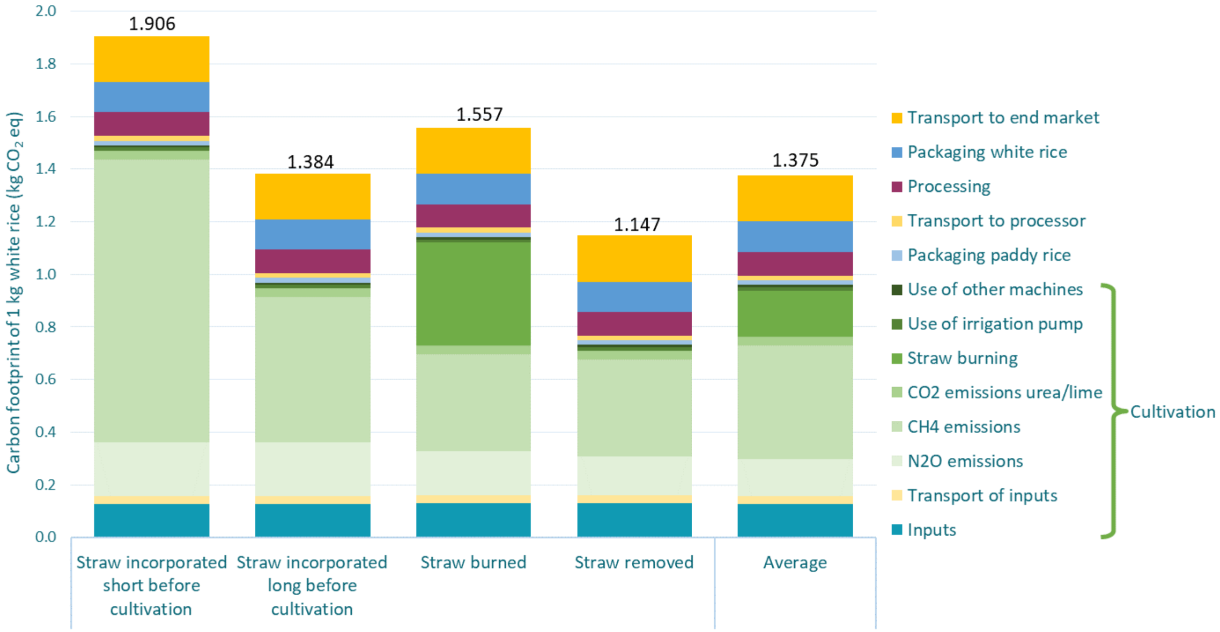


Figure 25 Carbon footprint of different uses of rice straw

7.2.2.6 Sensitivity analysis - Organic vs. synthetic fertilizer

The study investigated which of the following two scenarios leads to a higher carbon footprint: using organic amendments or synthetic fertilizers to provide nitrogen to the rice crops.

For both scenarios, 100 kg of nitrogen was considered. For synthetic fertilizer scenario, similar fertilizers were selected as for the average farmer. For the organic scenario, it was assumed that all straw is incorporated (long before cultivation), and that the remainder of the nitrogen is provided by a combination of animal manure, compost and green manure. The quantities are listed in the table below.

Table 24 Organic and synthetic fertilizers that provide 100 kg of nitrogen

	N content (%)	*Quantity (kg)*	*Total N (kg)*
Nitrogen provided by synthetic fertilizers			
NPK compound (NPK 15-15-15)	15.00%	200	30.00
Urea, as 100% CO(NH2)2 (NPK 46.6-0-0)	46.60%	150.2	70.0
Total			**100.0**
Nitrogen provided by organic amendments			
Straw (in dry weight (= freshweight *0.89))	0.70%	5000	35.0
Animal manure, applied by farmer	0.71%	5330	37.8
Animal manure, from grazing	0.71%	500	3.6
Compost	0.58%	2000	11.6
Green manure	0.60%	2000	12.0
Total			**100.0**

As can be seen in the figure below, the use of only organic amendments to provide nitrogen leads to highest emissions, as result of the methane that is emitted through anaerobic decomposition. The synthetic scenario has higher emissions for inputs and straw burning, but has lower overall emissions.

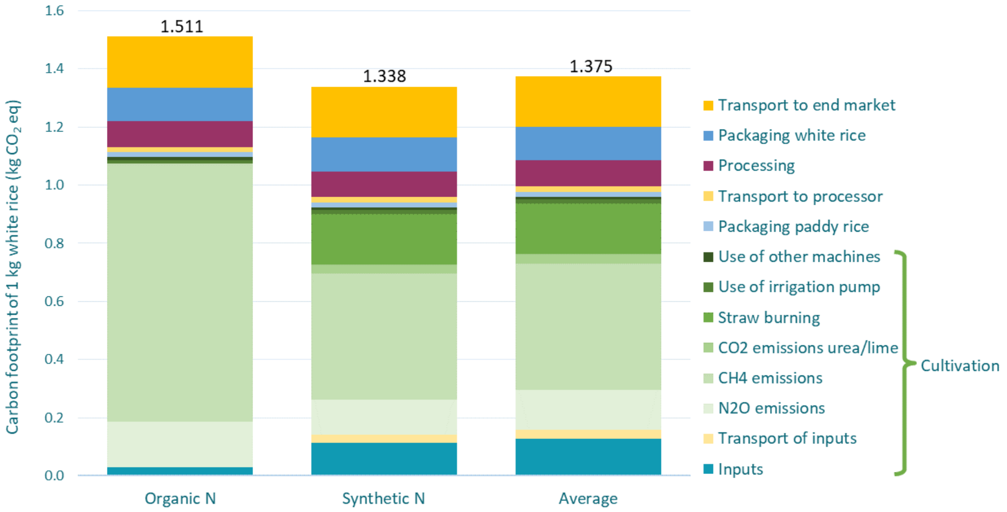


Figure 26 Carbon footprint for rice that has been cultivated with organic amendments (Organic N) or synthetic fertilizers (Synthetic N), both providing 100 kg N/ha

7.2.2.7 Sensitivity analysis - Different baseline emission factor for methane

As has been elaborated in the methodology (4.6.2.1), a specific baseline emission factor has been calculated for Africa based on two African studies, as there was no value available in the IPCC guidelines. These guidelines suggest using the global average baseline factor, which is 1.19. The emission factor that was calculated in this report is 0.79. For Vietnam, a regional specific baseline factor was available, which was 1.22 (South East Asia).

The impact of using the global average baseline emission factor was assessed, for both methane emissions and the overall carbon footprint of the rice. When using this global baseline emission factor, methane emissions increase by 51%. The figure below shows that the overall footprint increases by 19% for irrigated rice, 6% for rainfed rice, and 16% for the average rice. The footprints for Nigerian rice however still remain much lower than the footprint of rice imported from Vietnam.

This shows the importance of performing more actual measurements of methane from rice fields in Africa, as methane emissions depend quite a lot on conditions specific to the climate, soils and ecosystem of a certain region.

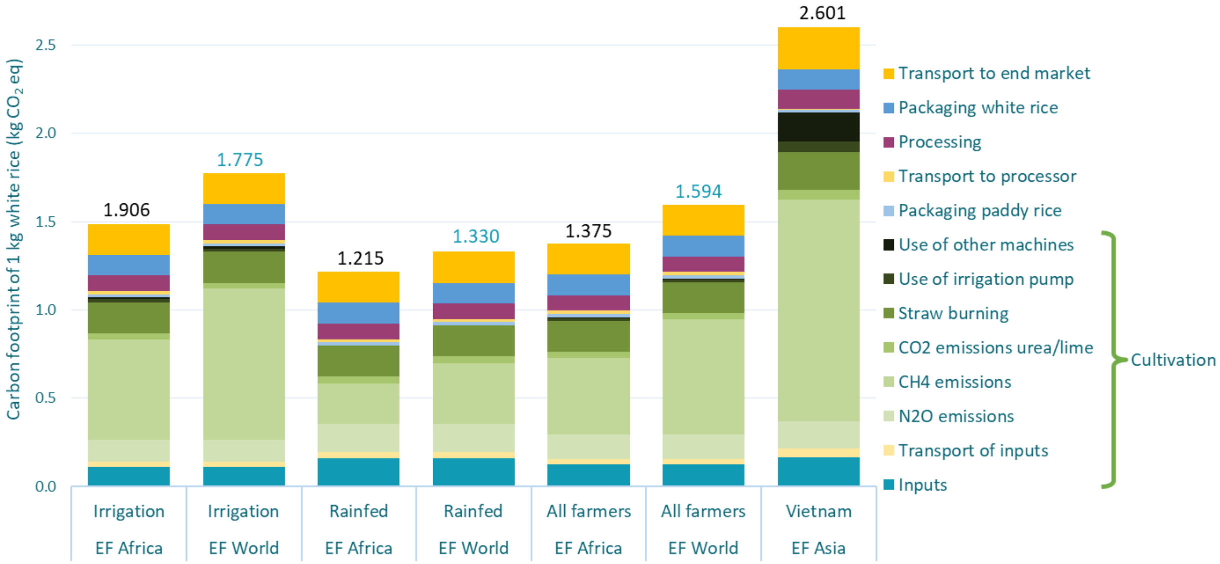


Figure 27 Carbon footprint for the different rice groups calculated with baseline emission factor for Africa (EF Africa) and with world average baseline emission (EF world)

Contrary to Africa, a lot of methane and nitrous oxide measurements have been performed in Asia, and even in Vietnam alone. To see whether the calculations using IPCC guidelines are similar to those measured in the field, relevant studies that could be derived from the internet are listed in Table 25 below. As can be seen in the table, the methane emissions show quite a big range, as most studies performed measurements for different management practices (e.g. continuous vs. single/multiple drainage). The methane emissions from this study are on the lower side compared to those found in literature. Nitrous oxide emissions from this study seem to be average if compared to values found in literature.

Table 25 Methane and nitrous oxide emissions in Vietnam based on calculations in this study and literature

Study	Emissions
	CH_4 emissions (kg CH_4/ha)
This study	145
Sandin, 2005	83 - 220
Tariq et al., 2017	36 - 749
Tran et al., 2018	401 - 542
Trang et al., 2019	198 – 380
	Direct N_2O emissions (kg N_2O/ha)
This study	1.18
Tariq et al., 2017	0.1 - 2.0
Tran et al., 2018	0.2 - 0.7
Trang et al., 2019	1.3 - 1.7

7.2.2.8 Sensitivity analysis - Influence of grain storage

Since it is likely that part of the rice from Vietnam is stored for some months before it is shipped to Nigeria, it is investigated what the environmental impact of grain storage would be. According to the IRRI website (IRRI, n.d.), storage in silos is not very common in Asia, and the rice is most likely stored in bags in granaries.

Those stores can be filled with gaseous pesticides (also called fumigants), to get rid of pests. Methyl bromide is a common pesticide used for fumigation of stored rice. About 36 g of methyl bromide is necessary for 1 tonne of rice (FAO, 1994). According to this publication, store fumigation (fumigating the entire content of a store instead of individual bags) is most common practice is South East Asia. The fumigants are usually applied by using sprayers, but an also be applied in solid form which reacts with the air. No information could be found on the use of electricity or other types of energy for this. Therefore, general energy data for grain storage, as also applied in Agri-footprint, has been used. It concerns energy for drying to avoid spoilage during storage, which amounts to 17,09 MJ of electricity and 512.66 MJ of process steam per 1 ton of grain. Likely this is an overestimation of actual energy use for rice, but is still used as approximation. The figure below shows the impact of the energy consumption for storage, which results in a 2.8% higher carbon footprint for the rice at distribution.

In terms of carbon footprint, the application of fumigant is negligible, as it is such a small amount (36 mg /kg rice). Also for ecotoxicity, the small quantity didn’t lead to a change in impact. It does however have an impact on the impact category human non-carcinogenic toxicity, which increased from 0.389 to 0.402 kg 1,4-DCB. Note that human carcinogenic and non-carcinogenic toxicity was not taken into account for ecotoxicity, as this is not linked to pesticide use, but other processes, such as burning of plastic waste.

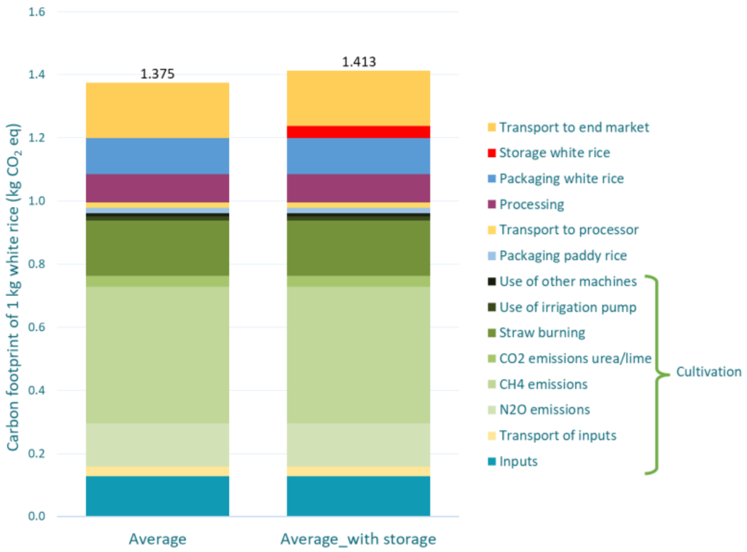


Figure 28 Carbon footprint of 1 kg of white rice, excluding and including storage in Vietnam

7.3 Cashew

7.3.1 Contribution analysis

Climate change

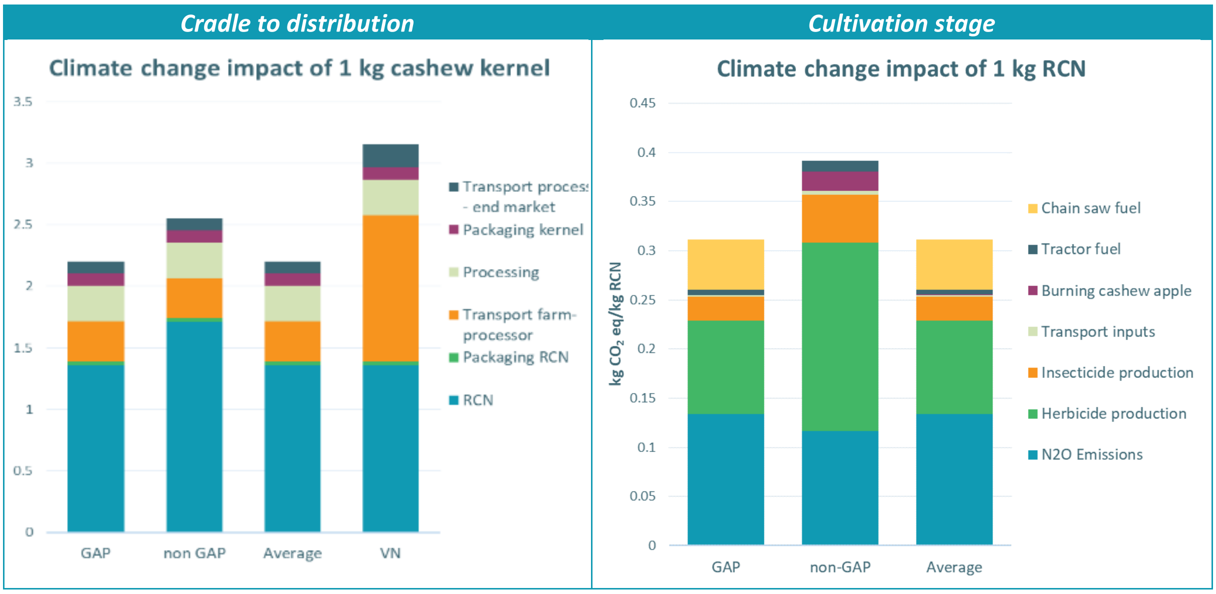


Figure 29 Climate change impact for the cradle-to-distribution stages (1 kg cashew kernel), and cultivation stage (1 kg RCN) of cashew

The figure shows that cultivation is the value chain stage that contributes most to the climate change impact, followed by transport to the processor and processing. For the fourth scenario, the transport has a considerably higher carbon footprint, as it concerns transport of the RCN from Ghana to Vietnam.

Figure 30 depicts the climate change impact for the different processing types. As the vast majority of raw cashew nuts in Ghana is processed by large processors, the average is close to this group of processors. The same processing data has been used for Vietnam (though with electricity mix specific to Vietnam), hence the same average level. It should be noted that all processing data is based on Nigerian processors (except for the small processor), and could therefore not be representative for Ghanaian and Vietnamese conditions. It could for example be that processing in Vietnam is in reality more efficient because of higher use of electricity.

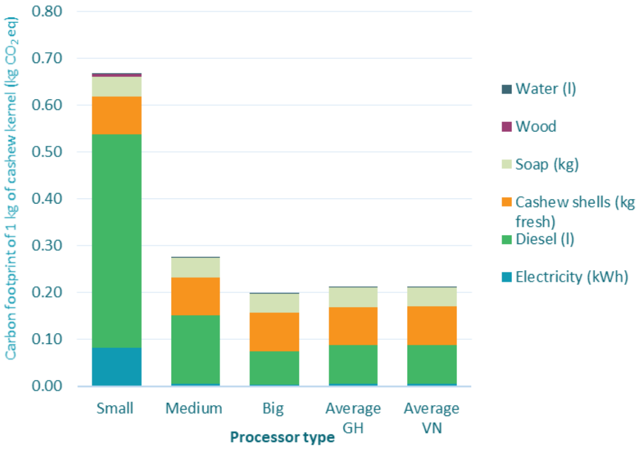


Figure 30 Climate change impact for different cashew processors

Fossil resource scarcity

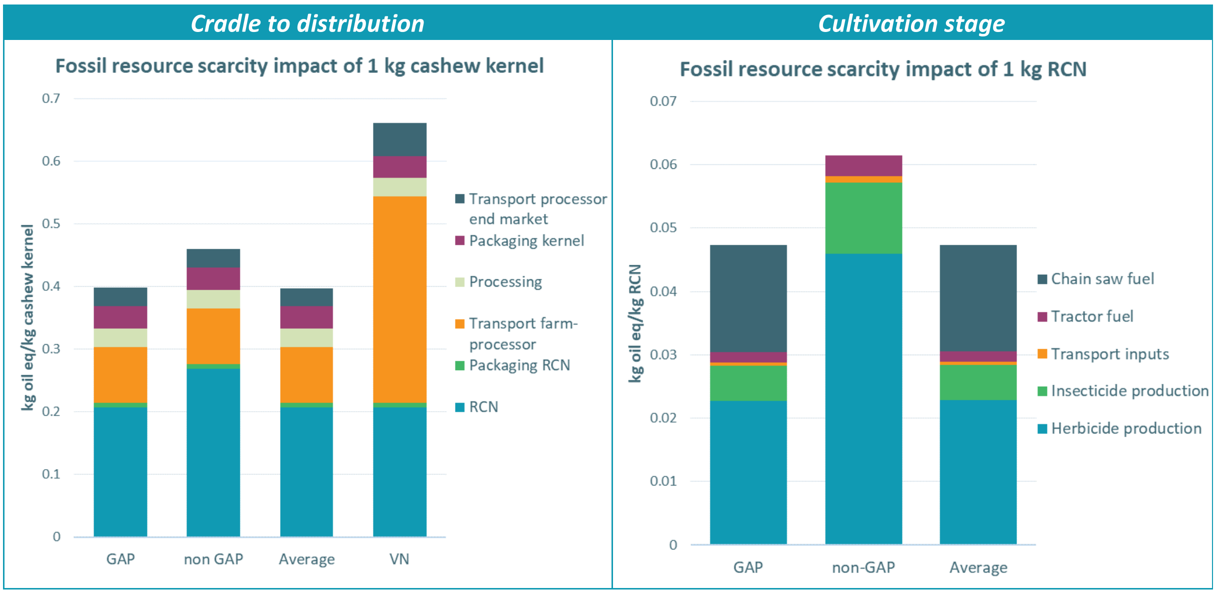


Figure 31 Fossil resource scarcity impact for the cradle-to-distribution stages (1 kg of cashew) and cultivation stage (1 kg RCN) of cashew

When it comes to fossil resource scarcity, the largest share of the impact is also attributable to the cultivation stage, except for the fourth scenario. In this scenario, the fossil fuels necessary to ship the raw cashew nut to Vietnam is responsible for the largest share of the total impact.

Of those processes that contribute to the cultivation stage, the production of herbicides necessitates most fossil fuels, followed by the chain saw. The impact of the chain saw is high compared to the tractor, as the tractor is only used in the first year (so 1/30 of the time), whereas the chain saw is used on a yearly basis.

Fine particulate matter

Fine particulate matter formation is mainly caused during processing, when diesel and cashew shells are burned. For the cashew that is processed in Vietnam, the transport from the farm (in Ghana) to the processor (in Vietnam) also causes a significant amount of fine particulate matter.

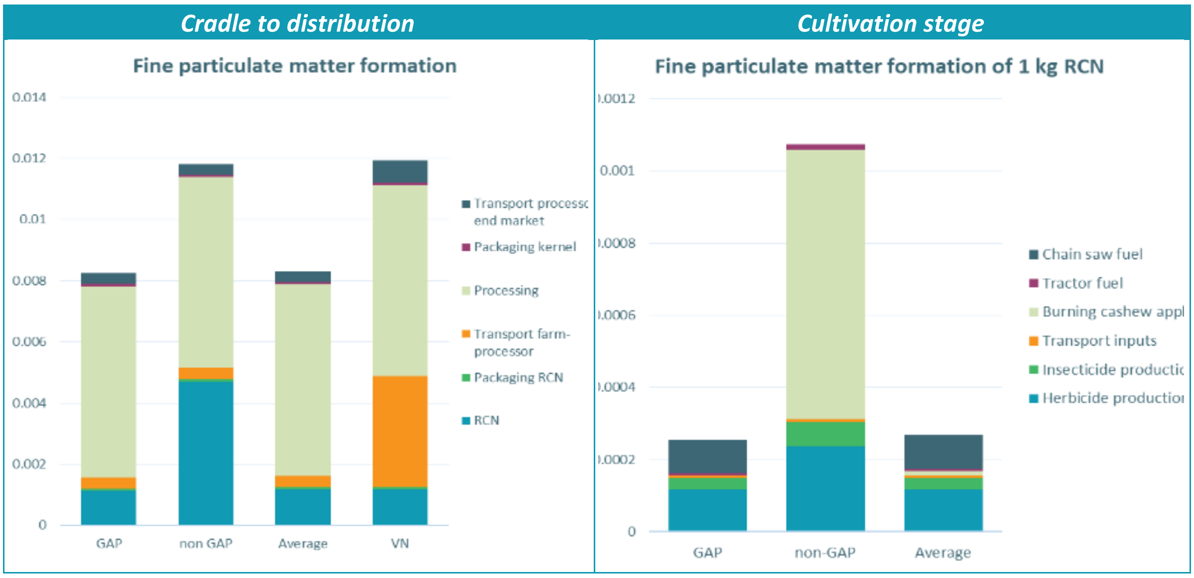


Figure 32 Fine particulate matter formation impact for the cradle-to-distribution stages (1 kg of cashew) and cultivation stage (1 kg RCN) of cashew

Water consumption

As no irrigation is used for cashew trees, overall water consumption is very low, and mainly involves water used in production processes, such as the production of herbicides. Because of the negligible amount of water, no contribution analysis has been done of water use, nor water scarcity.

7.3.2 Sensitivity check

7.3.2.1 Uncertainty analysis

An uncertainty analysis was carried out with SimaPro, focusing on those datapoints that are characterised by high uncertainty:

- Yields
- Prices (both at farm level and at processing)
- Processing data

The SimaPro pedigree function was used to assess the uncertainty value, which is calculated based on whether the data concerns an estimate, whether it is representative (geographical and temporal), what the sample size is etc. The uncertainty value is relatively high for prices (and thus allocation), especially for Vietnam, for which no country-specific data was available. The same applies for processing in Vietnam.

For other activity data (and emissions) the basic uncertainty value was used, to reflect generic uncertainties in activity data as well as background datasets.

The outcome for the 5 key indicators is depicted in the figures below. The error bars represent the 95% confidence interval. For global warming, fine particulate matter formation and fossil resource scarcity, the error bars of the ComCashew cashews processed in Ghana and processed in Vietnam do not overlap, which means that the results are significantly different. This is mainly caused by the additional transport needed for processing in Vietnam, for which uncertainty is low.

For land use and water consumption however, there is about a 50% chance that the impact for cashews processed in Vietnam is larger than cashews processed in Ghana.

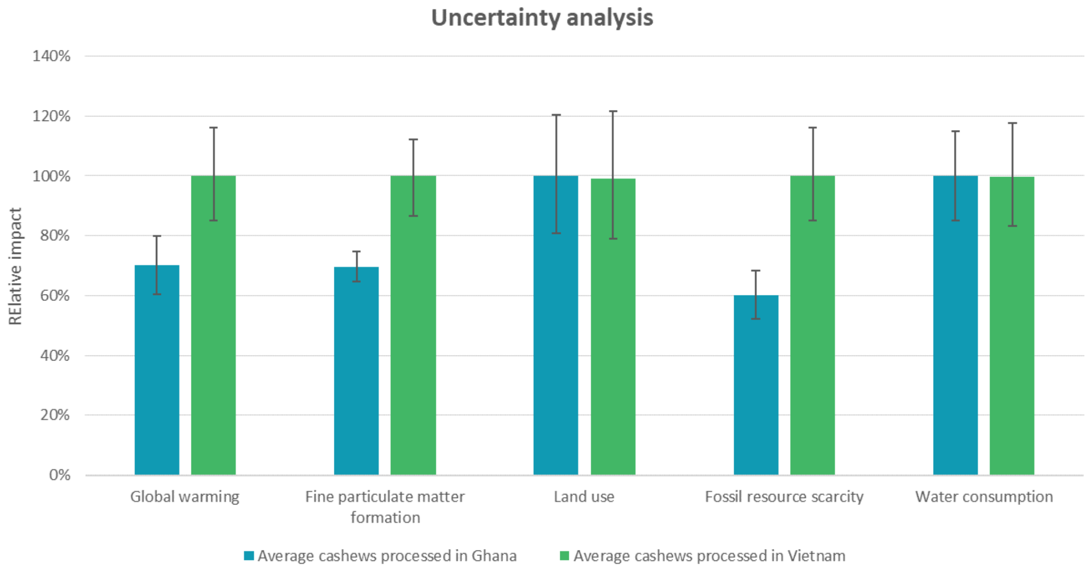


Figure 33 Uncertainty analysis for average cashew processed in Ghana or Vietnam. Error bars represent the 95% confidence interval.

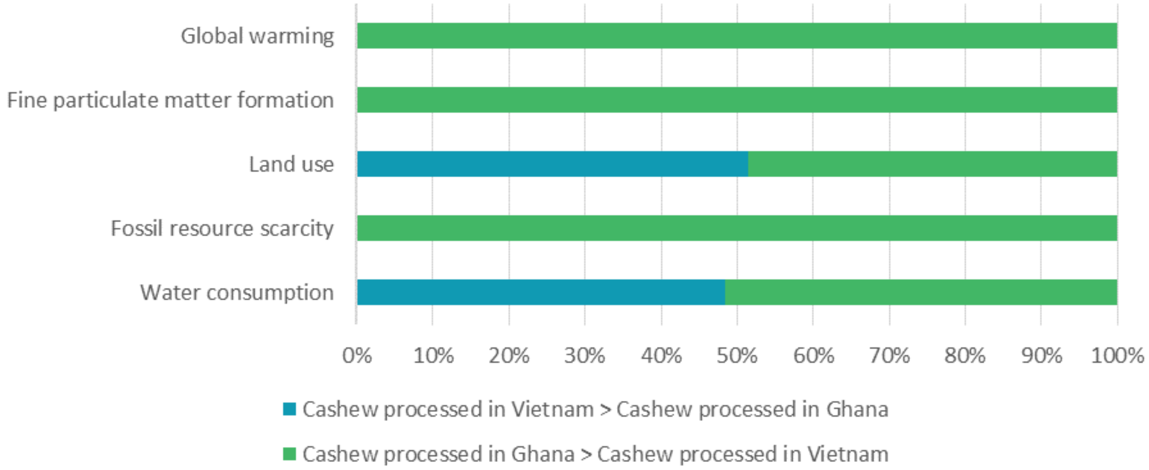


Figure 34 Uncertainty analysis, representing the cashew processed in Vietnam minus the cashew processed in Ghana. The percentages show the chance that one has a higher impact than the other.

7.3.2.2 Sensitivity analysis - Influence of fertilizer use on intercrop

As a sensitivity analysis, it is investigated what the climate change impact of cashew is if it is assumed that part of the inputs used for the intercrop is attributed to cashew. According to the data collected by the ComCashew team, about 54% of farmers intercrop, and for these farmers, the intercrop covers about 30% of the farm area. Fertilizer data from the most common intercrops, maize, groundnut and yam, has been retrieved from the field. As the fertilizers are mostly applied close to the plant (contrary to broadcasting), it was assumed that 10% of the fertilizers applied on the intercrop can be attributed to cashew. The same assumption was made for other inputs used for intercrops, notably pesticides.

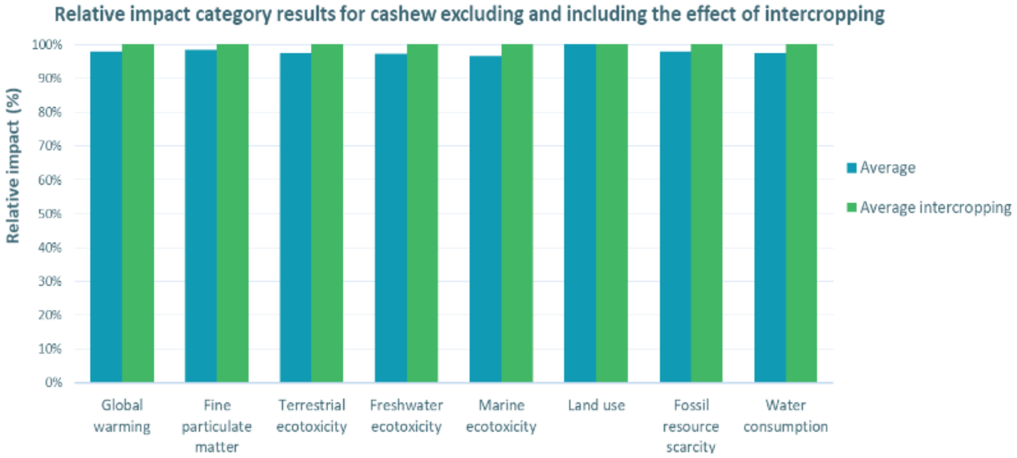
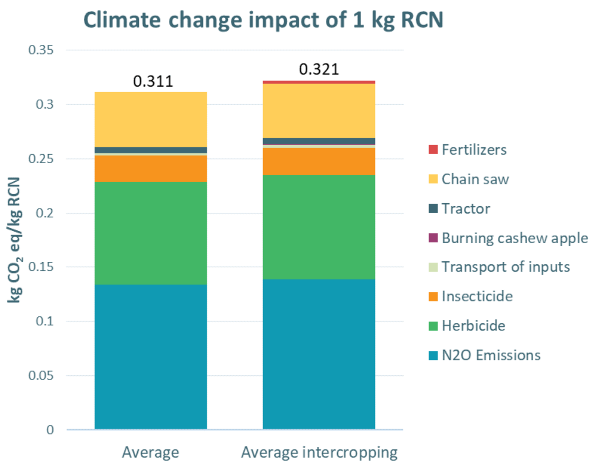


Figure 35 Relative impact category results for cashew excluding and including the effect of intercropping



These data were implemented for the 'average' cashew scenario. The results, as depicted in the figures, show that the intercropping scenario only leads to a 2.1% higher climate change impact of the cashew kernel compared to the average scenario. For the raw cashew nut, the climate change impact is 3.4% higher.

Figure 36 Climate change impact excluding and including the effect of intercropping

7.3.2.3 Sensitivity analysis - Changes in processing efficiency

As already mentioned, processing data for cashew is based on values from literature on cashew processing in Nigeria. As this might not represent actual conditions, it is investigated how a different processing efficiency would influence the overall carbon footprint of cashew.

A worst case scenario was investigated, in which it was assumed that processing in Ghana is 50% less efficient, whilst processing in Vietnam is 50% more efficient (combined, this makes the processing in Vietnam 3 times more efficient than in Ghana). The figure below shows the resulting carbon footprint. Even with this worst-case scenario, the average cashew from Ghana would still have a 22% lower footprint than cashew processed in Vietnam. Originally, the cashew processed in Ghana had a 30% lower footprint than cashew processed in Vietnam.

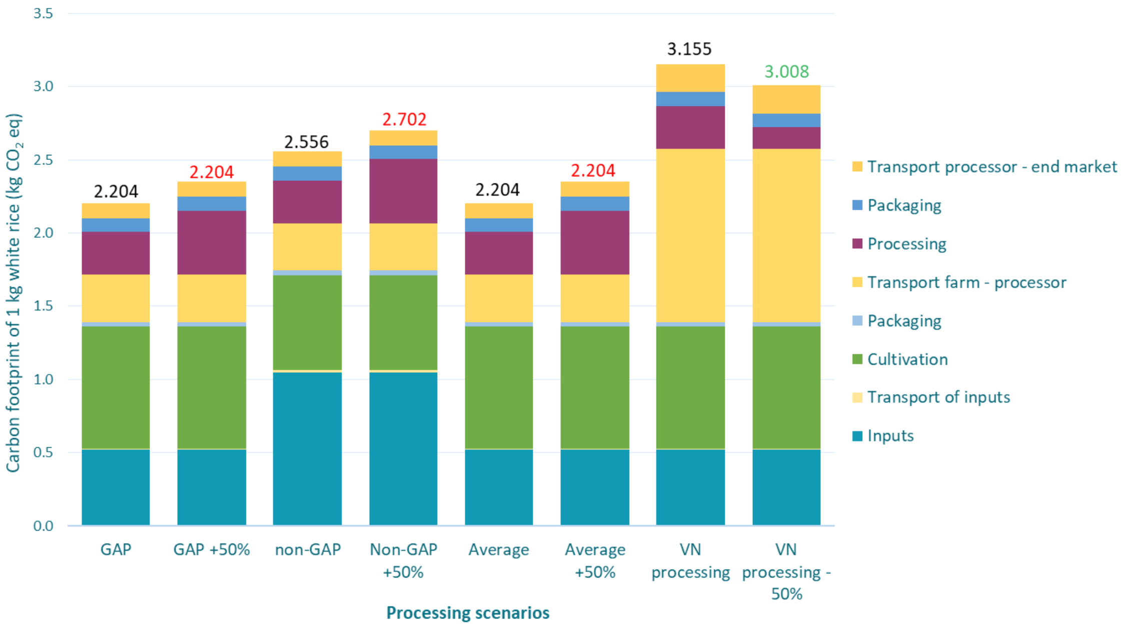


Figure 37 Carbon footprint f 1 kg white rice for different processing scenarios: for Ghana, the footprint of the processing stage was made 50% higher, for Vietnam (last two bars) it was made 50% lower

7.3.2.4 Sensitivity analysis - Carbon sequestration of cashew trees

According to ISO standards and the PEF standard from the European Commission, carbon sequestration can only be included if the carbon is stored for over 100 years, and would thus not apply for cashew trees as they have a lifespan of about 30 years. However, in many voluntary carbon credit schemes, carbon sequestration in trees is nonetheless considered. Therefore, a sensitivity analysis was performed to investigate what the potential impact would be if carbon sequestration would be accounted for.

According to (Daouda et al., 2017), who investigated carbon stocks in 15-year old cashew plantations in Benin, these plantations store on average 18.8 t C/ha (average of 5 production zones with trees of average 15 years, considering both above and below ground biomass). Although carbon sequestration in trees is not a linear process, for reasons of simplicity we assume it is, which means that with an age of 15 years, the annual sequestration rate amounts to 1.25 tons of carbon per hectare. This rate is relatively low considering temperate and tropical forests sequester between 0.7-10 tonnes of carbon on an annual basis (FAO, 2001), however tree densities on plantations are much lower than in forests and the value is therefore regarded as realistic. Taking into account the molecular weight (44/12), the sequestration rate comes down to 4.58 ton CO_2 eq/ha/year. If this amount would be allocated to the cashew tree products, this means that about 35.5 kg CO_2 is sequestered per kg cashew kernel, which by far exceeds the carbon footprint of cashew kernel production, which is 2.2 kg CO_2 eq/kg kernel.

7.3.2.5 Sensitivity analysis - Nitrogen balance

A very simplified nitrogen balance is created, which considers the main nitrogen fluxes through the cashew apple, nut and through atmospheric deposition. The nitrogen which is recycled through leaves is considered relatively constant (as it is recycled within the system) and is hence left out.

The balance points out that the soil is depleted from nitrogen, with 3.7 kg of N/ha being extracted on an annual basis. As no fertilizer is applied, the soil quality is gradually decreasing, which will also affect cashew yields.

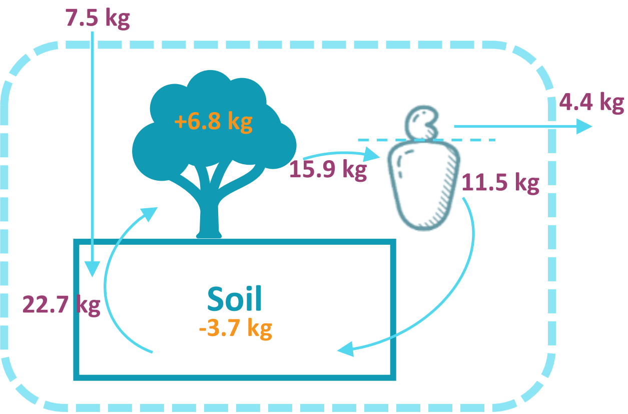


Figure 38 Simplified N balance for ComCashew farmers

Table 26 Nitrogen balance for ComCashew, with values per hectare

	Mass (kg)	*N content (%)*	*Nitrogen (kg)*	*Comments*
Cashew kernel	103.63	3.36%	3.48	Assuming protein content of 21%
Cashew shell	414.51	0.21%	0.87	Based on https://www.researchgate.net/figure/Properties-of-the-cashew-nut-shells_tbl1_230275430
Cashew apple	4663.24	0.25%	11.5	N content based on (Kinh, Do, & Phuong, 1997)
Total N output in apple + RCN			15.89	
Nitrogen use efficiency (NUE)			0.7	Based on (Oenema et al., 2015)
Total N input			22.70	= total N output/ NUE
N atmospheric deposition			7.5	Based on (Galy-Lacaux et al., 2016)
N deficit soil			-3.66	= N apple + N atmosphere – N input
N 'sequestration' in tree			6.81	= N input total – N output total

If the cashew apple would not be left on the field, but used for other purposes (e.g. as food or feed, or to make juice etc), the overall balance would be more negative. In that case, the nitrogen deficit would amount to 15.2 kg N per hectare.

7.3.2.6 Sensitivity analysis - Use of cashew apple

Currently, the majority of cashew apples is left on the field. It is investigated what the effect on the footprint would be if all cashew apples would be used. It is still assumed that the apple is sold at 0.46 GHC/kg (1/10 of the price of raw cashew nut). Since the mass of cashew apples is nine times that of raw cashew nuts, the economic allocation to raw cashew nut reduces from 91.74% to 52.63%. This results in a much lower overall carbon footprint, as shown in the figure below. Since the apples no longer decompose on the field, the N_2O emissions are also much lower. The effect on the nitrogen balance was discussed above.

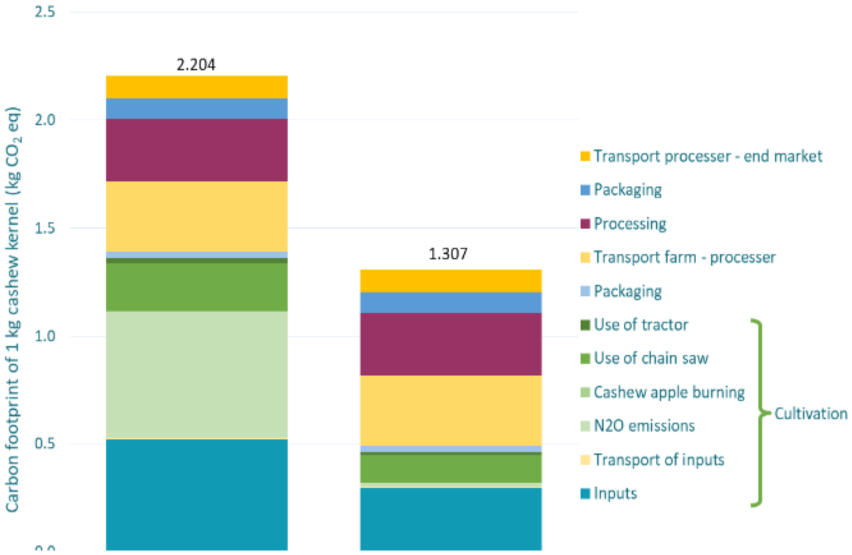


Figure 39 Carbon footprint for 1 kg of cashew, for average cashew production (left) and for the scenario in which all cashew apples are sold (right)

8. Conclusion, discussion and recommendations

A screening life cycle assessment was performed to assess the environmental impact of rice value chain in Nigeria and the cashew value chain in Ghana, and compare these to rice imported from Vietnam and cashew processed in Vietnam.

8.1 Rice

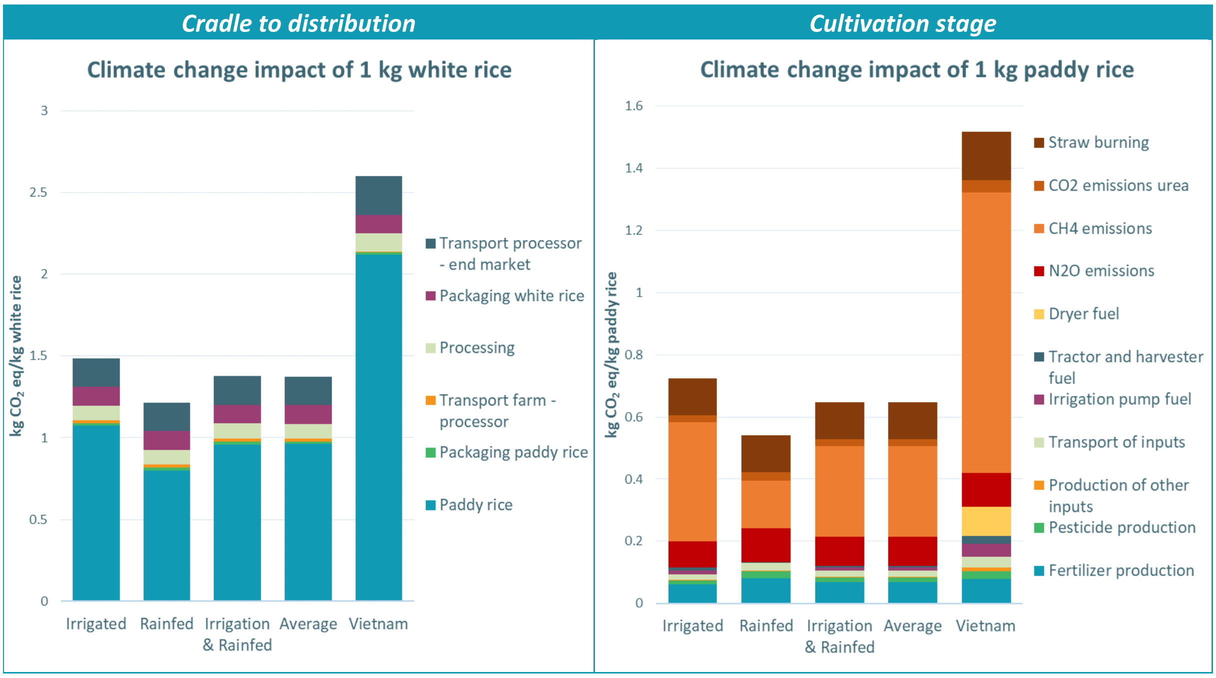


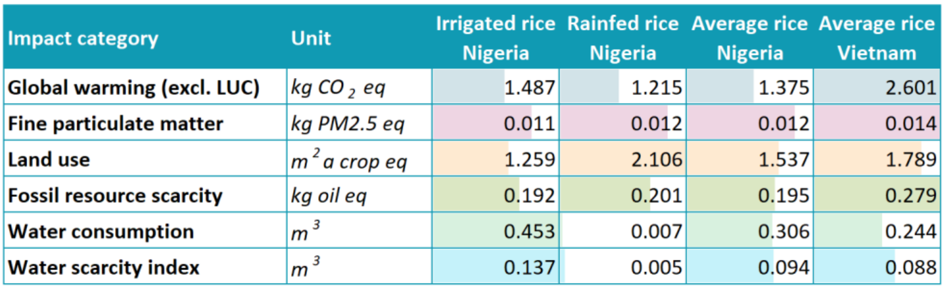
Figure 40 Climate change impact for the cradle-to-distribution stages (1 kg white rice), and cultivation stage (1 kg paddy rice) of rice

For the rice value chain, the impact results point out that rice imported from Vietnam carries the highest carbon footprint, whereas rainfed rice from Nigeria carries the lowest. The carbon footprint is largely determined by methane emissions; rice that is irrigated with no or few drainage periods provides anaerobic conditions that cause high methane emissions. If the paddy fields are drained regularly, and especially if it concerns upland fields which are scarcely flooded - these emissions are much lower.

The rice in Vietnam is more resource and energy intensive, with a high use of irrigation pumps, mechanical dryers, tractors and harvesters, which cause a relatively high impact when it comes to global warming as well as fossil resource scarcity.

The impact on marine, freshwater and terrestrial ecotoxicity has been calculated using active ingredients of pesticides applied in Nigeria and Vietnam. The average Nigerian rice has a lower impact than Vietnamese rice for all three categories. The use of insecticides contributes most to the impact for both countries.

Note that the processing stage in Vietnam is modelled based on data from other Asian countries (with the Vietnamese electricity mix), and might therefore not accurately represent the actual situation in Vietnam. The processing stage is however a relatively small contributor to the overall climate change impact. Uncertainty related to data points (especially prices, yields and water use) has been assessed in the sensitivity analyses, and points out that for the carbon footprint, fossil resource scarcity and fine particulate matter formation, the Nigerian rice has a significant lower impact than Vietnamese rice.



Impact category	Unit	Irrigated rice Nigeria	Rainfed rice Nigeria	Average rice Nigeria	Average rice Vietnam
Global warming (excl. LUC)	*kg CO_2 eq*	1.487	1.215	1.375	2.601
Fine particulate matter	*kg PM2.5 eq*	0.011	0.012	0.012	0.014
Land use	*m^2a crop eq*	1.259	2.106	1.537	1.789
Fossil resource scarcity	*kg oil eq*	0.192	0.201	0.195	0.279
Water consumption	*m^3*	0.453	0.007	0.306	0.244
Water scarcity index	*m^3*	0.137	0.005	0.094	0.088

Figure 41 Environmental impact category results for 1 kg of white rice, with the coloured bars showing the relative result for each category

8.2 Cashew

Cashew that is grown with good agricultural practices (GAP) and processed in Ghana has the lowest environmental impact for all impact categories under consideration.

Ghanaian cashew that is transported to Vietnam for processing results in the highest carbon footprint and use of fossil fuels, which is attributed to the long transport distance.

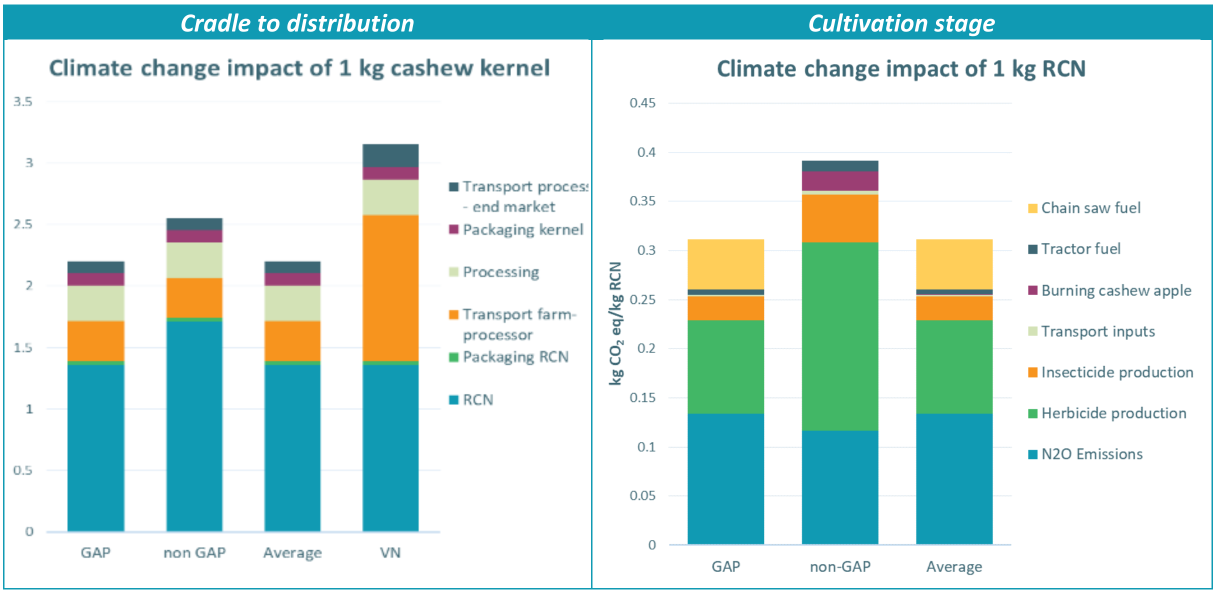
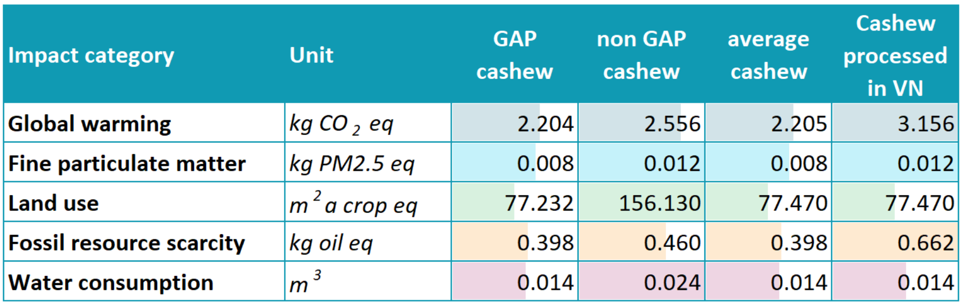


Figure 42 Climate change impact for the cradle-to-distribution stages (1 kg cashew kernel), and cultivation stage (1 kg RCN) of cashew

Due to its low yields, cashew that is produced with conventional practices (non GAP) has a relative high impact for impact categories land use and water consumption.

As little to no processing data was available for cashew processing in Ghana and Vietnam, a study was used on cashew processing in Nigeria. The sensitivity analysis points out that even if processing in Ghana would be 50% less efficient and in Vietnam 50% more efficient, cashew processed in Ghana would still have a lower carbon footprint.

Also other uncertainties related to data points (such as yields and prices) were assessed in the sensitivity analyses, and point out that for carbon footprint, fossil resource scarcity and fine particulate matter formation, the impact of cashew processed in Ghana is significantly lower than cashew processed in Vietnam.



Impact category	Unit	GAP cashew	non GAP cashew	average cashew	Cashew processed in VN
Global warming	*kg CO_2 eq*	2.204	2.556	2.205	3.156
Fine particulate matter	*kg PM2.5 eq*	0.008	0.012	0.008	0.012
Land use	*m^2 a crop eq*	77.232	156.130	77.470	77.470
Fossil resource scarcity	*kg oil eq*	0.398	0.460	0.398	0.662
Water consumption	*m^3*	0.014	0.024	0.014	0.014

Figure 43 Environmental impact category results for 1 kg of cashew kernel, with the coloured bars showing the relative result for each category

Recommendations

Based on the above conclusions, the following recommendations can be made to improve data quality, and to lower the environmental footprint of cashew and rice value chains:

Improved data quality

Cashew:

- Data availability for processing is currently weak for cashew processing in both Ghana and Vietnam. In-country data collection would enhance data quality.
- As the age of cashew trees influences yields, it would be beneficial to differentiate between different age groups to get a more accurate picture of the carbon footprint.

Rice:

- Since no field measurements exist of methane emissions for rice cultivated in West Africa, the emissions are now modelled using generic emission factors which disregard local conditions. Data quality would enhance significantly if actual field measurements of methane emissions are performed.
- The quantity of irrigation water and associated energy used for pumping are now based on generic models, and would become more accurate if measured in the field.
- Emissions as a result of land use change has been determined with a simplified model, which calculates the impact of land use change based on the expansion of agricultural land at the cost of forest and the relative expansion of rice. The resulting value for rice is relatively high. It concerns a country-level average for rice, which doesn’t take into account that carbon emissions from deforestation are much lower in the north where the natural vegetation is sparsely vegetated savanna instead of the dense rainforest in the south. Collecting local data on land use change would significantly improve accuracy.
- Data for rice processing in Vietnam is now based on literature from other Asian countries, and could be improved by collecting primary data. Also water use would benefit from primary data collection, both for Vietnam and Nigeria.

Lower environmental impact

Cashew:

- Stimulating local processing in Ghana instead of in Vietnam would lead to a 30% lower environmental footprint of cashew nuts.
- Implementing good agricultural practices, including pruning and fire prevention, significantly lowers the impact in all environmental impact categories compared to conventional practices.

- If the cashew apple would be used productively, this would lower the allocation factor, and thus the overall environmental impact, of cashew kernels.
- Using fertilizers for cashew cultivation could improve yields and avert the current negative nitrogen balance. Using only a small amount of fertilizer would already be effective, and would keep the footprint low.

Rice:

- Methane emissions, the biggest contributing factor of the carbon footprint for rice, can be lowered by (further) promoting more frequent drainage of rice fields during cultivation.
- For most crops, it is recommended to incorporate organic matter into the soil as it benefits soil quality and soil fertility. For irrigated rice, it however leads to high methane emissions and should therefore be kept to a minimum, and should be incorporated long before cultivation starts. Using synthetic fertilizers as nitrogen source leads to a lower carbon footprint than using organic material. It would be beneficial to remove the straw from the field, however if it would be burned it would again lead to greenhouse gas emissions (unless it would be burned to replace a fossil fuel which would lead to overall lower emissions, see next point).
- Using rice husk as energy source for processing would lower the carbon footprint of this stage. Also rice straw could be considered for this purpose. However, it should be ensured that a filter is installed to avoid high emissions of fine particulate matter (which are higher for rice husk compared to diesel).

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Appendix I: Explanation of the LCA methodology

Figure 44: Example of life cycle approach

Life Cycle Assessment (LCA) is a method to evaluate and quantify the environmental impact of a product or service. Life Cycle Assessment captures the whole supply chain (from cradle to grave) with its individual stages. From raw-material production, production, distribution, transportation, use and disposal of a specific product (or service). Different environmental impacts are assessed, for instance greenhouse gas emissions, water consumption and fossil depletion.

The goal of an LCA is to get insights in the environmental impacts of a product or service, by quantifying all inputs and outputs of material flows. The results of an LCA can be applied for product development, strategic planning, marketing and communication towards customers.

Why assess the impact?

There are different motives to assess the impact of a product. Some examples are: decouple environmental impact from growth, reduce resource depletion and create novel products (for example alternative protein sources, energy efficient solutions), establish cost reduction, raise public awareness and involvement (for example regarding deforestation, sustainable fishing, healthy and sustainable nutrition), adaptation of healthy lifestyles.

Steps of an LCA

In order to review all the inputs and outputs and calculate the environmental impacts various steps need to be undertaken. The International Organisation for Standardisation (ISO) provides guidelines related to LCA (ISO 14040 and 14044 (ISO, 2006a, 2006b). Four different steps are proposed, each of them are explained in more detail.

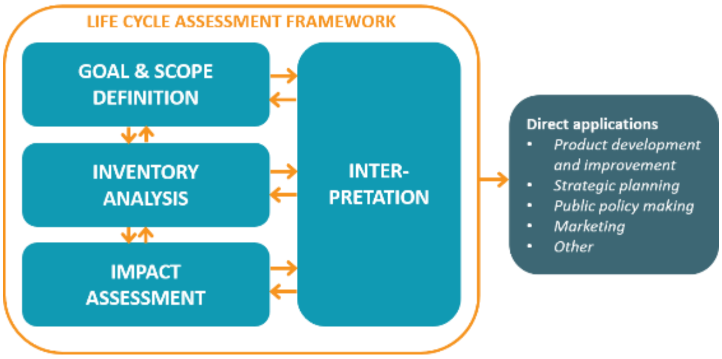


Figure 45 Methodological steps in LCA

1. Goal & Scope definition

The first step of goal and scope definition involves the stating and justification of the whole study. First, the goal of the study is explained, together with its primary intentions, followed by the intended audience and the involved parties of the study. In order to define the goal of the study the following questions need to be answered: ‘What is the reason for carrying out the study?’, ‘What is the intended application?’ and ‘What is the targeted audience of the deliverables?’.

The scope definition phase establishes the main characteristics of the whole study. What to analyse and how? The product system is introduced and the scope of the analysed product system is explained (e.g. cradle-to-grave or cradle-to-gate).

2. Inventory analysis: Data collection

The life cycle inventory (LCI) stage estimates the consumption of resources and quantifies the waste flows and emissions caused or attributable to the product's life cycle. In LCA, each and every flow should be followed until its economic inputs and outputs have all been translated into environmental interventions (=emission or resource), from economy to environment or vice versa. To do this, three different system boundaries need to be defined:

- Economy-environmental system boundary: describes which processes belong to the economy and environment.
- Cut-off: discusses the processes that are irrelevant or not taken into consideration during the whole LCA study.
- Allocation: assigning the environmental impacts of multifunctional systems. Three different multifunctional processes exist: coproduction, recycling and combined waste processing. In each of the scenarios the environmental impacts need to be allocated over de different functional flows. The allocation method can either based of physical properties of the flows (mass or energy content), economic value or substitution (avoided product).

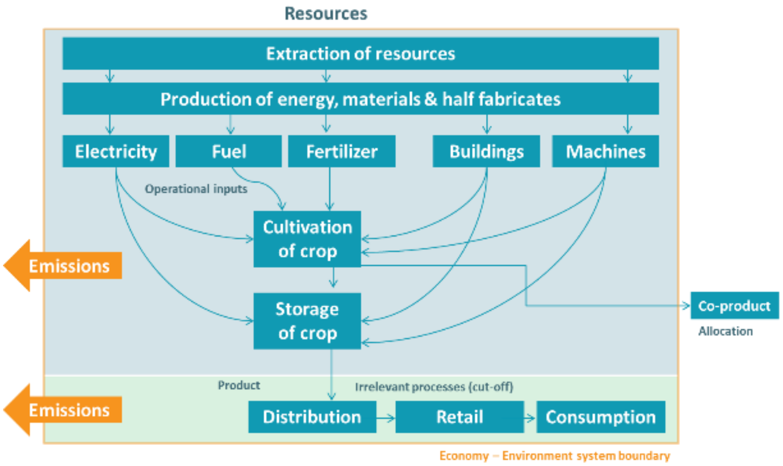


Figure 46: Example of the cradle-to-gate system boundaries that is applied for agricultural products.

At this stage data needs to be collected and modelled. This forms the main part of the LCA studies. It gives inputs for the Life Cycle Impact Assessment and gives feedback to the initial scope setting. The collected data consists preferably of primary data for the most important processes, the so-called fore-ground processes. Economic flows of these foreground processes are connected to so-called background processes to include inventory data from up- and downstream processes. Background databases can be used for this purpose, examples include Agri-footprint®, ELCD and Ecoinvent database. Result of the LCI is the inventory table, which is an extensive list of environmental interventions.

3. Impact Assessment

During the life cycle impact assessment (LCIA) the inventory tables from the LCI are used to determine the environmental impact of reference flows for different impact categories. This is done by first selecting the impact categories that are relevant for the study. This depends on the type and goal & scope of the study. More information about impact categories, in the next paragraphs.

Next step is to translate the inventory table into impact indicator results (impact categories). This is usually performed using specialized software, like Simapro. The following steps are performed to get from the inventory table to impact category results. This can be best explained using the impact category “climate change” as example, but works similarly for all impact categories.

- Classification – the software classifies the emitted greenhouse gasses from the inventory table. Hereby all non-greenhouse gasses are left out from the analysis for this impact category.
- Characterisation – the impact of each greenhouse is calculated based on the mass and potency of the greenhouse gas in respect to the indicator unit. The indicator unit for global warming at mid-point level is kg CO_2-equivalents. Each kg of emitted carbon dioxide is 1 kg CO_2-eq., however methane is a more potent greenhouse gas and each kg of emitted methane is equivalent to 25 kg of CO_2. The potency of the greenhouse gasses or “characterisation factors” for greenhouse gasses are derived from IPCC and updated from time to time.
- Normalisation – this is an optional step to compare the significance of the footprint to the total impact of the world or European region. This can give an idea about the significance of the category impact.
- Weighting - this is an optional step to aggregate indicator results of various impact categories into a single score. However, weighting has always been a controversial issue in LCA studies (Finnveden, Eldh, & Johansson, 2006) and is therefore usually not performed.

4. Interpretation

The final phase of the LCA discusses the overall result from the previous steps. Interpretation begins with a consistency and completeness check to determine the soundness of the study. The contribution and sensitivity analysis helps to bolster the robustness of the results in preparation of the discussion and conclusion of the report. Each of the four optional steps are discussed in more detail.

- Consistency check: the objective of the consistency check is to determine whether assumptions, methods, models and data are consistent with the goal and scope of the study.
- Completeness check: ensure that the information and data used for this study are available and complete.
- Contribution analysis: illustrates the main contributing processes for each impact category. This aids in understanding the product system(s) better.
- Sensitivity analysis: assesses the influence on the results of variations in process data, model choices and other variables. During the sensitivity analysis some of the important parameters are deliberately changed in order to determine the robustness of the results.

What follows is the discussion and the conclusion of the main research question for the study.

Presenting results in LCA studies

LCA results can be shown in multiple ways, at midpoint and at endpoint level. Midpoint are considered to be a point in the environmental cause-effect chain mechanism of a particular impact category (See Figure 47), prior to the endpoint at which characterization factors can be calculated to reflect the relative importance of an emission or extraction in a life cycle inventory (Bare, Hofstetter, Pennington, & Haes, 2000). Both midpoint and endpoint level indicators have complimentary merits and limitations. Results at mid-point indicators are argued to be more certain but can have lower relevance for decision support. Whereas endpoint indicators are considered to have higher relevance but lower certainty.

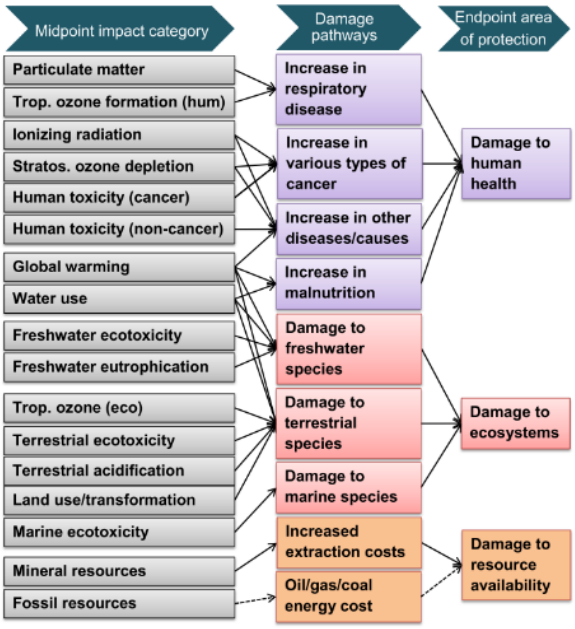


Figure 47: Graphic illustration of basic differences between the midpoint and the endpoint results (Goedkoop et al., 2013)

Because end-points have lower certainty and involve the controversial process of weighting different impact categories, mid-points are always used to present results of LCA studies performed by Blonk Consultants. As default, impact categories from ReCiPe (version 1.13) are used to present results, using the hierarchical version. ReCiPe is chosen, since it is the most recent and harmonized indicator approach available in life cycle impact assessment. Optionally the mid-point results can be aggregated into a single score end-point result using the ReCiPe endpoint method.

Definitions used in LCA

Following LCA definitions are derived from the LCA handbook (Guinée et al., 2002)

Impact category: a class representing environmental issue of concern to which environmental interventions are assigned, e.g. climate change, loss of biodiversity.

Category indicator: A quantifiable representation of an impact category, e.g. infrared radioactive forcing for climate change.

Category unit: Unit to express the category indicator.

Characterisation factor: a factor derived from a characterisation model for expressing a particular environmental intervention in terms of a common unit of the category indicator.

Characterisation method: a method for quantifying the impact of environmental interventions with respect to a particular impact category; it compromises a category indicator, a characterisation model and characterisation factors derived from the model.

Characterisation unit: used to express the indicator result which is the numerical result of the characterisation step for a particular impact category, e.g. 12 kg CO_2-equivalents for climate change.

Impact categories

An LCA evaluates the environmental impact of a product or service. There exist various impact categories, such as climate change, fresh water eutrophication and agricultural land occupation. *Table 27* gives an overview of the impact categories, defined by ReCiPe methodology. In order to transform the extensive list of life cycle inventory results into a limited number of indicator scores the ReCiPe methods has been developed. These indicator scores express the relative severity on an environmental impact category.

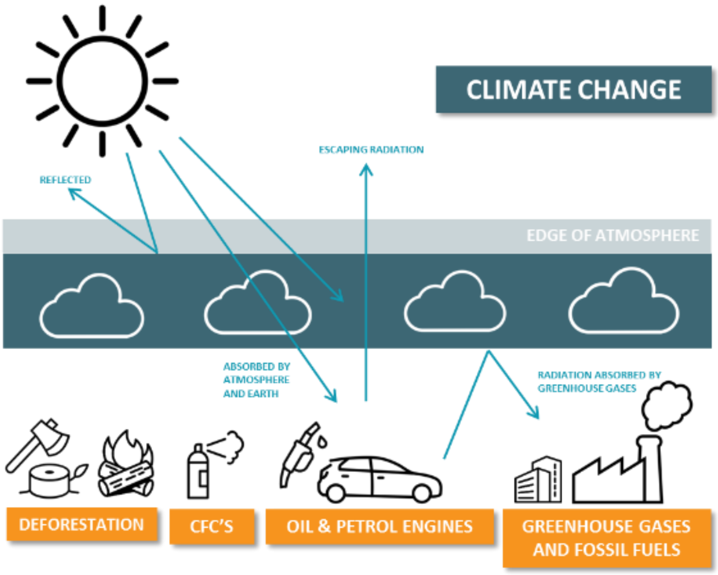
Table 27: category indicators, units, characterisation factors, indicators results for 18 ReCiPe impact categories

Impact category	Category indicator	Indicator unit (mid-point)	Characterisation factor (mid-point)	Indicator unit (mid-point)	End-point	Indicator unit (end-point)
Climate change	infra-red radiative forcing	W*yr/m^2	GWP_{100}	kg CO_2 eq.	✓ (2x)	DALY + species/yr
Ozone depletion	Stratospheric ozone concentration	ppt*yr	ODP	kg CFC-11 eq.	✓	DALY
Terrestrial acidification	base saturation	yr*m^2	TAP	kg SO_2 eq.	✓	species/yr
Freshwater eutrophication	phosphorus concentration	yr*kg/m^3	FEP	kg P eq.	✓	species/yr
Marine eutrophication	nitrogen concentration	yr*kg/m^3	MEP	kg N eq.		
Human toxicity	hazard-weighted dose	m^2*yr	HTP	kg 1,4-DB eq.	✓	DALY
Photochemical oxidant formation	photochemical ozone concentration	kg	POFP	kg NMVOC	✓	DALY
Particulate matter formation	PM_{10} intake	kg	PMFP	kg PM10 eq.	✓	DALY
Terrestrial ecotoxicity	hazard-weighted dose	m^2*yr	TETP	kg 1,4-DB eq.	✓	species/yr
Freshwater ecotoxicity	hazard-weighted dose	m^2*yr	FETP	kg 1,4-DB eq.	✓	species/yr
Marine ecotoxicity	hazard-weighted dose	m^2*yr	METP	kg 1,4-DB eq.	✓	species/yr
Ionising radiation	absorbed dose	man*Sv	IRP	kBq U235 eq.	✓	DALY
Agricultural land occupation	occupation	m^2	ALOP	$m_2$anually	✓	species/yr
Urban land occupation	occupation	m^2	ULOP	$m_2$anually	✓	species/yr
Natural land transformation	transformation	m^2	NLOP	m_2	✓	species/yr
Water depletion	amount of water	m^3	WDP	m_3		
Metal depletion	grade decrease	kg^{-1}	MDP	kg Fe eq.	✓	$
Fossil depletion	upper heating value	MJ	FDP	kg oil eq.	✓	$

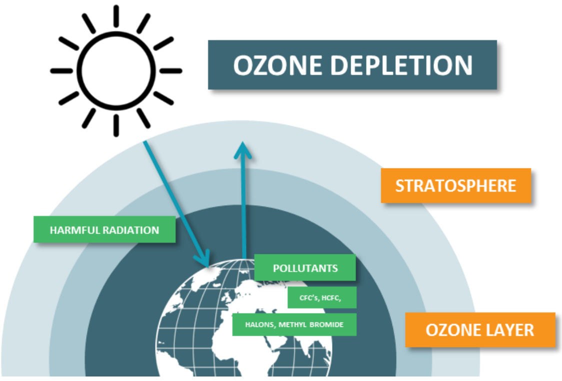
Most ReCiPe mid-point impact categories can be translated to end-point result. First, the environmental impact are grouped into three different domains: human heath, ecosystems and resources. Reference unit at end-point are DALY, species lost per year and surplus cost for each domain respectively. These results can then be further aggregated into a single score (points). A short description of the impact categories and their main mechanisms are explained for 13 most impact categories hereafter.

Climate change

Climate change refers to the change in weather patterns. Climate change heats up the earth slowly and is often called global warming. These changes have an impact on the quality of life on earth. Climate change is caused by various factors, such as biotic processes, plate tectonics, variations in solar radiation received by the earth, volcanic eruptions. Besides that, human activities have significant influence on climate change. Examples are fossil fuel combustion, agriculture and deforestation. These processes result in higher concentration of greenhouse gases (GHG's) in the atmosphere. CO_2 is one of the greenhouse gases (GHG) that has an impact on climate change. Besides that, there exist other greenhouse gases that contribute to global warming, for instance methane and nitrous oxide. These other gases, with an impact on climate change, are also included and expressed in equivalents with the same impact as CO_2. For results at mid-point, carbon dioxide is taken as reference unit, therefore 1 kg of CO_2 is 1 kg CO_2 equivalents. More potent greenhouse gasses include methane (34 kg CO_2-eq/kg) and nitrous oxide (298 kg CO_2-eq/kg). Within LCA studies, for the impact category climate



change only human activities are taken into account. At end-point results for global warming are presented in human health effects (DALY) and effects on the environment (species lost per year).

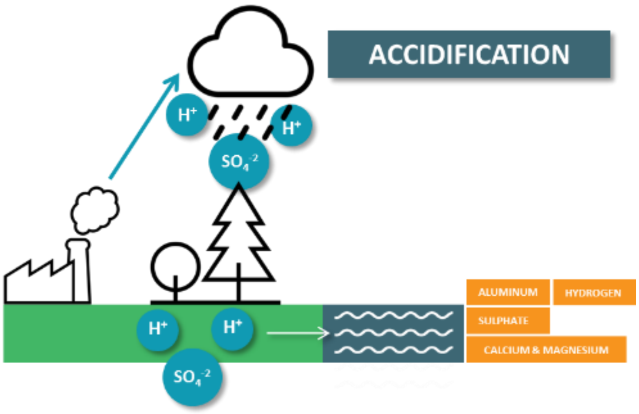


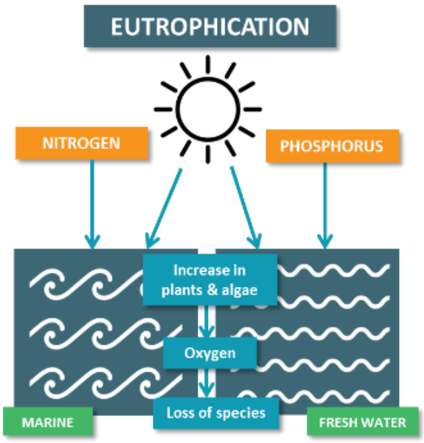
Ozone depletion

Ozone is a naturally occurring molecule containing three oxygen atoms. These molecules form a gaseous layer in the atmosphere (stratosphere). This layer encircles the earth and protects our planet from harmful radiations (solar ultraviolet UV-B radiation) that comes from the sun. However, human activities affect the ozone layer and results into depletion of stratospheric ozone. These ozone depleting substances are able to destroy ozone in the stratosphere. Their potency is expressed in ozone depletion potential using CFC-11 as a reference unit. At end-point, ozone depletion has impact on the human health domain.

Terrestrial acidification

Changes in acidity of the soil are caused by atmospheric deposition of acidic substances. Serious changes are harmful for specific species. In the ReCiPe methodology three acidifying emissions are taken into account. These emissions are: NOx, NH3 and SO2. NOx is mainly formed during combustion processes. Agriculture is the main source for NH3. And energy combustion (coal) counts mainly for SO2 emissions. The characterisation unit for this impact category is SO2 equivalents, which is 2.45 for nitrogen oxides and 0.56 for ammonia. Terrestrial acidification has impact on ecosystems in end-point results.



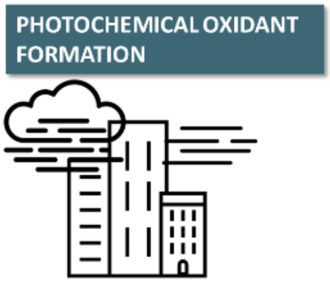


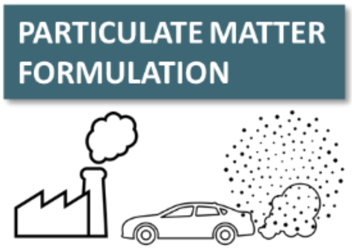
Freshwater & Marine eutrophication

Eutrophication is the enrichment of a water body with nutrients, usually an excess amount of nutrients that induces growth of plants and algae to the biomass load. The extreme growth may result in oxygen depletion of the water body and cause species to suffocate. Freshwater and marine eutrophication both have their distinct nutrients which cause excessive growth of plants and algae, since the limiting growth factor is different in both waterbodies. For freshwater waterbodies the limiting factor are phosphorus containing substances, usually from fertilizers or phosphorus containing detergents. Therefore for reference unit for freshwater eutrophication is kg phosphor equivalents. For marine waters the limiting factors factor is nitrogen and therefore marine eutrophication potential is expressed in kg nitrogen equivalents. Only freshwater eutrophication is considered at end-point result for ecosystems domain.

Photochemical oxidant formation

Other names for photochemical oxidant formation are urban smog or photochemical air pollution. Smog refers to air pollution, which consists of smoke and fog. This kind of visible air polution composes of nitrogen oxides, sulfur oxides, ozone, smoke, carbon monoxide and CFCs. Antrophogenic smog is usually derived from coal combustion, vehicle emissions, industrial emissions, forest fires and other photochemical emissions. Reference unit at mid-point level is kg non-methane volatile organic compounds (NMVOCs) and end-point result belong to human health domain.



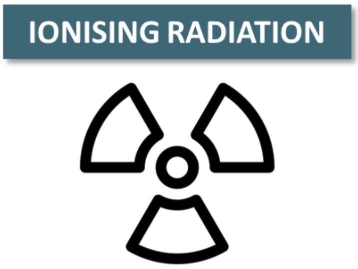


Particulate matter formation

Particulate matter refers to all solid and liquid particles suspended in air many of which are hazardous. It includes organic and inorganic particles, for instance ammonia, sulfurdioxide and paticulate matter. One of the main sources of particulate is the combustion of diesel fuel in vehicles, but also other combustion processes and fireplaces. At mid-point level the reference unit is PM10 equivalents and at end-point the emissions belong to the human health domain, since the impact category has large impact on respiratory organs, in which the impact is expressed in DALYs.

Ionising radiation

Ionising radiation is radiation which is released by atoms, which travels as electromagnetic waves or particles. When the atom has sufficient energy it can cause ionisation or remove electrons from an atom. Ionizing radiation can be dangerous. When living cells become ionised they can die or mutates incorrectly and become cancerous. Radioactive substances exist naturally, examples are rocks and soil, however these levels are rather low. Most common source of ionising radiation is the extraction and use of radioactive materials for nuclear power generation. Reference unit for ionising radiation is kBq Uranium^{235} equivalents. At end-point the impact category belong to the human health domain.

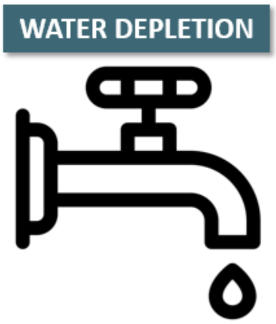


Agricultural and urban land occupation

The area of land on the globe available for cultivation is limited. Land occupation refers to the area of rural or urban land that is occupied for a certain time period. Reference unit at mid-point is occupation of square meters annually. Lowering the impact means minimizing the number of square meters (m2) per year used to produce a certain product, this will have positive impact on the ecosystems domain in the end-point results in less species lost.

Natural land transformation

Closely related to land use is natural land transformation. For some production systems the land is reclaimed and occupied at the expense of other types of land. Most problematic examples are the reclamation of forests in Brazil and Indonesia for the production of soybeans and palm oil respectively. The emissions of reclaiming land (e.g. burning of forests) are allocated to the product systems over a certain time period. Reference unit is transformed land expressed in square meters. End-point results are included to the ecosystems domain, expressed in lost species per year.

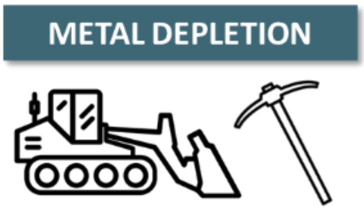


Water Depletion

For water depletion it is important to make a clear distinction between water use and water depletion. If water evaporates or is used as an input for the production of concrete of other chemicals, the water is lost from that area. But if the water is consumed but also released near the point of consumption, it may be argued that the water is not lost and does not cause water shortages. Example of this is the use of cooling water in power stations, where the mayority of the water is discharged in the same water body it orginates from. Mid-point reference flow is cubic meter of water consumed. No End-point modelling is available at the moment.

Metal depletion

Metal is a non-renewable resource, which means that consumption of this resource can lead to depletion. Results at mid-point are expressed in the relative scarcity of metals in iron equivalents, for 20 different metals. At end-point the results are presented as $ per kg extraction. Extracting one kilo of iron will cost the society 7 cents, uranium $ 8.76 and platinum a staggering 11 thousand dollar. Metal depletion belongs to the mineral surplus domain.

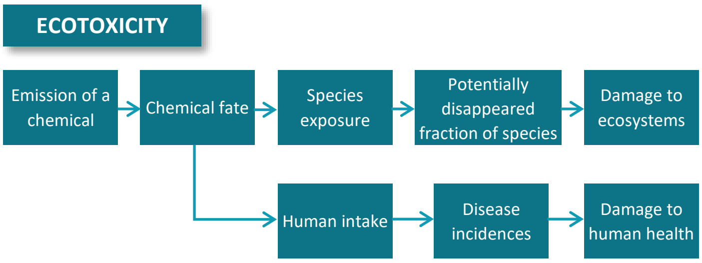


Fossil depletion

Fossil depletion refers to the depletion of resources that contain hydrocarbons. This group of hydrocarbon include coal, oil and natural gas, which are all considered for results mid-point. The ReCiPe mid-point method is very similar to metal depletion, in a way that is includes the scarcity of these resources based on the reserves of these fossil fuels. Fossil fuel depletion is given in kg oil equivalents. At end-point the fossil depletion impact category is aggregated to surplus costs to society.

Ecotoxicity

Human toxicity and ecotoxicity accounts for the environmental persistence (fate), accumulation in the human food chain (exposure), and toxicity (effect) of a chemical. The figure below shows the cause-effect pathway, from emission to the environment, via fate and exposure, to affected species and disease incidences, leading finally to damage to ecosystems and human health.



Appendix II: Background data

Table 28: Overview of the background datasets that are used throughout the study

Emissions related to burning of crop residues

Emissions for burning rice straw were modelled by taking the average of available literature studies, which are summarized below. Note that the CO_2 is not accounted for as it is biogenic.

Source	CO_2 (biogenic)	CO	CH_4	N_2O	NO_x	SO_2	PM2.5	PM10	Black carbon	Organic carbon
(Bakker, Elbersen, Poppens, & Lesschen, 2013)	1460	72.4	0.74	0.79	3.52	0.15	12.95			
(Gadde, Bonnet, Menke, & Garivait, 2009)	1460	34.7	1.2	0.07	3.1	2	12.95			
(Arai et al., 2015)	1078.2	128	13.35	0.16						
(Kim Oanh et al., 2011)	1177	93	9.6		0.49	0.51	8.3	9.4	0.53	3.1
(Zhang et al., 2013)	1064.6	81.9			3.225		15.2	17.3		9.65
(Ni et al., 2015)	1393	57.2					8.5			3.3
(Andreae & Merlet, 2001)	1515		3.95		2.5		3.9	13	0.69	
(Akagi et al., 2011)	1585	102			3.11		6.26			
(Kanokkanjana & Garivait, 2010)	1185	132.2					27.63			
Average	**1324.2**	**87.68**	**5.77**	**0.34**	**2.66**	**0.89**	**11.96**	**13.23**	**0.61**	**5.35**

Emissions for burning rice husk were also retrieved from literature. As less literature was available for burning of rice husk compared to rice straw, values for PM2.5, PM10, black carbon and organic carbon were borrowed from rice straw, assuming that both are relatively similar.

Source	CO_2 (biogenic)	CO	CH_4	N_2O	NO_x	SO_2	PM2.5	PM10	Black carbon	Organic carbon	NO2	NO
(Irfan et al., 2014)	880.5	14.0			2.3	0.1					0.2	1.4
(Ahiduzzaman & Sadrul Islam, 2009)	1277.6	56.5	6.2	0.3								
Average	**1079.1**	**35.3**	**6.2**	**0.3**	**2.3**	**0.1**	**12.0**	**13.2**	**0.6**	**5.4**	**0.2**	**1.4**

Transport by motorcycle

Motorcycle transport was not available in Ecoinvent nor Agri-Footprint databases and has thus been modelled using existing literature. According to (UNEP, 2010), about 85% of motorcycles globally concern two-strokes, with the remainder being four-strokes. Two studies (Dröge, Hensema, ten Broeke, & Hulskodtte, 2011; Meszler, 2007) were used to derive emissions for both type of motorcycles, every time taking the worst case from both studies (assuming relatively higher polluting motorcycles in Africa). The weighted average has been calculated using the 85/15 ratio as mentioned above.

	VOC total	CO	NO_x	PM	CO_2	N_2O	CH_4
2-stroke	16.75	18	0.05	0.5	88.5	0.002	0.15
4-stroke	2.25	14.1	0.275	0.1	99	0.002	0.2
weighted average	14.575	17.415	0.08375	0.44	90.075	0.002	0.1575

Pesticide use

Pesticides were modelled based on their main active ingredients. Based on data from GIZ, the active ingredients and quantities are as follows for Nigeria. Concentrations were estimated based on literature.

	Active ingredient	Quantity (l/ha)	Concentration of A.I. (g/l)	Quantity of A.I. per hectare (g/ha)	Pesticide emissions (g/ha)		
					Soil	Water	Air
Herbicides	**Glyphosate**	3.76	250	940.00	1252.08	125.21	13.91
Insecticides	**Cypermethrin**	0.31	200	62.60	56.34	5.63	0.63
	Lambda-Cyhalothrin	0.31	200	62.60	56.34	5.63	0.63
	Deltamethrin	0.31	26	8.14	7.32	0.73	0.08

For Vietnam, data on total quantity of active ingredients was provided by the IAE, based on the report from (World Bank, 2017). This publication, together with data from (Vietnam Pesticide Association, 2016) was used to estimate average pesticide use and active ingredients for rice. Note that only the most common active ingredients were used to represent the different pesticide groups. The total quantity of pesticides was estimated by assuming the concentration of active ingredients is on average 200g/l for fungicides and insecticides and 400 g/l for herbicides.

	Quantity (l/ha)	Quantity AI/ha (g/l)	Active ingredient	Quantity of AI/ha	Pesticide emissions (g/ha)		
					Soil	Water	Air
Fungicide	3.94	788.95	Hexaconazole	789.0	710.06	71.01	7.89
Herbicide	1.27	508.12	Glyphosate	310.9	279.77	27.98	3.11
			Dimethoate	76.4	68.74	6.87	0.76
			Paraquat	120.9	108.80	10.88	1.21
Insecticide	3.80	760.72	Cypermethrin	156.88	141.19	14.12	1.57
			Chlorpyrifos	603.84	543.46	54.35	6.04

Appendix III: All environmental impact categories

Rice

Contribution analysis – white rice

Climate change impact of 1 kg white rice

	Unit	Total	Paddy rice	Packaging paddy rice	Transport farm - processor	Processing	Packaging white rice	Transport processor - end market
Irrigated Nigeria	kg CO2 eq	**1.4874**	1.0725	0.0171	0.0183	0.0890	0.1155	0.1751
Rainfed Nigeria	kg CO2 eq	**1.2154**	0.8004	0.0171	0.0183	0.0889	0.1155	0.1752
Irrigated & Rainfed Nigeria	kg CO2 eq	**1.3776**	0.9593	0.0171	0.0183	0.0923	0.1155	0.1751
Average Nigeria	kg CO2 eq	**1.3752**	0.9603	0.0171	0.0183	0.0889	0.1155	0.1751
Average Vietnam	kg CO2 eq	**2.6010**	2.1183	0.0161	0.0040	0.1108	0.1155	0.2363

Fossil resource scarcity of 1 kg white rice

	Unit	**Total**	**Paddy rice**	**Packaging paddy rice**	**Transport farm - processor**	**Processing**	**Packaging white rice**	**Transport processor - end market**
Irrigated Nigeria	kg oil eq	**0.191791**	0.0625	0.0076	0.0045	0.0122	0.0512	0.0537
Rainfed Nigeria	kg oil eq	**0.2010239**	0.0717	0.0076	0.0045	0.0122	0.0512	0.0537
Irrigated & Rainfed Nigeria	kg oil eq	**0.1948603**	0.0656	0.0076	0.0045	0.0122	0.0512	0.0537
Average Nigeria	kg oil eq	**0.1948268**	0.0656	0.0076	0.0045	0.0122	0.0512	0.0537
Average Vietnam	kg oil eq	**0.2790024**	0.1373	0.0071	0.0012	0.0152	0.0512	0.0669

Fine particulate matter formation of 1 kg white rice

	Unit	**Total**	**Paddy rice**	**Packaging paddy rice**	**Transport farm - processor**	**Processing**	**Packaging white rice**	**Transport processor - end market**
Irrigated Nigeria	kg PM2.5 eq	**0.01144**	0.008712	0.000013	0.000017	0.002378	0.000085	0.000238
Rainfed Nigeria	kg PM2.5 eq	**0.01176**	0.009031	0.000013	0.000017	0.002378	0.000085	0.000238
Irrigated & Rainfed Nigeria	kg PM2.5 eq	**0.01170**	0.008818	0.000013	0.000017	0.002525	0.000085	0.000238
Average Nigeria	kg PM2.5 eq	**0.01155**	0.008817	0.000013	0.000017	0.002378	0.000085	0.000238
Average Vietnam	kg PM2.5 eq	**0.01448**	0.008712	0.000013	0.000017	0.002378	0.000085	0.000238

Contribution analysis – paddy rice

Climate change impact of 1 kg paddy rice

Impact category	Unit	Fertilizer production	Pesticide production	Production other inputs	Transport of inputs	Irrigation pump fuel	Tractor & harvester fuel	Dryer fuel	N2O emissions	CH4 emissions	CO2 emissions urea	Straw burning
Irrigated	*kg CO2 eq*	0.0610	0.0127	0.0020	0.0180	0.0127	0.0083	0.0000	0.0853	0.3834	0.0213	0.1188
Rainfed	*kg CO2 eq*	0.0819	0.0212	0.0035	0.0239	0.0000	0.0020	0.0000	0.1099	0.1524	0.0262	0.1192
Irrigation & Rainfed	*kg CO2 eq*	0.0680	0.0155	0.0025	0.0200	0.0085	0.0062	0.0000	0.0936	0.2911	0.0230	0.1189
Average	*kg CO2 eq*	0.0679	0.0155	0.0025	0.0200	0.0086	0.0063	0.0000	0.0935	0.2920	0.0229	0.1189
Vietnam	*kg CO2 eq*	0.0790	0.0229	0.0125	0.0355	0.0417	0.0245	0.0936	0.1108	0.9008	0.0398	0.1573

Fossil resource scarcity impact of 1 kg paddy rice

Impact category	Unit	Total	Fertilizer production	Pesticide production	Production of other inputs	Transport of inputs	Straw burning	Irrigation pump fuel	Tractor & harvester fuel	Dryer fuel
Irrigated	*kg oil eq*	0.0422	0.0275	0.0030	0.0000	0.0053	0.0000	0.0039	0.0025	0.0000
Rainfed	*kg oil eq*	0.0484	0.0357	0.0051	0.0001	0.0070	0.0000	0.0000	0.0006	0.0000
Irrigation & Rainfed	*kg oil eq*	0.0443	0.0302	0.0037	0.0000	0.0059	0.0000	0.0026	0.0019	0.0000
Average	*kg oil eq*	0.0443	0.0302	0.0037	0.0000	0.0059	0.0000	0.0026	0.0019	0.0000
Vietnam	*kg oil eq*	0.0985	0.0438	0.0054	0.0003	0.0108	0.0000	0.0125	0.0074	0.0182

Fine particulate matter formation impact of 1 kg paddy rice

Impact category	Unit	Total	Fertilizer production	Pesticide production	Production of other inputs	Transport of inputs	Straw burning	Irrigation pump fuel	Tractor & harvester fuel	Dryer fuel
Irrigated	*kg PM2.5 eq*	5.878E-03	3.710E-05	1.591E-05	4.054E-06	3.406E-05	4.996E-03	1.776E-05	1.162E-05	0.000E+00
Rainfed	*kg PM2.5 eq*	6.094E-03	5.047E-05	2.663E-05	6.881E-06	4.522E-05	5.011E-03	0.000E+00	2.811E-06	0.000E+00
Irrigation & Rainfed	*kg PM2.5 eq*	5.950E-03	4.155E-05	1.947E-05	4.962E-06	3.777E-05	5.001E-03	1.189E-05	8.698E-06	0.000E+00
Average	*kg PM2.5 eq*	5.950E-03	4.150E-05	1.944E-05	4.953E-06	3.773E-05	5.001E-03	1.195E-05	8.718E-06	0.000E+00
Vietnam	*kg PM2.5 eq*	7.801E-03	4.994E-05	3.047E-05	2.506E-05	4.781E-05	6.614E-03	6.825E-05	3.409E-05	1.776E-04

Sensitivity analyses

Ecotoxicity

Freshwater ecotoxicity of 1 kg white rice (kg 1,4 DCB/kg white rice)

	Irrigated	Rainfed	Irrigated & Rainfed	Average	Vietnam rice
Cypermethrin	0.01104	0.01848	0.01351	0.01349	0.03039
Lambda-cyhalothrin	0.00871	0.01457	0.01066	0.01064	0.00027
Vanadium	0.00258	0.00258	0.00258	0.00258	0.00270
Zinc	0.00205	0.00237	0.00216	0.00216	0.00571
Copper	0.00086	0.00095	0.00089	0.00089	0.00566
Deltamethrin	0.00015	0.00025	0.00018	0.00018	0.00000
Glyphosate	0.00012	0.00021	0.00015	0.00015	0.00003
Chlorpyrifos	0.00000	0.00000	0.00000	0.00000	0.06845
Other	0.00005	0.00006	0.00005	0.00005	0.00075
Total	**0.02556**	**0.03946**	**0.03018**	**0.03014**	**0.11398**

Terrestrial ecotoxicity of 1 kg white rice (kg 1,4 DCB/kg white rice)

	Irrigated	Rainfed	Irrigated & Rainfed	Average	Vietnam rice
Vanadium	0.49665	0.49791	0.49707	0.49707	0.54328
Lambda-cyhalothrin	0.40304	0.67458	0.49329	0.49237	0.01273
Copper	0.41772	0.43083	0.42208	0.42203	0.49289
Cypermethrin	0.07709	0.12903	0.09436	0.09418	0.21225
Glyphosate	0.03644	0.06098	0.04459	0.04451	0.01008
Zinc	0.01351	0.01329	0.01344	0.01344	0.12404
Nickel	0.00802	0.00842	0.00815	0.00815	0.05149
Deltamethrin	0.00496	0.00831	0.00608	0.00606	0.00016
Lead	0.00284	0.00288	0.00285	0.00285	0.02866
Chlorpyrifos	0.00000	0.00000	0.00000	0.00000	0.25220
Remaining processes	0.00454	0.00516	0.00475	0.00475	0.02137
Total	**1.46761**	**1.83435**	**1.58949**	**1.58824**	**1.76137**

Marine ecotoxicity of 1 kg white rice (kg 1,4 DCB/kg white rice)

	Irrigated	Rainfed	Irrigated & Rainfed	Average	Vietnam rice
Lambda-cyhalothrin	0.03530	0.05908	0.04320	0.04312	0.00111
Cypermethrin	0.00796	0.01332	0.00974	0.00972	0.02191
Vanadium	0.00384	0.00384	0.00384	0.00384	0.00404
Zinc	0.00307	0.00351	0.00322	0.00322	0.00838
Copper	0.00125	0.00136	0.00129	0.00128	0.00700
Deltamethrin	0.00030	0.00050	0.00037	0.00036	0.00001
Chlorpyrifos	0.00000	0.00000	0.00000	0.00000	0.01912
Remaining	0.00015	0.00015	0.00015	0.00015	0.00093
Total	**0.05186**	**0.08176**	**0.06180**	**0.06170**	**0.06249**

Different applications of straw

Carbon footprint (in kg CO2-eq) for 1 kg of white rice

	Straw incorporated short before cultivation	**Straw incorporated long before cultivation**	**Straw burned**	**Straw removed**	**Average**
Inputs	0.1283	0.1283	0.1309	0.1309	0.1283
Transport of inputs	0.0295	0.0295	0.0295	0.0295	0.0295
N_2O emissions	0.2034	0.2034	0.1663	0.1456	0.1386
CH_4 emissions	1.0739	0.5516	0.3703	0.3703	0.4327
CO_2 emissions urea/lime	0.0340	0.0340	0.0340	0.0340	0.0340
Straw burning	0.0000	0.0000	0.3894	0.0000	0.1752
Use of irrigation pump	0.0126	0.0126	0.0126	0.0126	0.0126
Use of other machines	0.0092	0.0092	0.0092	0.0092	0.0092
Packaging paddy rice	0.0171	0.0171	0.0171	0.0171	0.0171
Transport to processor	0.0183	0.0183	0.0183	0.0183	0.0183
Processing	0.0889	0.0889	0.0889	0.0889	0.0889
Packaging white rice	0.1155	0.1155	0.1155	0.1155	0.1155
Transport to end market	0.1750	0.1750	0.1750	0.1750	0.1750
Total	**1.9059**	**1.3835**	**1.5571**	**1.1470**	**1.3751**

Organic vs synthetic fertilizer

Carbon footprint (kg CO2-eq) for 1 kg of white rice

	Organic N	Synthetic N	Average
Inputs	0.0283	0.1145	0.1283
Transport of inputs	0.0003	0.0257	0.0295
N_2O emissions	0.1566	0.1230	0.1386
CH_4 emissions	0.8889	0.4317	0.4327
CO_2 emissions urea/lime	0.0000	0.0314	0.0340
Straw burning	0.0000	0.1752	0.1752
Use of irrigation pump	0.0126	0.0126	0.0126
Use of other machines	0.0092	0.0092	0.0092
Packaging paddy rice	0.0171	0.0171	0.0171
Transport to processor	0.0183	0.0183	0.0183
Processing	0.0889	0.0889	0.0889
Packaging white rice	0.1155	0.1155	0.1155
Transport to end market	0.1750	0.1750	0.1750
Total	**1.5109**	**1.3382**	**1.3751**

Different baseline emission factors for methane

Carbon footprint (in kg CO2-eq) for 1 kg of white rice

	EF Africa Irrigation	EF World Irrigation	EF Africa Rainfed	EF World Rainfed	EF Africa All farmers	EF World All farmers	EF Asia Vietnam
Inputs	0.1131	0.1131	0.1594	0.1594	0.1283	0.1283	0.1642
Transport of inputs	0.0267	0.0267	0.0354	0.0354	0.0295	0.0295	0.0495
N_2O emissions	0.1264	0.1264	0.1629	0.1629	0.1386	0.1386	0.1546
CH4 emissions	0.5683	0.8560	0.2259	0.3402	0.4327	0.6518	1.2569
CO2 emissions urea/lime	0.0316	0.0316	0.0388	0.0388	0.0340	0.0340	0.0556
Straw burning	0.1752	0.1752	0.1752	0.1752	0.1752	0.1752	0.2149
Use of irrigation pump	0.0188	0.0188	0.0000	0.0000	0.0126	0.0126	0.0582
Use of other machines	0.0123	0.0123	0.0029	0.0029	0.0092	0.0092	0.1645
Packaging paddy rice	0.0171	0.0171	0.0171	0.0171	0.0171	0.0171	0.0161
Transport to processor	0.0183	0.0183	0.0183	0.0183	0.0183	0.0183	0.0040
Processing	0.0889	0.0889	0.0889	0.0889	0.0889	0.0889	0.1108
Packaging white rice	0.1155	0.1155	0.1155	0.1155	0.1155	0.1155	0.1155
Transport to end market	0.1750	0.1750	0.1750	0.1750	0.1750	0.1750	0.2358
Total excl LUC	**1.4873**	**1.7750**	**1.2153**	**1.3297**	**1.3751**	**1.5942**	**2.6005**

Grain storage

Carbon footprint (kg CO2-eq) for 1 kg of white rice

	Average	**Average with storage**
Inputs	0.1283	0.1283
Transport of inputs	0.0295	0.0295
N_2O emissions	0.1386	0.1386
CH_4 emissions	0.4327	0.4327
CO_2 emissions urea/lime	0.0340	0.0340
Straw burning	0.1752	0.1752
Use of irrigation pump	0.0126	0.0126
Use of other machines	0.0092	0.0092
Packaging paddy rice	0.0171	0.0171
Transport to processor	0.0183	0.0183
Processing	0.0889	0.0889

Packaging white rice	0.1155	0.1155
Storage white rice	0.0000	0.0383
Transport to end market	0.1750	0.1750
Total	**1.3751**	**1.4135**

Cashew

Contribution analysis – cashew kernel

Climate change impact of 1 kg cashew kernel

	Unit	Total	RCN	Packaging RCN	Transport farm-processor	Processing	Packaging kernel	Transport processor - end market
GAP cashew	*kg CO2 eq*	2.20426	1.35980	0.03174	0.32257	0.29252	0.09421	0.10343
non GAP cashew	*kg CO2 eq*	2.55558	1.71111	0.03174	0.32257	0.29252	0.09421	0.10343
Average cashew	*kg CO2 eq*	2.20466	1.36019	0.03174	0.32257	0.29252	0.09421	0.10343
Cashew processed in VN	*kg CO2 eq*	3.15565	1.36019	0.03174	1.18465	0.29343	0.09421	0.19143

Fossil resource scarcity impact of 1 kg cashew kernel

	Unit	Total	RCN	Packaging RCN	Transport farm-processor	Processing	Packaging kernel	Transport processor - end market
GAP cashew	kg oil eq	0.39808	0.20705	0.00764	0.08917	0.02951	0.03546	0.02926
non GAP cashew	kg oil eq	0.45991	0.26887	0.00764	0.08917	0.02951	0.03546	0.02926
Average cashew	kg oil eq	0.39778	0.20674	0.00764	0.08917	0.02951	0.03546	0.02926
Cashew processed in VN	kg oil eq	0.66211	0.20674	0.00764	0.32927	0.02963	0.03546	0.05337

Fine particulate matter formation of 1 kg cashew kernel

	Unit	Total	RCN	Packaging RCN	Transport farm-processor	Processing	Packaging kernel	Transport processor - end market
GAP cashew	*kg PM2.5 eq*	8.252E-03	1.121E-03	8.364E-05	3.668E-04	6.248E-03	8.122E-05	3.515E-04
non GAP cashew	*kg PM2.5 eq*	1.183E-02	4.696E-03	8.364E-05	3.668E-04	6.248E-03	8.122E-05	3.515E-04
Average cashew	*kg PM2.5 eq*	8.306E-03	1.175E-03	8.364E-05	3.668E-04	6.248E-03	8.122E-05	3.515E-04
Cashew processed in VN	*kg PM2.5 eq*	1.193E-02	1.175E-03	8.364E-05	3.622E-03	6.250E-03	8.122E-05	7.178E-04

Contribution analysis – raw cashew nut

Climate change impact of 1 kg raw cashew nut

Global warming	Unit	Total	N2O Emissions	Herbicide production	Insecticide production	Transport inputs	Burning cashew apple	Tractor fuel	Chain saw fuel
GAP cashew	*kg CO2 eq*	0.31114	0.13414	0.09467	0.02404	0.00179	0.00000	0.00540	0.05110
non-GAP cashew	*kg CO2 eq*	0.39152	0.11680	0.19145	0.04861	0.00361	0.02014	0.01091	0.00000
Average cashew	*kg CO2 eq*	0.31123	0.13399	0.09497	0.02411	0.00179	0.00035	0.00541	0.05061

Fossil resource scarcity impact of 1 kg raw cashew nut

Global warming	Unit	Total	Herbicide production	Insecticide production	Transport inputs	Burning cashew apple	Tractor fuel	Chain saw fuel
GAP cashew	*kg oil eq*	0.04737	0.02274	0.00555	0.00051	0	0.00163	0.01695
non-GAP cashew	*kg oil eq*	0.06152	0.04599	0.01121	0.00102	0	0.00330	0.00000
Average cashew	*kg oil eq*	0.04730	0.02281	0.00556	0.00051	0	0.00164	0.01679

Fine particulate matter formation impact of 1 kg raw cashew nut

Global warming	Unit	Total	Herbicide production	Insecticide production	Transport inputs	Burning cashew apple	Tractor fuel	Chain saw fuel
GAP cashew	*kg PM2.5 eq*	2.564E-04	1.169E-04	3.305E-05	4.854E-06	0.000E+00	7.520E-06	9.411E-05
non-GAP cashew	*kg PM2.5 eq*	1.074E-03	2.364E-04	6.684E-05	9.816E-06	7.462E-04	1.521E-05	0.000E+00
Average cashew	*kg PM2.5 eq*	2.688E-04	1.172E-04	3.316E-05	4.869E-06	1.279E-05	7.543E-06	9.320E-05

Sensitivity analyses

Influence of fertilizer use of intercrop

Environmental impact results for 1 kg of cashew kernel

Impact category	Unit	Average	Average intercropping
Global warming	*kg CO2 eq*	2.20466	2.25124
Fine particulate matter formation	*kg PM2.5 eq*	0.00831	0.00843
Terrestrial ecotoxicity	*kg 1,4-DCB*	42.74956	43.83833
Freshwater ecotoxicity	*kg 1,4-DCB*	8.61887	8.86717
Marine ecotoxicity	*kg 1,4-DCB*	2.25657	2.33873
Land use	*m2a crop eq*	77.46988	77.47076
Fossil resource scarcity	*kg oil eq*	0.39778	0.40567
Water consumption	*m3*	0.01427	0.01464

Climate change impact for 1 kg of cashew kernel

	Unit	Total	N2O Emissions	Herbicide	Insecticide	Transport of inputs	Burning cashew apple	Tractor	Chain saw	Fertilizers
Average	*kg CO2 eq*	0.31123	0.13399	0.09497	0.02411	0.00179	0.00035	0.00541	0.05061	
Average with intercropping	*kg CO2 eq*	0.32189	0.13868	0.09652	0.02508	0.00271	0.00035	0.00541	0.05061	0.00253

Changes in processing efficiency

Carbon footprint for 1 kg of cashew kernel (kg CO2-eq)

	GAP	GAP +50%	non-GAP	Non-GAP +50%	Average	Average +50%	VN processing	VN processing - 50%
Inputs	0.5188	0.5188	1.0492	1.0492	0.5204	0.5204	0.5204	0.5204
Transport of inputs	0.0078	0.0078	0.0158	0.0158	0.0078	0.0078	0.0078	0.0078
Cultivation	0.8333	0.8333	0.6467	0.6467	0.8313	0.8313	0.8313	0.8313
Packaging	0.0317	0.0317	0.0317	0.0317	0.0317	0.0317	0.0317	0.0317
Transport farm - processor	0.3226	0.3226	0.3226	0.3226	0.3226	0.3226	1.1847	1.1847
Processing	0.2925	0.4387	0.2925	0.4387	0.2925	0.4387	0.2935	0.1467
Packaging	0.0942	0.0942	0.0942	0.0942	0.0942	0.0942	0.0942	0.0942
Transport processor - end market	0.1034	0.1034	0.1034	0.1034	0.1034	0.1034	0.1914	0.1914
Total	**2.204**	**2.351**	**2.556**	**2.702**	**2.204**	**2.350**	**3.155**	**3.008**

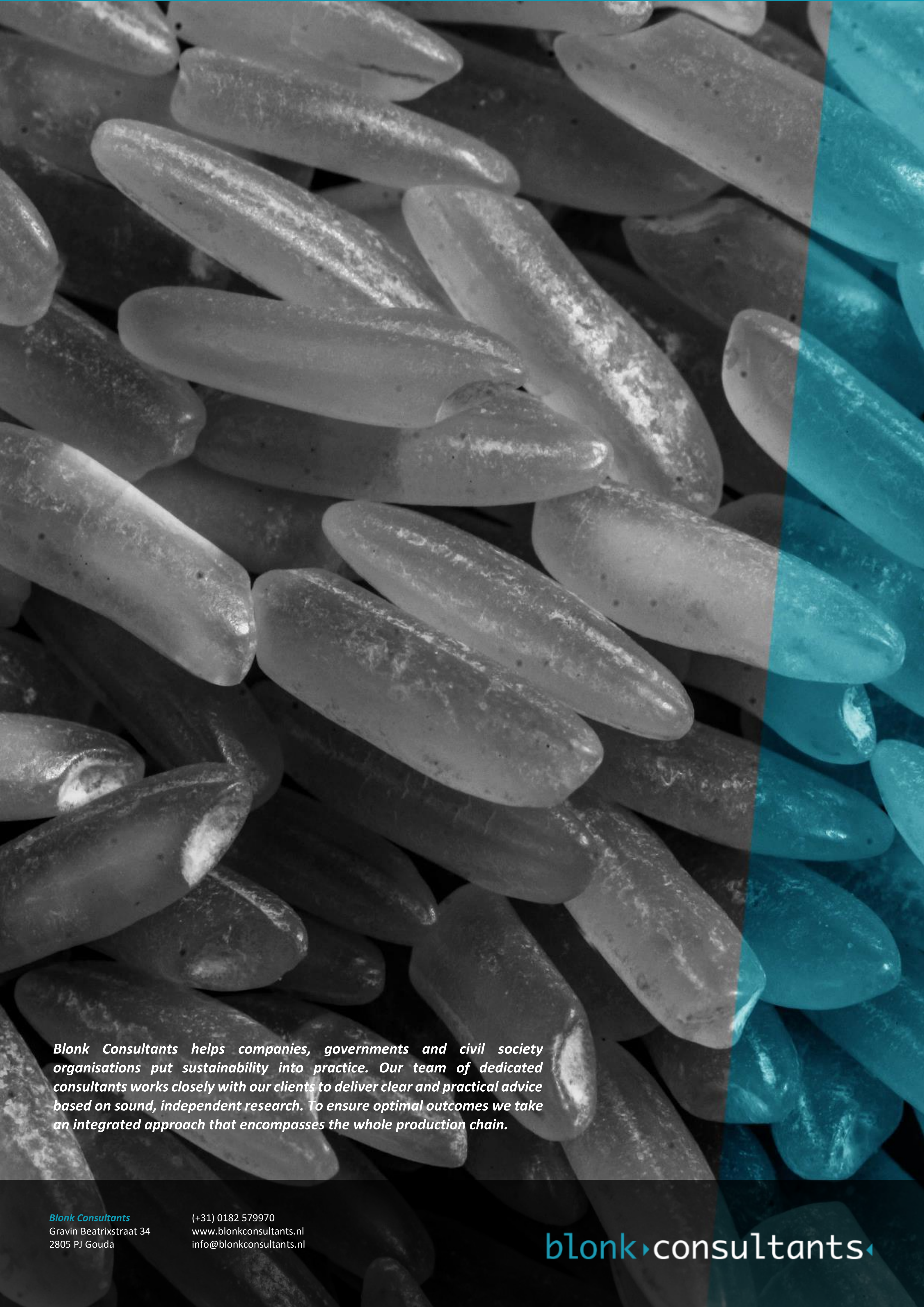
Comparison with other nuts

Environmental impact category results for 1 kg of nuts

		average	VN processing	Almonds	Cashew	Hazelnuts	Walnuts
Global warming	*kg CO2 eq*	2.20466	3.15565	2.77006	3.76564	3.01825	2.21626
Fossil resource scarcity	*kg oil eq*	0.39778	0.66211	0.58222	0.60565	0.50587	0.36197
Water consumption	*m3*	0.01427	0.01434	4.16092	6.47463	1.57357	1.50996
Fine particulate matter formation	*kg PM2.5 eq*	0.00831	0.01193	0.00900	0.00942	0.00677	0.00513

Use of cashew apple

	Average	Cashew apple sold
Inputs	0.52041	0.29855
Transport of inputs	0.00783	0.00449
N2O emissions	0.58556	0.01813
CO2 emissions urea/lime	0.00000	0.00000
Cashew apple burning	0.00053	0.00031
Use of chain saw	0.22129	0.12695
Use of tractor	0.02390	0.01371
Packaging	0.03174	0.03174
Transport farm - processer	0.32257	0.32257
Processing	0.29250	0.29250
Packaging	0.09421	0.09421
Transport processer - end market	0.10343	0.10343
Total	**2.20398**	**1.30659**



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