Federal Ministry
for Economic Cooperation
and Development

Post-Harvest Losses of Rice in Nigeria and their Ecological Footprint

Pulished by:

giz Deutsche Gesellschaft
für Internationale
Zusammenarbeit (GIZ) GmbH

German Food Partnership
GFP

CARI

SNRD Sector Network Rural Development, Africa
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Acronyms

BMZ	German Federal Ministry for Economic Cooperation and Development
CARI	Competitive African Rice Initiative
CO_2 eq.	Carbon dioxide equivalents (see Appendix 1 for explanation)
€/EUR	EURO
FAO	Food and Agriculture Organization of the United Nations
GaBi 6	Software system for life cycle engineering, developed by PE INTERNATIONAL
GHG	Greenhouse gases
GIZ	Deutsche Gesellschaft für Internationale Zusammenarbeit GmbH
GWP	Global warming potential
ha	Hectare
ibid.	ibidem – in the same place
kg	Kilogramme
km	Kilometre
LCA	Life Cycle Assessment
LCIA	Life Cycle Impact Assessment
LGA	Local Governments Areas
l	Litre
NGN	Nigerian Naira
UNEP	United Nations Environment Programme
PE	PE INTERNATIONAL AG
PHL	Post-harvest losses
SETAC	Society for Environmental Toxicology and Chemistry
WSI	Water Stress Index

Currency exchange rate: EUR 1 = NGN 214 (August 2014)

Abstract

Nigeria is currently the largest rice producer in West Africa. Due to its large population, the country is also the region's largest consumer of rice in absolute terms. Its estimated annual demand for milled rice is 5.2 million tonnes, while the average national production is 3.3 million tonnes. The supply and demand gap of 1.9 million tonnes can be bridged only by importing rice. Nigeria's rice processing capacity is 2.8 million tonnes of paddy (Jica, 2013). In spite of these sizeable food imports, the Food and Agriculture Organization (FAO, 2014) states that in 2012 about 9.4 million Nigerians or about 6 per cent of the population were undernourished and the poverty level in 2010 was estimated at 69 per cent (NBS, 2012). Given this level of poverty, food insecurity and undernourishment in Nigeria, food losses and waste, which occur along the entire food value chain, are unacceptable.

Food losses not only have effects on a social and economic scale, but also represent a waste of resources used in production such as land, water, energy and other inputs. This study considers the multifaceted impacts of food losses and thus has a twofold objective. First, it offers a sound analysis of the losses occurring along the rice value chain in Nigeria. Second, it highlights and assesses the consequential environmental impacts of the rice value chain activities.

The study is mainly based on primary data from field surveys analysing the production, processing and trading of rice in Kogi and Niger States: two states in which the Competitive African Rice Initiative (CARI) is supporting public and private sector parties along the value chain. The production chain in these two regions is typical for Nigeria and therefore representative of the entire country. The results of the two regions serve as a learning example for the rice sector in other states. The final results show an estimated post-harvest loss of 24.9 per cent, resulting in a substantial loss of revenue for farmers.

A Life Cycle Assessment (LCA) was used to evaluate the environmental impacts along the value chain of rice in Nigeria. The LCA is a standardised scientific method for the systematic analysis of environmental impacts. It covers all the processing steps from cultivation to distribution (cradle-to-shelf approach). The final product considered in this study is parboiled white rice. The following environmental impact categories are assessed: global warming potential, water stress footprint and land occupation. The impacts on biodiversity are assessed in a qualitative manner.

The post-harvest losses of rice along the complete value chain account for emissions of around 0.65 million tonnes of CO_2 eq. into the atmosphere. Consequently, halving the losses along the value chain would result in a reduction of 0.4 per cent of all greenhouse gas (GHG) emissions in Nigeria. The cultivation phase is the key contributor to global warming along the rice value chain, specifically the methane emission caused by anaerobic decomposition of organic material in flooded paddy fields. The yields from 19 per cent of the area cultivated with rice are wasted due to post-harvest losses. Even though it was found that water does not appear as an environmental hotspot in the rice value chain, the results are a clear indicator that the environmental impact caused by food losses is significant. A reduction in food losses will therefore lead to strong environmental benefits on various levels and in various impact areas.

The issue of food loss is a crucial factor in securing the stable production required to combat hunger and raise incomes. Food security is a priority area of German development policy. Therefore, the German Federal Ministry for Economic Cooperation and Development (BMZ) has launched the special unit 'One World – No Hunger' in order to intensify its dedication to alleviating hunger and malnutrition. This study, commissioned by the Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH on behalf of BMZ, contributes to these efforts.

Executive Summary

Globally an estimated 1.3 billion metric tonnes of food are lost or wasted every year; 30 per cent of the total food produced, varying among regions and crops (FAO, 2011). Significant reductions in food loss and waste would increase the amount of food available for human consumption and enhance global food security. Moreover, yields lost at farmer level constitute a loss of income and contribute to rural poverty. The issue of food losses is therefore of crucial importance in the efforts to combat hunger, raise incomes and improve food security in the world's poorest countries.

Food losses do not merely reduce the food available for human consumption: the associated externalities negatively affect society in the form of the costs of waste management, the production of greenhouse gases (GHG), and the loss of scarce resources used in their production (Vermeulen et al., 2012), as well as health risks. There are therefore additional incentives for society to aim to reduce food losses.

Food losses also mean that resources used in production including for instance land, water, energy and other inputs such as fertilisers are effectively wasted. These environmental impacts of food losses along the value chain form part of the focus of this study.

Nigeria is currently the largest rice producer in West Africa. Due to its large population, the country is also the region's largest consumer of rice in absolute terms. Its estimated annual demand for milled rice is 5.2 million tonnes, while the average national production is 3.3 million tonnes. The supply and demand gap of 1.9 million tonnes can only be bridged by importing rice. Nigeria's rice processing capacity is 2.8 million tonnes of paddy (Jica, 2013). In spite of these sizeable food imports, the Food and Agriculture Organization (FAO, 2014) states that in 2012 about 9.4 million Nigerians or about 6 per cent of the population were undernourished and the poverty level in 2010 was estimated at 69 per cent (NBS, 2012). Given this level of poverty, food insecurity and undernourishment in Nigeria, food losses and waste, which occur along the entire food value chain, are unacceptable.

Food losses not only have effects on a social and economic scale, but also represent a waste of resources used in production such as land, water, energy and other inputs. This study considers the multifaceted impacts of food losses and thus has a twofold objective. First, it serves as a sound analysis of the losses occurring along the rice value chain in Nigeria. Second, it highlights and assesses the consequential environmental impacts of the rice value chain activities.

The study is mainly based on primary data from field surveys analysing the production, processing and trade of rice in Kogi and Niger State: two states in which the Competitive African Rice Initiative (CARI) is supporting public and private sector parties along the value chain. The production chain in these two regions is typical for Nigeria and therefore representative of the entire country. The results of the two regions serve as a lesson learned for the rice sector in other states. The final results show an estimated post-harvest loss of 24.9 per cent, resulting in a substantial loss of revenue for farmers.

The data on losses in the value chain shown below in Figure 1 describes the damages and losses reported at each stage of the chain (farmers, processors, marketers). The percentages are based on various produce quantities and are therefore not part of an overall percentage. However, they do reveal significant hotspots and challenges in terms of post-harvest losses. Harvesting and parboiling are the main hotspots followed by losses occurring during milling. The retail level also contributes to losses.

A Life Cycle Assessment (LCA) was used to evaluate the environmental impacts along the value chain of rice in Nigeria. The LCA is a standardised scientific method for the systematic analysis of environmental impacts. It covers all the processing steps from cultivation to distribution (cradle-to-shelf approach). The final product considered in this study is parboiled white rice. The following environmental impact categories were assessed: global warming potential (GWP), water stress footprint and land occupation. The impacts on biodiversity were assessed in a qualitative manner.

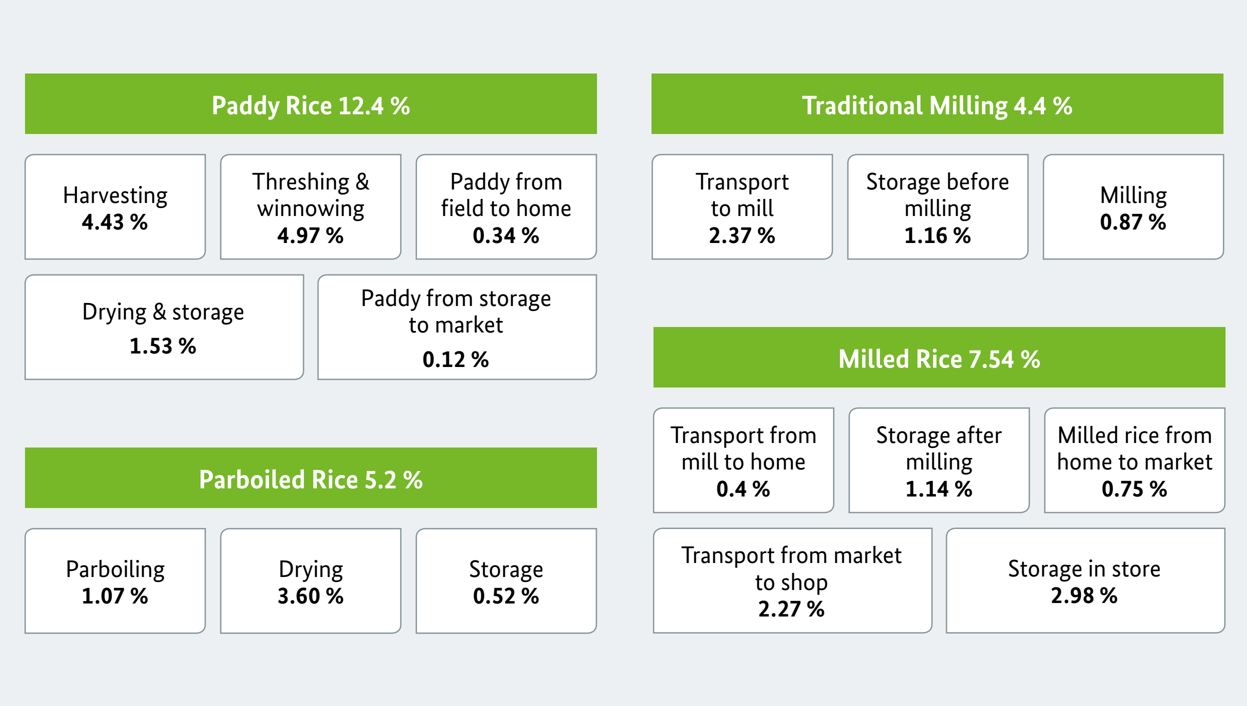

Figure 1: Synopsis of reported damage and loss occurring within various market channels

PE INTERNATIONAL conducted a LCA in accordance with ISO 14040/44 (ISO, 2006) for the environmental impacts of food losses in the rice value chain in Nigeria on behalf of GIZ. The product system under investigation covers the process steps from cultivation to distribution: cultivation, post-harvest losses (PHL), processing to final product, and transport to point of retail (cradle-to-shelf approach). The final product considered is parboiled milled rice. The geographical context is Kogi and Niger – the two major rice producing states of Nigeria. In Nigeria a distinction can be drawn between a traditional and an industrial value chain. The comparison between the two is based on 1 tonne of final product as well as its value, in order to address differences in product quality. The result of the LCA is an aggregated environmental impact of all losses along the value chain. Finally, the impacts of the present rice production in Nigeria are set in perspective by outlining the perceivable effects of potential future, improved rice cultivation and the impact of rice imported from India.

The cultivation phase is the key contributor to GWP along the rice value chain. About 80 per cent of all emissions caused until the final product is made occur on the field (91 per cent even for the industrial value chain). Methane emission caused by anaerobic decomposition of organic material in flooded rice fields is the main source of greenhouse gases (GHG). The main difference between the traditional and the industrial value chain lies in the emissions caused by parboiling on open fires in the traditional production process. However, the reduction potential shown for the industrial value chain could also be achieved in small scale processing systems, if losses are reduced and improved parboiling techniques like the use of micro-gasifiers are applied.

Looking at the entire GWP along the complete rice value chain, it can be seen that the food losses investigated in this study do indeed have a large environmental footprint. The losses in the rice value chain account for the emission of around 0.65 million tonnes of CO_2 eq. into the atmosphere. Consequently, halving the losses along the value chain would result in a reduction of 0.4 per cent of all GHG emissions in Nigeria. This gives a clear indication that reducing food losses along the rice value chain as well as increasing productivity in rice cultivation (as intended by the CARI[1] initiative) could contribute significantly to a reduction in GHG emissions on a national level. This conclusion is further strengthened by the fact that the rice currently imported from India is very likely to have a much larger GWP than rice domestically produced in Nigeria.

Even though it was found that water does not appear as an environmental hotspot in the rice value chain, the results are a clear indicator that the environmental impact caused by food losses is significant. A reduction in food losses will therefore lead to strong environmental benefits on various levels and in various impact areas.

Rice is still mainly rainfed in the regions under investigation, and because these regions are characterised by a low water stress index (WSI), water use itself does not appear as an environmental hotspot in the rice value chain. On the contrary, when the water stress footprint of rice in Nigeria is compared to the water stress footprint of rice from India, the statement about the advantage of locally produced rice can only be repeated.

The yields from 19 per cent of the area cultivated with rice are wasted due to post-harvest losses.

The impact of production systems with regard to biodiversity is difficult to quantify. Nevertheless, it can be stated that a direct link to biodiversity can be made from each impact category assessed in this report. Taking biodiversity into consideration can therefore only further add to the preventable environmental burden of food losses.

The results presented in this study constitute a major step forward in terms of gaining more insight into the dynamics of food losses and their environmental impact in Nigeria and potentially in Africa as a continent. However, further investigation, validation of the numbers generated so far and further details are needed to make more reliable quantitative claims. Nevertheless, the results are a clear indicator that the total environmental impact of all losses combined is significant, even when set in the perspective of resource use in Nigeria as a whole. A reduction of food losses in the agricultural sector will therefore lead to considerable environmental benefits on various levels and in various impact areas.

All measures to reduce losses along the value chain will in consequence also lessen the environmental impact of the final product, because fewer resources are needed and wasted to produce 1 tonne of final product. Additionally, the scenario analyses conducted in Chapter 5 give a clear indication of the options to reduce the environmental impact of the rice value chain in Nigeria. Increases in the productivity of rice cultivation, using improved stoves for traditional parboiling and substituting imported rice from India with domestic production could lead to a significant decrease in GHG emissions. Additional possible reduction strategies during cultivation to limit methane emissions include:

- The early incorporation of rice straw into the paddy soil during the fallow period or no incorporation at all (the decomposition of organic biomass while the field is flooded is the source of methane emissions).

- The application of ammonium sulphate fertiliser can also reduce the CH_4 emissions to a certain extent (Dannemann, 2009).

- Alternate drying and wetting periods, or multiple aeration periods, are also effective in the reduction of GWP (see also IPCC, 2006).

Looking at the mere figures a reduction of food losses is only one measure to reduce the ecological footprint of rice production and measures cutting methane emissions are far more potent in addressing the overall environmental impact. However, along with improving environmental performance, investing in getting more of the final product in better quality to the consumer is vital to ensure a higher food and nutrition security.

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[1] The goal of the Competitive African Rice Initiative (CARI) is to significantly improve the livelihoods of rice farmers in selected countries in Africa by increasing the competitiveness of domestic rice supply to meet increasing regional demand. CARI will be implemented in Ghana, Burkina Faso, Tanzania and Nigeria with the aim of reaching 90,000 African male and female rice producers. The direct beneficiaries of this project are male and female (at least 30 per cent) smallholder rice farmers with a daily income below USD 2. The project will aim to work with rice processors and traders as value chain anchors who provide the much needed ‘pull’ to stimulate more production of rice by smallholder farmers. The secondary beneficiaries are rural service providers, e.g. agro-dealers, suppliers and operators of agricultural machinery and rice millers improving their sourcing capacity of quality paddy. The difference CARI will make is to ensure that rice millers are the anchor to link consumers and service providers in the rice value chain and where rice farmers and rice millers meet as agribusiness partners.

1. Introduction

1.1 Background

Nigeria, almost food self-sufficient in the 1960s, has become a food-deficit country importing large quantities of foods. In 2010, the value of Nigeria's imports of food and beverages was EUR 2.974 million (NBS, 2011).[2]

About 85 per cent of Nigeria's total land area is agricultural land (78.5 million hectares) out of which 39.5 million ha is arable. Of the arable land, only 60 per cent has so far been cultivated. Presently, only 13 per cent of the country's agricultural land is irrigated (Eluhaiwe, 2010). With regard to the prevalent natural resources, there is no reason why Nigeria should be a net importer of large quantities of food.

In spite of the considerable food imports, the Food and Agriculture Organization (FAO, 2012) indicated that about 9.4 million Nigerians were undernourished, which represented about 6 per cent of the population as at 2009 while the poverty level in 2010 for Nigeria was estimated at 69 per cent (NBS, 2012). Given the level of poverty, food insecurity and undernourishment in Nigeria, food losses and waste, which occur along the entire food value chain, are unacceptable. Against this background, not enough attention has been paid to the potential for increasing food availability through a reduction in food losses and waste along the value chain. In fact, studies on post-harvest losses in the food value chain in Nigeria are scarce.

Rice is a major staple food in Nigeria. Due to its large population, Nigeria is also the region's largest consumer of rice in absolute terms. The country's estimated annual demand for milled rice is 5.2 million tonnes, while the average national production is 3.3 million tonnes. The supply and demand gap of 1.9 million tonnes can only be bridged by importing rice. Nigeria's rice processing capacity is 2.8 million tonnes of paddy (Jica, 2013).

Over the years Nigeria has attempted to increase local rice production with a view to reducing imports. It has used various tariff and levy regimes as well as imposing restrictions to discourage imports and encourage local production. Currently there is 10 per cent import tax and 100 per cent levy on the import of semi-milled or wholly milled rice (Federal Ministry of Finance, 2014). The goal of the current Federal Government's rice transformation agenda is self-sufficiency in rice production and the complete cessation of rice imports.[3]

1.2 Study Objectives

Considering the high demand for rice in Nigeria, a study designed to quantify losses and wastes along its value chains has the potential to generate information that can be used to design interventions that may be able to counter these problems and hence increase food availability.

Food losses not only reduce the food available for human consumption: the associated externalities negatively affect society in the form of the costs of waste management and the production of GHG. Food loss is estimated to be equivalent to 6 to 10 per cent of human-generated GHG emissions (Vermeulen et al., 2012).

The Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH has been studying the impact and possible prevention of food losses for a long time. Prior to this study, GIZ conducted an investigation of food losses and their environmental impact along the cassava and maize value chain in Nigeria (Oguntade, 2012; GIZ, 2013). The study clearly indicated that food losses in the two value chains have a significant impact on the environment, emitting up to 2.3 million tonnes of CO_2 eq. into the atmosphere.

This study follows the approach of its precursors. The aim is to improve data availability concerning food losses in rice value chains in Nigeria and to identify options for the public as well as the private sector to engage in rice post-harvest loss reduction

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[2] The Nigerian Naira was converted at the rate of NGN 214 to the euro.

[3] Federal Ministry of Agriculture, Rice Transformation Project Proposal.

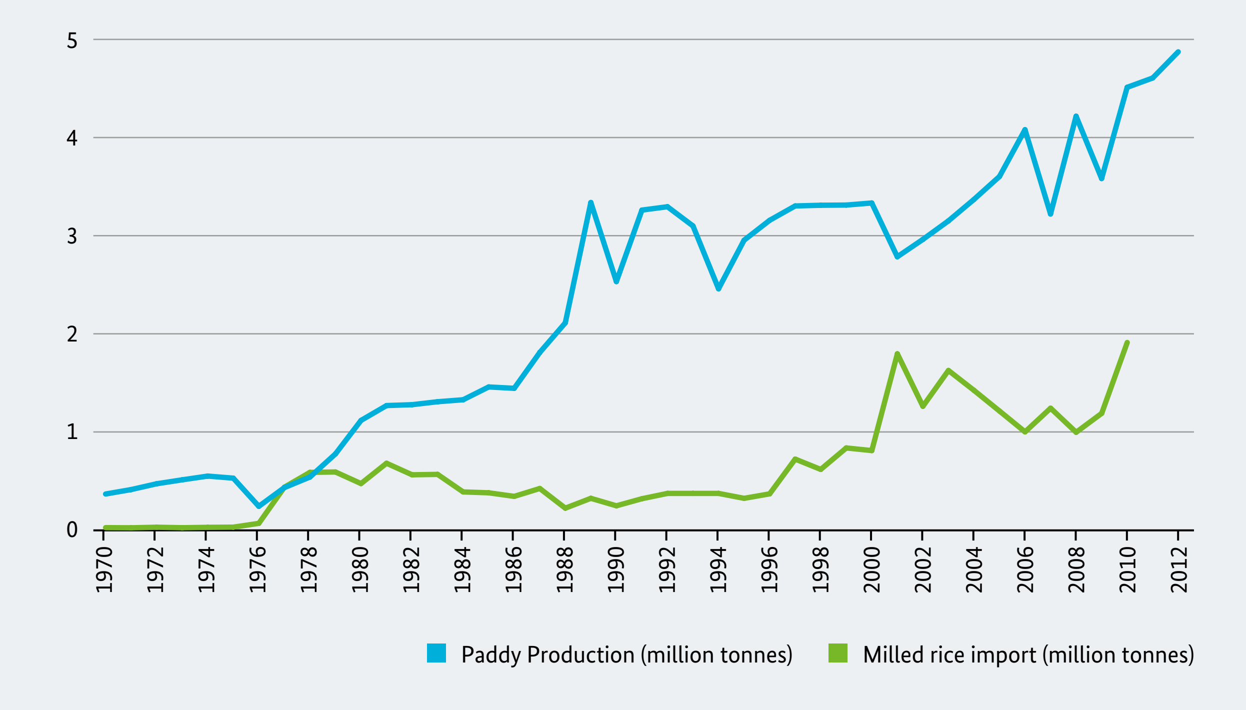

Figure 2: Rice paddy production and imports of milled rice in Nigeria. Source: FAOSTAT (2014)

programmes. The study comprises two parts: Part 1 describes and analyses the rice value chain and quantifies the losses. Part 2 builds on the insights of Part 1 and provides an estimation of the impacts of food losses on natural resources such as soil, water and biodiversity with regard to climate change (GHG).

The intended audience of this study is made up of members of GIZ and their consultants, experts in the agricultural sector (especially those dealing with PHL), policy-makers in Nigeria, LCA practitioners, and the interested public.

1.3 Study Area

Rice is cultivated throughout Nigeria, from the mangrove swamps of the Niger Delta to the arid regions near Lake Chad. However, three federal states are crucial for rice cultivation: Niger, Kogi and Nasarwa. This study has therefore selected Kogi and Niger as target areas. The dominant rice systems in these areas are irrigated lowlands, rainfed lowlands and rainfed uplands (Longtau, 2013). These systems are defined as follows (*ibid.*):

- Lowland: rainfed or irrigated rice in aquatic conditions or medium ground water table. Water covers the soil completely at some stage during the cropping season. These are called shallow swamps or fadama (irrigable land) (Figure 4).

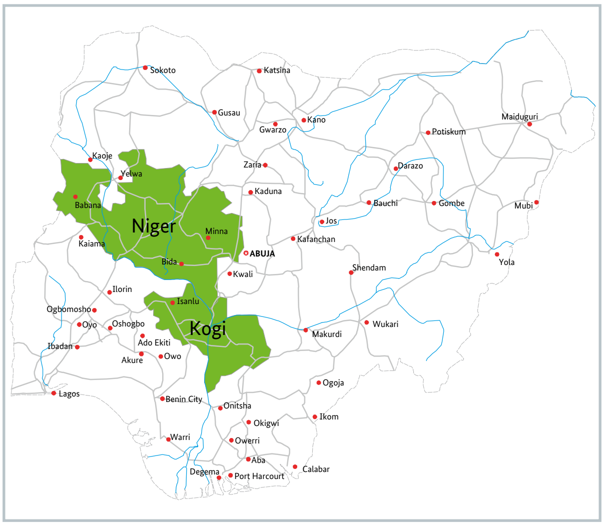

Figure 3: Administrative map of Nigeria

- Upland: rainfed rice grown on free-draining fertile soils. These are also called dry uplands.

This study focuses on lowland rice cultivation (mainly rainfed, in some places irrigated), which makes up 55 per cent of rice production in Nigeria (*ibid.*), and is even more prominent in the two target areas.

As more fertiliser is used in Niger than in Kogi, one of the main differences in term of rice production between the two states lies in the yields. Irrigation is also more widespread in Niger.

Figure 4: Rainfed low land rice cultivation system in Benin

Variable	All	Niger	Kogi
Farm Size (all crops ha)	4.7	5.73	3.60
Farm Size (rice farm ha)	2.49	3.10	1.83
Distance from farm to homestead (km)	4.04	6.05	1.84
Percentage of milled rice consumed (%)	31.2	25.00	40.66
Percentage of milled rice sold (%)	69.8	75.00	61.00
Quantity of rice seed planted (kg)	110.6	144.81	74.37
Value of rice seed planted (NGN)	8,304.34	13,468.68	3,980.81
Quantity of fertiliser applied (kg)	277.99	461.21	89.16
Value of fertiliser applied (NGN)	2,7842.5	47,156.74	8,732.54
Quantity of insecticide applied (l)	3.87	6.91	2.14
Value of insecticide applied (NGN)	3,479.28	15,444.03	2,127.69
Quantity of herbicide applied (l)	19.45	29.07	8.77
Value of herbicide applied (NGN)	19,588.1	29,638.66	8,744.31
Cost of treatment applied to infected rice field (NGN)	9,070.3	10,478.81	7,947.30
Yield of paddy harvested (year with good weather) (kg/ha)	2,963.87	3,678.75	2,248.99
Yield of paddy harvested (year with normal weather) (kg/ha)	2,127	2,332.27	1,919.64

Table 1: Description of key variables in rice production (Mean Values) in Kogi and Niger States

2. Methods

2.1 Definition of Food Losses

According to the FAO (2011), the term 'food losses' refers to the decrease in edible food mass throughout the part of the supply chain that specifically leads to edible food for human consumption. By contrast, food losses occurring at the end of the food chain (retail and final consumption) are referred to as 'food waste', which relates to retailer and consumer behaviour. Food waste is thus not covered in this study.

Five system boundaries were distinguished in the food supply chains of vegetable and animal commodities by FAO (2011):

1. Agricultural production: losses due to mechanical damage and/or spillage during harvest operation, crops sorted out after harvest, etc.

2. Post-harvest handling and storage: including losses due to spillage and degradation during handling, storage and transportation between farm and distribution.

3. Processing: including losses due to spillage and degradation during industrial or domestic processing, e.g. juice production, canning and bread baking. Losses may occur when crops are sorted out if not suitable for processing or during washing, peeling, slicing and boiling, or during process interruptions and accidental spillage.

4. Distribution: including losses and waste in the market system, at e.g. wholesale markets, supermarkets, retailers and wet markets.

5. Consumption: including losses and waste during consumption at the household level.

In this study, only food losses occurring up to the end of processing and retailing are considered (cradle-to-shelf approach – phases 1 to 4). The losses on the consumer level are difficult to estimate and always subject to high data uncertainty and are therefore not considered in this study.

2.2 Data Collection on Food Losses

2.2.1 Sampling

Various actors in the value chain in Niger and Kogi State such as farmers, marketers (wholesalers and retailers) and millers/processors were interviewed by trained enumerators. In each of Niger and Kogi States, two Local Governments Areas (LGAs)[4] that are high producers of rice were selected. Four LGAs were thus selected for the study. The sample of respondents was selected at random from a list of rice farmers and other actors along the value chain. Altogether, 211 farmers, 32 marketers and 32 millers were interviewed.

The cultivation of rice is dominated by smallholder farmers and their household members while rice paddy processing is undertaken by two separate actors using two different technologies. On the one hand there are the cottage entrepreneurs who produce basic milled rice and on the other the industrial processors who operate integrated mills and produce value-added rice (see Chapter 3). The study therefore includes data from one modern rice mill in Niger State. The geographical distribution of the sample is provided in Table 2.

2.2.2 Measurement

The pre-field data collection visits to Kogi and Niger States identified the need to use direct measurements to complement the questionnaire in order to calibrate the various volume measures that are being used along the rice value chain. Also, the measurements in use (bucket, oyomoyo, mudu and adamu – Figure 5) are not standardised across all locations. In Kogi State, bucket, oyomoyo and adamu are used while in Niger State, mudu is the common unit of measurement. Therefore, as part of the study, direct measurements were undertaken to convert the traditional measurements into weight equivalents (see Table 3).

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[4] Local Government Areas are administrative units similar to counties.

State	LGA	Farmers	Marketers	Millers
Kogi	Ibaji	52	10	10
	Idah	49	10	10
	Sub-total	101	20	20
Niger	Lavun	49	5	5
	Wushishi	61	7	7
	Sub-total	110	12	12
TOTAL		**211**	**32**	**32**

Table 2: Geographical distribution of respondents

Traditional measures	Metric equivalent (kg)	
	Kogi State	Niger State
Mudu (Paddy)	1.61	1.12
Mudu (Milled rice)	1.73	1.80
Oyomoyo (Paddy)	2.13	-
Oyomoyo (Milled rice)	3.45	-
Bucket (Paddy)	20.42	-
Bucket (Milled rice)	21.16	-
Adamu (Paddy)	178.92	-
Adamu (Milled rice)	289.80	-

Table 3: Traditional measures and their metric conversions

Figure 5: Traditional measures Oyomoyo (left), Adamu (right)

2.3 Environmental Footprint

2.3.1 Life Cycle Assessment (LCA)

In order to assess the environmental impacts of food losses in rice production in Nigeria (Part 2), an LCA in accordance with ISO 14040/44 (ISO, 2006) was carried out. LCA is a standardised scientific method for the systematic analysis of flows (e.g. mass and energy) associated with the life cycle of a specific product, technology, service or manufacturing process system in order to assess environmental impacts.

According to these standards an LCA study consists of four phases (ISO, 2006):

1. Definition of goal and scope (framework and objective of the study);
2. Life cycle inventory (input/output analysis of mass and energy flows);
3. Life cycle impact assessment (evaluation of environmental relevance, e.g. GWP); and
4. Interpretation (e.g. optimisation potential).

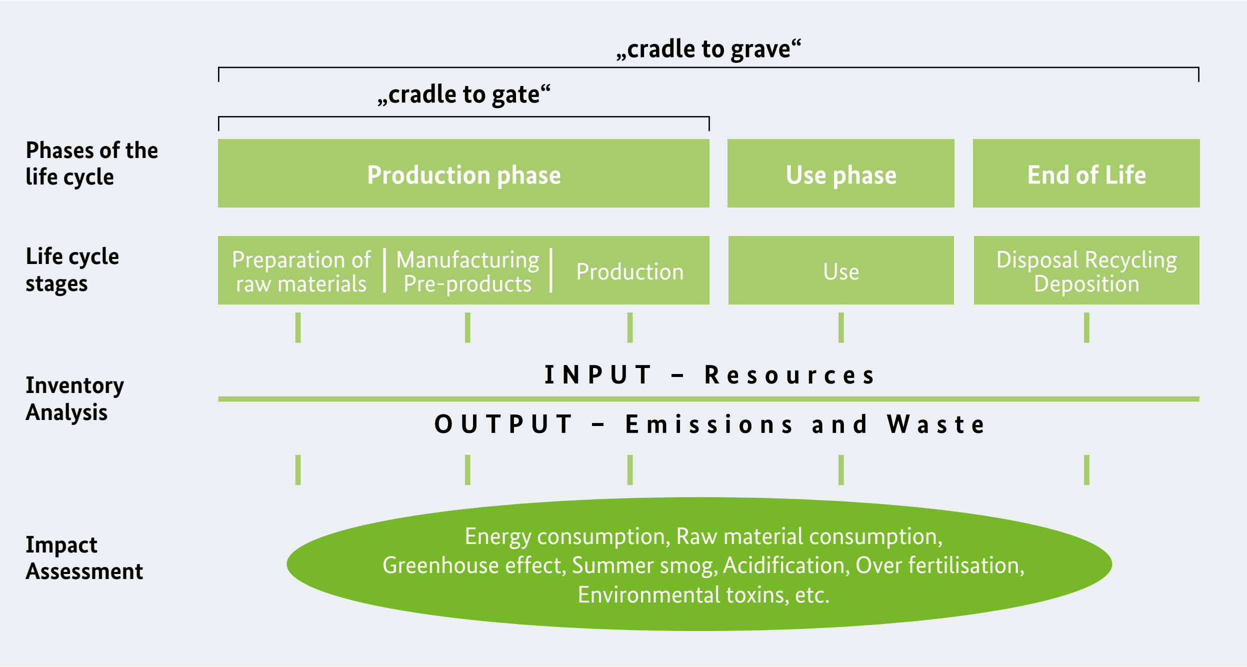

Figure 6: Principles of the LCA scheme[5]

2.3.2 Selection of Impact Assessment Categories

The study includes the following inventory flows and environmental categories:

- GWP;
- water footprint;
- land occupation.

An overview of the impact categories is given in Table 4. A more detailed description of the impact categories and the methodology used can be found in Appendix A.

The evaluation methodology for some environmental impacts is less mature. The ‘impacts on biodiversity’ are one such category. Qualitative assessments and some inventory results were used to address these impacts in this study (see Appendix B).

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[5] The LCA model is created using the GaBi 6 Software system for life cycle engineering, developed by PE INTERNATIONAL AG. The GaBi database provides the life cycle inventory data for background systems such as fuels and energy, fertiliser and pesticide production, transport emissions etc.

2.3.3 Data Collection and Treatment

The primary and secondary data collected were added to GaBi 6 background data. Table 5 provides an overview of the main production steps and the data sources.

The modelling was based on the following assumptions:

- Cultivation: Methane emissions were modelled according to IPCC (2006). The assumed system according to the IPCC classification is a rainfed water regime, drought-prone, non-flooded pre-season > 180 days;
- The irrigation water requirement is modelled based on data from Pfister et al. (2009). The values for expected irrigation water consumption for rice in Nigeria given by Pfister et al. (*ibid.*) were weighted with the share of farmers that use irrigation (3 per cent in Kogi, 24 per cent in Niger State);
- Traditional parboiling: emissions for the combustion of biomass in open fires are modelled according to Akagi et al. (2011), the amount of biomass burned is estimated based on Bakari et al. (2010);
- Losses are assumed to be either used as animal feed or to be simply discarded as organic waste, so that they leave the system burden-free and, no further treatment or burden is assumed;
- The assumptions made with regard to by-products are described in the following chapter.

2.3.4 By-product Allocation

White rice is not the only product to emerge from the mill: rice bran, rice husks and broken grains are also produced. In the traditional processing routes, these products cannot be separated and are considered waste. In their questionnaires some millers indicated that the mixture can be used as fertiliser, or animal feed. Others dispose of it as waste (Figure 7). In this study the waste of the traditional milling route leaves the system burden-free. No credit is given (which would be justified if it was used as fertiliser or feed) nor is a burden attributed to the waste (which would be justified if emissions occurred during decomposition).

In the integrated industrial milling route, rice bran, rice husks and broken grains are separated and available as valuable by-products. The husk is used as fuel for the parboiling process, so it stays within the system and no allocation of environmental burden is necessary (its contribution to the system can be seen in reduced energy demand). For the remaining three products the environmental burden of the upstream processes is distributed proportionally according to their price – a procedure known as economic allocation. Hence the burden is distributed as follows:

- White rice: 73.5 per cent;
- Broken grains: 14.5 per cent;
- Rice bran: 12.0 per cent.

Figure 7: Rice husk and bran deposited as waste behind the mill processing sites (Kogi State)

LCIA categories and indicators used to assess the environmental footprint of PHL rice and rice production in Nigeria

Category Indicator	Impact category	Description	Unit	Reference
Climate Change	Global Warming Potential* (GWP)	A measure of GHG emissions, such as CO_2 and methane. These emissions are causing an increase in the absorption of radiation emitted by the earth, magnifying the natural greenhouse effect. This impact category is also often referred to as 'Carbon Footprint', but as global warming potential is a more precise description, the term GWP is used in this study.	kg CO_2 equivalent	IPCC (2006), 100 year GWP is used
Water	Water stress footprint	The water stress footprint of a system is a set of different calculations and should be used as an umbrella term rather than to communicate a single number. Up till now, water footprinting has focused on the water lost to the watershed, i.e. water consumption. Water consumption is considered to have a direct impact on the environment (e.g. freshwater depletion and impacts on biodiversity). In the assessment of water consumption the location is crucial. This is addressed by applying the water stress index (WSI) developed by Pfister et al. (2009). See Appendix A for details.	m^3	Bayart et al. (2010) ISO 14046 (in progress) Pfister et al. (2009)
Land use (occupation)		As a sub-group of *land use* (functional dimension of land and area that is used for urban, agricultural, forestry and other purposes) *land occupation* can be defined as the maintenance of an area in a particular state over a particular period of time	hectare	ILCD (2011)

Table 4: Life cycle impact assessment categories & indicators

* The terminology 'potential' is used by ISO to clearly indicate that LCA shows possible impacts in the future. For example for climate change the GWP represents the potential impact of GHG emissions.

Overview of sources for the different stages of rice production and distribution in Nigeria

data	data source
Cultivation	Primary data from food loss survey, PE agricultural model; GaBi 6 background data, IPCC (2006)
Transport	Transport distances based on food loss survey; emissions: GaBi 6 background data
Processing	Primary data from food loss survey, traders specification, industrial integrated: NIIR Board of Consultants & Engineers (2006), World Academy of Science, Engineering and Technology (2009);
Distribution	Primary data from food loss survey; GaBi 6 background
Combustion of biomass (parboiling)	Traditional value chain: Akagi et al. (2011), Industrial value chain: GaBi 6 Database

Table 5: Overview of data sources

3. Description of the Rice Value Chain

Figure 8 shows a map of the rice value chain in Nigeria. The map indicates the operators and products at each stage of the value chain. It also indicates links between the operators across the stages. Basic milled and value-added rice are the two main final products of the rice value chain. The other products are rice flour and livestock feed.[6]

3.1 Production

At least 90 per cent of all rice farms belong to the category of subsistence smallholders with an average farm size of around 2.5 ha selling only their surplus paddy production. Cultivation includes:

- Land preparation (clearing);
- Planting (laying-out, tilling, planting);
- Weeding/farm maintenance;
- Harvesting/transportation for off-farm activities;
- Threshing and winnowing incl. consideration of losses.

Land preparation for rice cultivation is mostly done manually. Planting is done by direct seeding or broadcasting of seeds. In some instances, rice seed-

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[6] The flour millers process (broken) rice grains into rice flour while the feed millers use rice bran as one of the ingredients for livestock feed production.

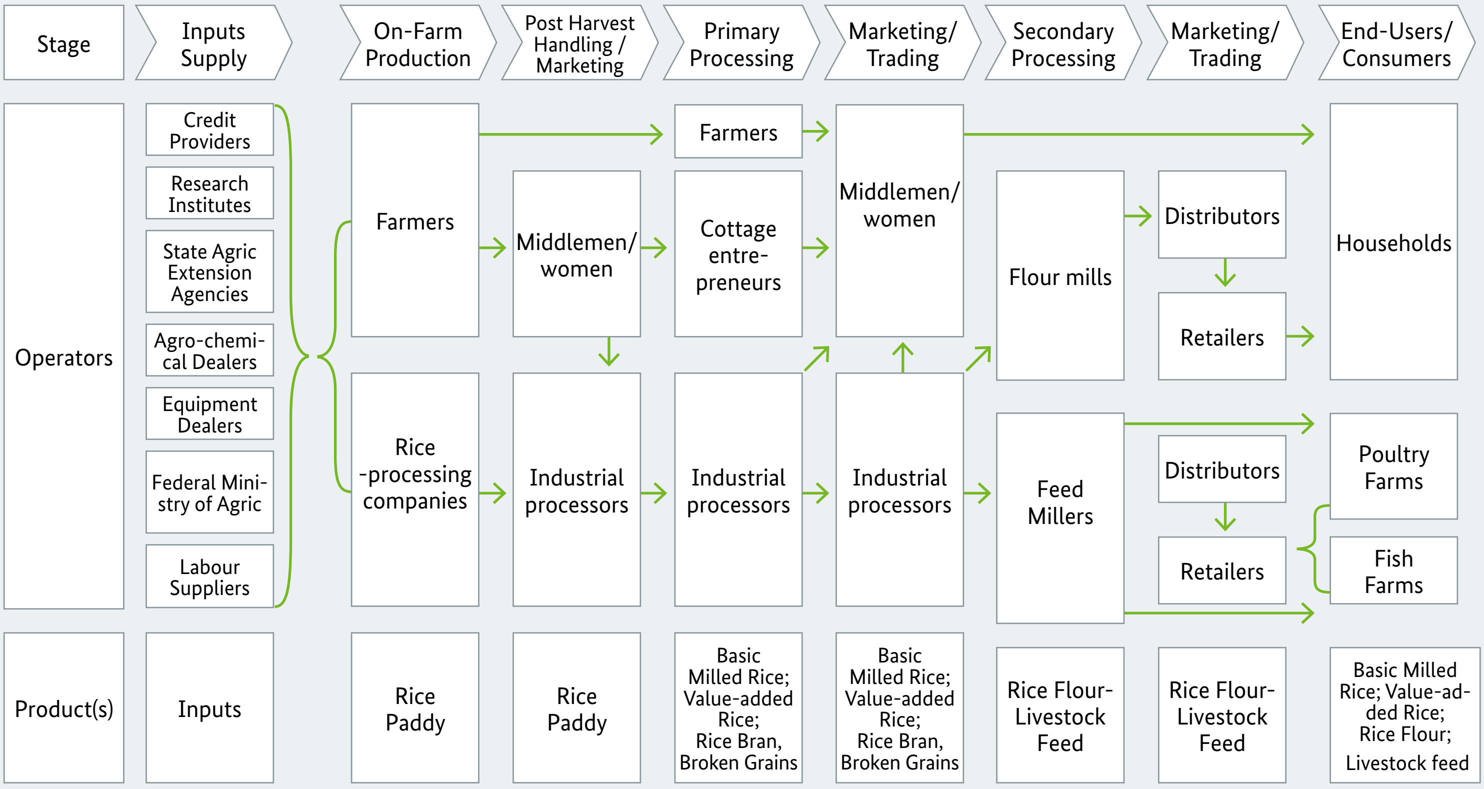

Figure 8: Rice value chain map

lings are raised in nurseries and then transplanted. Most of the rice cultivation is rainfed, but there are a few locations in Niger and Kogi States where irrigation is practised.[7] In Kogi and Niger States, rice is mostly cultivated in the flood plains. Production cycles are thus dependent on the flooding cycles.

Usually a sickle is used for harvesting (Figure 10). The paddy is then threshed (again mostly manually) against a hard object (e.g. drums, tree trunks) or the sheaves are laid on tarpaulin or the bare floor and beaten with sticks in order to separate the grain (Figure 9).

This is the first stage at which losses of rice grains can occur. It is difficult for farmers to quantify the losses during the field work due to the process itself and the environment in which it is undertaken. Drying and winnowing are often combined and usually carried out on drying floors. This dried rice, still including the husk, is called 'paddy rice'. The paddy rice is bagged, taken home, kept in storage and gradually sold by the farmers.

Figure 9: Rice threshing

Pictures taken in Benin

Figure 10: Rice harvest by sickle

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[7] Kogi State Government is promoting rice cultivation under irrigation in Lokoja along the Lokoja – Abuja expressway while irrigation is already practised in Niger State.

Variable	Options	Percentage
Type of rice	Both milled and paddy	35.6
	Milled	9.7
	Paddy	54.8
Milled rice stored at home	Yes	56.6
	No	43.4
Home consumption of milled rice	> 25 %	67.3
	25 % – 50 %	18.2
	> 50 % – 75 %	14.5
Use of waste product from milling	Animal Feed	19.1
	Used as fertiliser on farm	13.5
	Throw away	67.4
Yield of basic milled rice from paddy	Up to 50 %	8.3
	> 50 % to 70 %	25.0
	About 75 %	58.3
	About 80 %	8.3

Table 6: Information gathered from farmers processing their rice paddy in Kogi and Niger States

3.1.1 Processing

Various processing routes for paddy exist. It can be milled directly to remove the husk, and polished afterwards, to result in white rice. This way most of the nutrients are lost. This is why in the two study areas in Nigeria paddy is always parboiled. During parboiling, the rice is soaked in water, left in hot water steam and dried afterwards. This way most of the nutrients are transferred into the rice grain. The rice is milled afterwards to remove the husk. The resulting product is called parboiled white rice and considered the final product of the value chains under consideration in this study.

Two levels of processing (parboiling and milling) exist. One can be described as 'traditional', the other as 'integrated'. In the traditional processing route, rice is parboiled directly on the farms, a task usually fulfilled by women, using large pots and an open fire (fuel wood) in front of their houses (Figure 11). Afterwards the parboiled rice is dried on mats or polythene sheets on the street (Figure 12). The dried parboiled rice is then transported to local mills that provide milling as a service. Local mills operate with small diesel-driven engines (Figure 13). The removed husks and rice bran are not separated and are considered waste, though according to reports sometimes they are used as animal feed or fertiliser.

The alternative integrated industrial route combines all these processing steps. The operators buy paddy from surrounding farmers, and the parboiling, drying, milling, polishing and colour sorting are performed consecutively in a modular system. The parboiling and drying step uses thermal energy generated by the combustion of the rice husks. According to the plant operators, electricity is used only in transporting the rice from one processing step to the next. The resulting product is stone-free, colour sorted, parboiled white rice, which is generally perceived to be of high quality, and thus achieves higher prices than rice produced the traditional way.

Figure 11: Traditional parboiling

Figure 12: Drying rice after parboiling

Figure 13: Community rice mill

Pictures taken in Benin

3.1.2 Transport, Storage, Marketing

The average Nigerian's idea of good quality rice is the American long grain rice, which was first introduced into the Nigerian market under the trade name 'Uncle Ben's' in the 1970s. In the Nigerian rice market, there are various brands, all striving to meet this quality standard. Because of bagging and re-bagging under local brand names, the original sources of the products are difficult to identify. Still, some of the value-added bagged rice produced in Nigeria easily competes with imported products (Oguntade, 2011).

The bagged milled rice is transported from the mills to wholesale stores in major towns and cities in 10-tonne lorries. Usually, a 10-tonne consignment of milled rice will be shared by a number of wholesalers in the same market. In order to share the burden of transportation costs they normally combine their individual small procurements (10 – 15 bags each). The wholesalers usually sell to retailers buying one to three bags for their market stalls. The retailers display the rice in open basins. The standard volume sold to final customers is locally known as mudu (1.73 kg).

In the wholesale and retail markets, imported and local rice are both traded and it is often difficult to differentiate the value-added (polished, size and colour sorted) local rice from the imported variety. Smaller quantities of rice are packaged in 10 kg portions and sold in the urban supermarkets.

4. Results

4.1 Quantitative and Economic Losses

PHL in food value chains include both measurable quantitative and economic losses over the course of transforming food from one form to another; right from the farm gate up to the consumers' table. The quantitative loss implies a reduction of the physical substance of the product that is reflected in weight loss. The weight losses considered in this study include that due to product loss and loss of by-products due to the processing technology's inability to separately capture rice bran and husk. To measure the economic losses, the two quality standards of rice that were covered in this study, basic milled and value-added rice were compared. The difference in the market values of the two types of rice formed the basis for assessing the qualitative losses.

Outputs per tonne of paddy in traditional and integrated rice mills

At the level of milling, the input-output information for both the traditional and the integrated rice mill is provided per tonne of rice paddy (Table 7). The traditional rice mills have basic milled rice as their single output with an efficiency of 71 per cent while the integrated mills produce broken rice grains (16 per cent of input), value-added rice (55.1 per cent), rice bran (8.9 per cent) and rice husk (20 per cent). The output of the traditional system seems to be higher, yet it produces a mixture of whole grain and broken rice with an overall lower quality compared to the value-added rice of the integrated mill. The residue of the traditional mill is a mixture of broken grains, bran and husk. Most of the farmers claim they simply throw it away. In the integrated rice milling system on the other hand, broken grain and rice bran are by-products that have economic value and are sold. Rice husk as a sole residue is used instead of fuel oil to fire the mill's boiler. The integrated mill consulted in this study placed a value of NGN 180 per kg on the husk. The only waste to be disposed of is therefore the rice husk ash.

Type of Rice Mill	Product	kg	Output per Input in %	Price (NGN/kg)	Value (NGN)
Integrated	Rice bran	89	8.9	180.00	16,020.00
	Rice husk	200	20.0	180.00	36,000.00
	Broken rice	160	16.0	113.00	18,080.00
	Value-added rice	551	55.1	170.00	93,670.00
	Total	1,000	100.0		163,770.00
Traditional	Basic milled rice	710	71.0	113.42	80,528.20
	Residue	290	29.0	Nil	Nil
	Total	1,000	100.0		80,528.20

Table 7: Outputs per tonne of paddy in traditional and integrated rice mills

The financial losses were estimated in this study by comparing the two rice quality standards, basic milled and value-added rice. The price of the value-added rice was NGN 170 per kg while the basic milled rice was sold at the rate of NGN 113.42 per kg, which is about the same price the integrated mill received for its broken grains.

Furthermore, traditional rice millers are losing rice bran because of using inappropriate technology. Rice bran is a raw material for the production of livestock feed. The loss of value amounted to NGN 16,020 for the 89 kg of rice bran per tonnes of paddy. In addition, the use of rice husk to fire the boiler and parboil rice paddy in the integrated mill saves wood fuel, which is the main source of energy for parboiling rice for the traditional mills.

The value of the outputs per tonne of paddy from the traditional and the integrated mill was NGN 80,528.20 and NGN 163,770.00, respectively. The difference of NGN 83,241.80 paints a clear picture regarding the differences in the financial performance of the two technologies.

The losses per tonne of paddy and milled rice in the two selected states are similar. Table 8 therefore presents the estimates of the quantities and values of PHL incurred by rice farmers and millers for Nigeria as a whole. The annual production of 4.83 million tonnes (FAOSTAT, 2014) of paddy for the year 2012 was used as a basis for extrapolation.

The NGN 40,000 per tonne of paddy used in the calculation was the price paid by the integrated mill which was consulted for this study. NGN 113,420 per tonne of milled rice was the market price for basic milled rice. Available milled rice was estimated at 2.78 million tonnes using the figure of 4.08 million tonnes of paddy transported to the processing

Food Loss Farmers/Millers/Marketers	Mean in %	Annual production in tonnes	Quantity lost in tonnes	Price per tonne (NGN)	Value of food losses (NGN)
Damaged rice panicles during harvest	4.35	4,830,000	210,000	40,000	34 billion (EUR 159 Mio)
Threshing and winnowing of paddy	4.98	4,620,000	230,000		
Transportation of paddy from farm to home	0.23	4,390,000	10,000		
Drying of paddy	0.23	4,380,000	10,000		
Storage of dried paddy	1.37	4,370,000	60,000		
Transportation of dried paddy to the market	0.23	4,310,000	10,000		
Damaged during parboiling	1.16	4,300,000	50,000		
Parboiled paddy while drying	3.53	4,250,000	150,000		
Parboiled paddy during storage	0.49	4,100,000	20,000		
Transport of parboiled rice to processing	2.45	4,080,000	100,000		
Sub-Total	17.6	4,830,000	850,000		
Transport of milled rice from processing to home	0.36	2,786,000*	10,000	113,420	6.8 billion (EUR 31.8 Mio)
Milled rice during storage	1.08	2,776,000	30,000		
Transportation of milled rice to market	0.73	2,746,000	20,000		
Sub-Total	2.2	2,786,000	60,000		
Transport from market to shop	2.20	2,726,000	60,000	113,420	15.9 billion (EUR 74.2 Mio)
In storage	3.00	2,666,000	80,000		
Sub-Total	**5.1**	**2,726,000**	**140,000**		
Total**	**24.9**	**4,830,000** (paddy at begin of value chain) 2,580,000 (milled rice at shop)			**56.7 billion (EUR 265 Mio)**

Table 8: Quantification of post-harvest loss of paddy and milled rice for Nigeria (farmers and millers)

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* Amount of paddy rice assumed to enter processing: 4,830,000 – 850,000 = 3,980,000 t.
Input–output coefficient of the rice mills: 0.7 (see footnote 14). 3,980,000*0.7=2,780,000 t.

** see also Table 9

centres and the input–output coefficient of the rice mills (0.70).[8]

The estimates in Table 8 indicate that a total of 0.85 million tonnes of paddy valued at NGN 34 billion would have been lost by the time processing of paddy into milled rice was completed. In addition, 0.06 million tonnes of milled rice worth NGN 6.8 billion would be lost during transportation and storage before the rice got into the hands of marketers (wholesalers and retailers). This adds up to a net loss of NGN 40.8 billion.

The food losses in the course of performing the marketing functions are estimated in Table 8. The value of food loss at the marketing stage was NGN 15.9 billion.

This collated information shows that the hotspots for losses are harvesting, threshing, parboiling and milling. In order to better understand the losses along the value chain in relation to a basis quantity, Table 9 summarizes the losses converted into 'milled rice equivalents'. That means that quantities reported at different stages in the value chain are converted into the corresponding quantity of the final product. 4.83 million t of paddy are required to produce 2.58 t of milled rice (final product at shop). That means that 1 t paddy corresponds to 0.53 t 'milled rice equivalent'. The national output of paddy in milled rice equivalent was 2.58 million tonnes while the total quantity of losses in milled rice equivalent was 0.64 million. Total PHL were 24.9 per cent of milled rice equivalent of paddy output (see Table 9).

Table 10 shows the total value of PHL along the rice value chain. The total annual food loss of NGN 56.7 billion (EUR 265 million) from the harvesting of paddy to the marketing of milled rice was extrapolated, based on the loss estimates for Kogi and Niger States. It should be noted that efficiencies along the rice value chain and the prices of paddy and milled rice vary from state to state in Nigeria. The figure calculated for Nigeria is thus based on extrapolation of this study's results for Kogi and Niger States should be considered with those factors in mind.

	Quantity (million tonnes)	Milled rice equivalent (million tonnes)
National output of paddy	4.83	2.58
Paddy total lost	0.85	0.45
Milled rice lost before marketing	0.06	0.06
Milled rice lost during marketing	0.14	0.13
Total milled rice equivalents lost		0.64
Milled rice lost as a percentage of milled rice equivalent of paddy output		**24.9**

Table 9: Milled rice equivalents of PHL for Nigeria

Post-harvest Loss	Value of Post-harvest Loss (NGN)
Quantified PHL of rice paddy (farm gate to processing centre)	34 billion (EUR 159 Mio)
Quantified PHL of milled rice (processing centre to market)	6.8 billion (EUR 31.8 Mio)
Quantified PHL of milled rice at the marketing phase	15.9 billion (EUR 74.2 Mio)
Total	**56.7 billion (EUR 265 Mio)**

Table 10: Summary of rice post-harvest loss quantification

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[8] For every 1000 kg of paddy milled, the traditional mills obtained 710 kg of basic milled rice while the integrated mill obtained 160 kg of broken rice and 551 kg of value-added rice, i.e. 711 kg of rice.

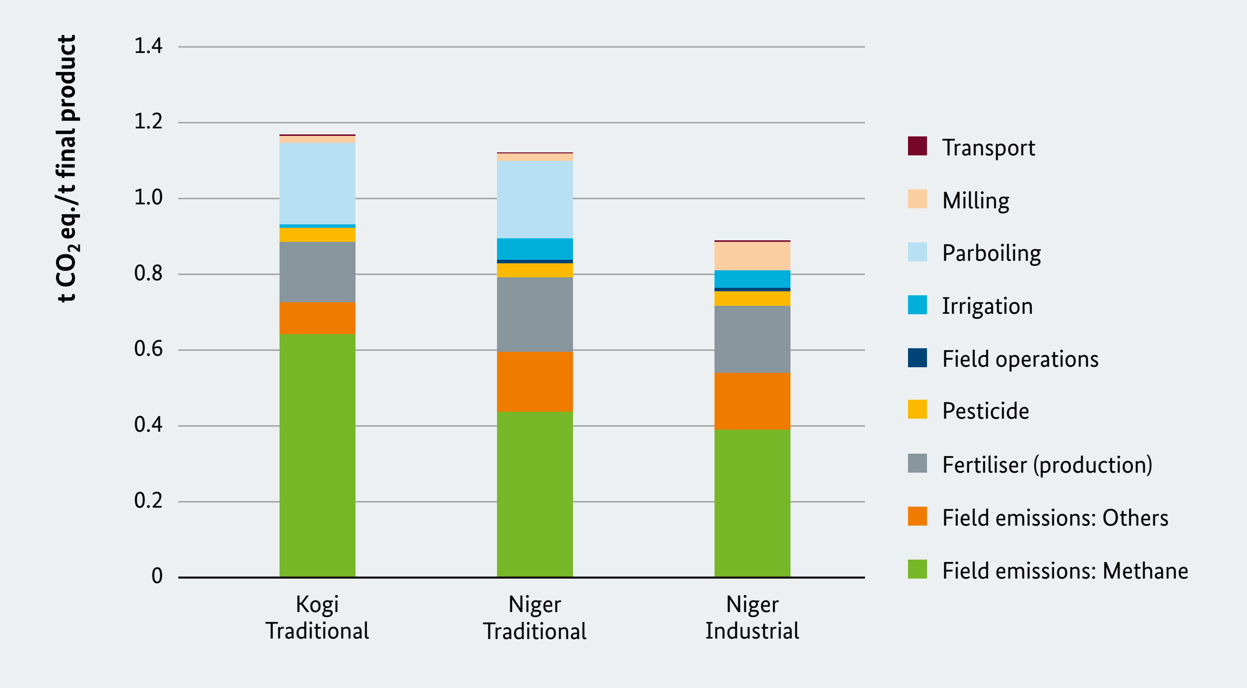

Figure 14: Contribution of various life cycle phases to the GWP of 1 tonne of rice

4.2 Environmental Impact of the Final Product

In order to understand the environmental impacts of PHL along the Nigerian rice value chain it is important to know the environmental impacts of 1 tonne of the final product (parboiled white rice) and the way in which these impacts are spread across the various lifecycle phases. The lifecycle phases along the rice value chain in Nigeria and their associated environmental impacts were defined as follows:

- **Field operations**: tractor operations e.g. sowing, fertilising, harvesting
- **Field emissions – methane:** Methane (CH_4) emissions caused by anaerobic decomposition of organic material in flooded paddy fields
- **Field emissions – others:** Other emissions than methane, into groundwater, air and soil from microbial transformation of mineral and organic nitrogen in the soil (e.g. laughing gas, nitrate). Includes benefits or impacts due to nutrient surplus or deficit. Depends on crop specific nutrient efficiency, soil parameters, previous and following crop and management practices
- **Fertiliser (production):** Impacts of fertiliser production
- **Pesticides:** Impacts of pesticide production
- **Irrigation:** Impacts caused by irrigation (water use and irrigation pump)
- **Parboiling:** Impacts caused by parboiling (use of fire wood as fuel), only traditional value chain
- **Milling:** Impacts occurring in the milling processing step (NB: in the industrial value chain, i.e. integrated mill, this life cycle phase includes parboiling)
- **Processing:** Emissions due to the energy consumption in processing
- **Transport:** All transport processes (farm, market, milling, market)

Figure 14 shows the contribution of these different life cycle phases to the GWP of 1 tonne of rice.

The GWP of 1 tonne of rice is 1.26 tonnes of CO_2 eq. in Kogi and 1.2 tonnes of CO_2 eq. in Niger per tonne of final product (parboiled milled rice) in the traditional value chain. The GWP is dominated by the methane emissions from the paddy field. The production of fertiliser used on the field and other field emissions (mainly laughing gas) also contribute significantly. But the second largest emissions occur during parboiling. Due to incomplete combustion a fraction of the carbon bound in the fuel wood is released as methane, which is 25 times more potent as a GHG than carbon (note that the CO_2 emissions

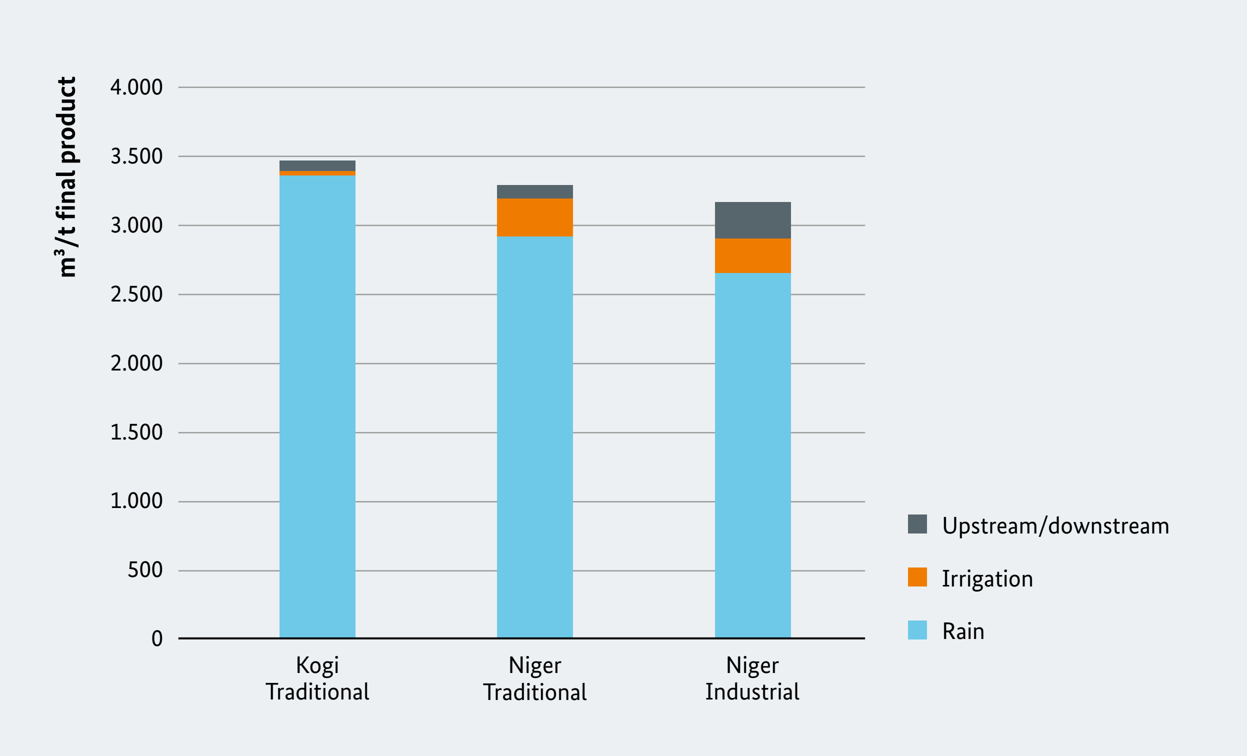

Figure 15: Contribution of various life cycle phases to total freshwater use [m^3] of 1 tonne of rice

during combustion are not accounted for, because the CO_2 was taken up in the biomass before)[9].

The differences between the Kogi and Niger value chain can be explained to a large extent by differences in rice yields. Methane emissions occur on an area basis and the higher the yield, the lower the emissions per kg of final product. As more fertiliser is used in Niger, the non-methane emissions ('other field emissions') in Niger are higher than in Kogi due to the larger availability of nitrogen. Furthermore, the emissions from irrigation (diesel consumption and combustion in irrigation pumps) are also higher in Niger as irrigation is more widespread in this region. Nevertheless, in total the GWP of 1 tonne of parboiled white rice is slightly lower in Niger than in Kogi.

The industrial value chain shows a 20 per cent lower GWP than the traditional value chain (0.96 tonnes of CO_2 eq. / tonne of final product). This can be explained by lower losses along the value chain, i.e. less paddy is needed to produce 1 tonne of final product, thus fewer field emissions are caused per tonne of final product. Further, in the industrial mill controlled combustion of biomass leads to much lower GHG emissions[10]. Additionally, as in the industrial milling process valuable by-products are produced (bran and broken grains), a fraction of the environmental burden of the upstream process can be attributed to these by-products. It is also worth mentioning that energy use in processing as well as transportation plays only a minor role in both value chains.

Figure 15 shows the contribution of different phases to total fresh water use. Fresh water use includes surface-, ground- and rain water (green water) (see Appendix A). Water use also includes water used for the provision of energy, where water used for cooling and the provision of hydro energy plays an important role.

The total freshwater use to produce 1 tonne of rice is 3,477 m^3 in Kogi, 3,297 m^3 in Niger (traditional value chain) and 3,176 m^3 in the industrial value chain. Water use is dominated by the use of natural precipi-

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[9] Please refer to Chapter 5.3 for an investigation of the influence of alternative cooking systems on the GWP.

[10] Note that in Figure 14 all emissions occurring during the industrial processing of rice are summarised in the category 'milling'.

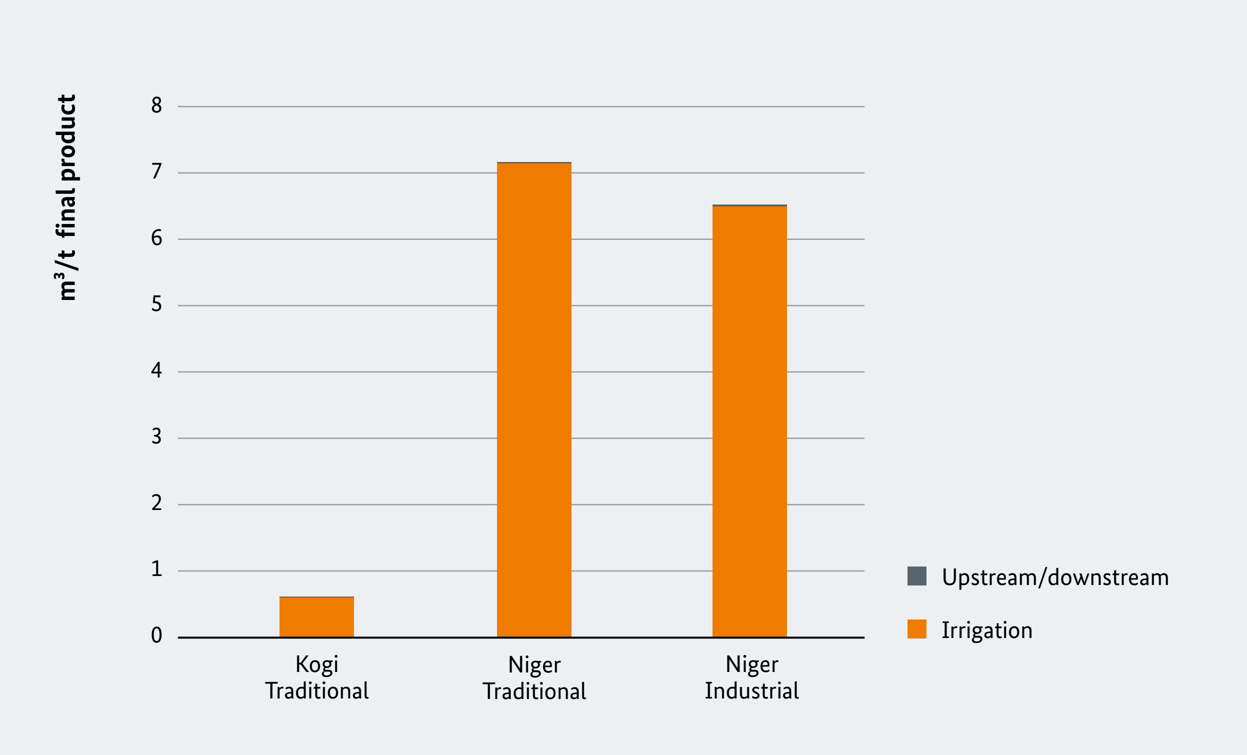

Figure 16: Contribution of different life cycle phases to water stress footprint [m^3] of 1 tonne of rice

tation. Upstream and downstream processes (provision of energy, processing) contribute little to water use. Due to the electricity used in the industrial parboiling process, the upstream water use (cooling water in generation of electricity) for industrially processed rice is a little higher than in the traditional value chain.

Following the rationale of Bayart et al. (2010) and the 'water use in LCA' – working group of the United Nations Environment Programme (UNEP) – Society for Environmental Toxicology and Chemistry (SETAC), water footprinting in an LCA context focuses on the water lost to the watershed, i.e. water consumption. Water consumption is considered to have a direct impact on the environment (e.g. freshwater depletion and impacts on biodiversity). When assessing water consumption it is crucial where the consumption takes place. In water abundant areas the effects of water consumption will have a very low impact, while in dry areas the effects will be large. This difference is addressed by applying the water stress index (WSI) developed by Pfister at al. (2009). The WSI is used to weight water consumption according to regional availability. The resulting value is known as the 'water stress footprint' (Figure 16). Rain water is not considered in that category (see Appendix A for further information).

It can be seen that only a minor fraction of the total freshwater use is relevant for environmental depletion in a narrow sense, i.e. is contributing to water stress. As rain water is not considered in that impact category, irrigation is the dominant contributor here. As only a minor fraction of farmers in Kogi use irrigation (or have access to irrigation) the water stress footprint of rice production in Kogi is smaller than in Niger. The WSI is 0.0103 in Kogi and 0.016 in Niger. This means that both areas have similar water availability and are not classified as water stressed (WSI > 0.2). For details on how the WSI is calculated and interpreted, please refer to Appendix A and Pfister et al. (2009).

The next impact category to be investigated is land occupation (Figure 17).

Occupation of land refers to the maintenance of an area in a particular state over a particular time period. Obviously this impact will be dominated by the agricultural phase, i.e. area required to cultivate the crop. Only a negligible fraction (< 0.5 per cent) of

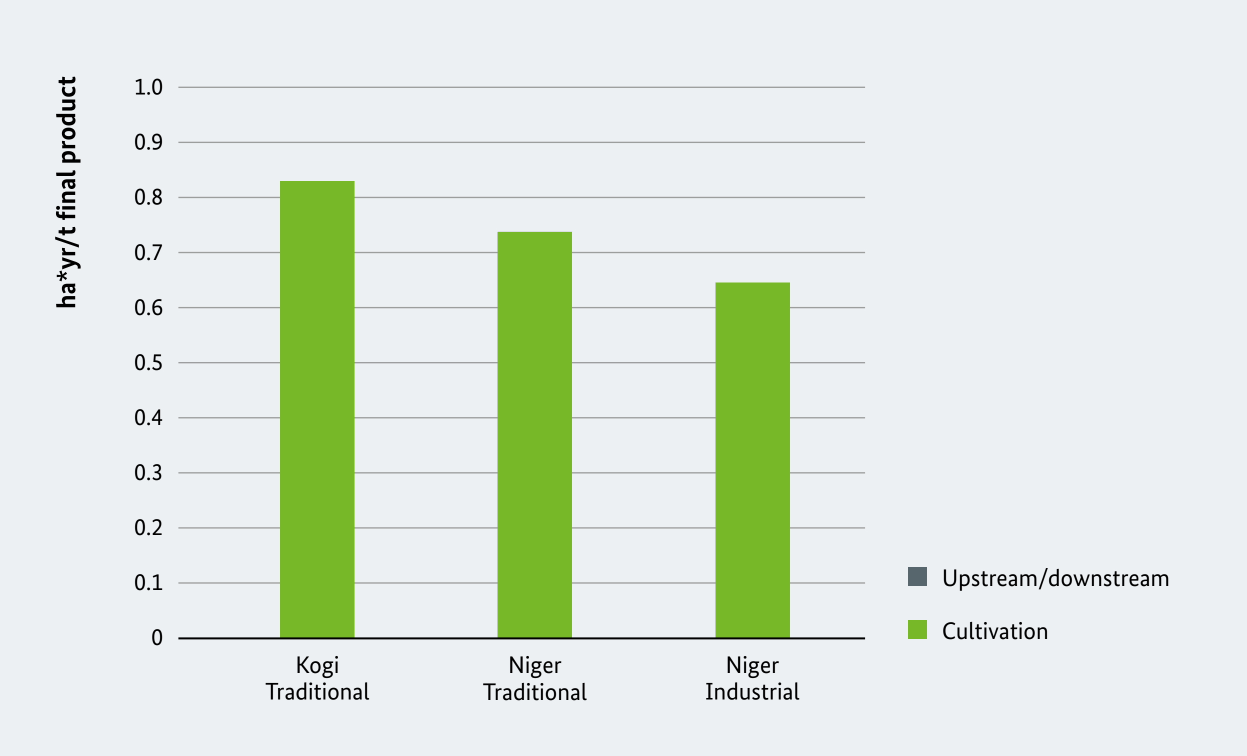

Figure 17: Contribution of different life cycle phases to land use (occupation) [ha*yr] of 1 tonne of rice

the total land occupation is associated with upstream processes. The difference between the value chain in Kogi and Niger can again be explained by the differences in yield, as the higher the yield, the smaller the area required to produce 1 tonne of final product. The differences between the industrial and the traditional value chain in Niger can be explained by lower losses and because part of the land use is attributed to the by-products generated in the industrial value chain.

4.3 Environmental Impact of Final Product – Value based

In the previous chapter, an assessment was made based on 1 tonne of final product, i.e. parboiled white rice. However, the quality of industrially processed rice is higher (stone-free, colour sorted, no broken grains) than of rice processed traditionally, as described in Chapter 4.1. This difference in quality obviously affects the price (113 NGN/kg for traditional rice, 170 NGN/kg for industrial rice) and shall be taken into account in this value chain assessment. The following figures show the environmental impact of rice per 100 NGN value of the final product (Figure 18 – Figure 20).

While the difference in GWP between 1 tonne of industrially and traditionally processed rice was 20 per cent, the GWP of industrial rice worth 100 NGN is almost half of the traditional (1.1 vs. 0.6 kg CO_2 eq. /100 NGN, 53 per cent). The same pattern is repeated in the other impact categories considered.

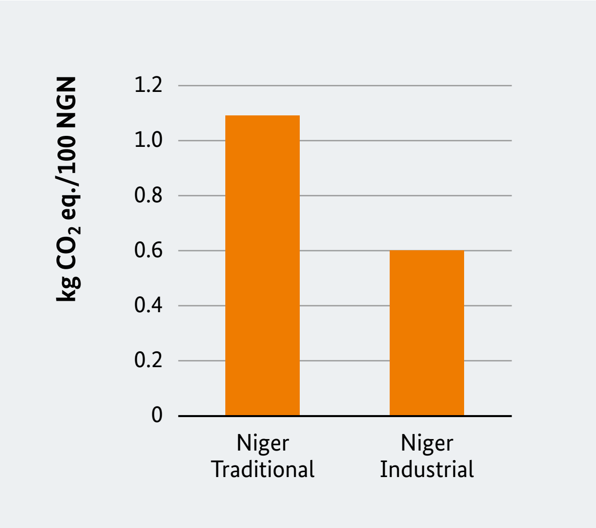

Figure 18: GWP of rice worth 100 NGN

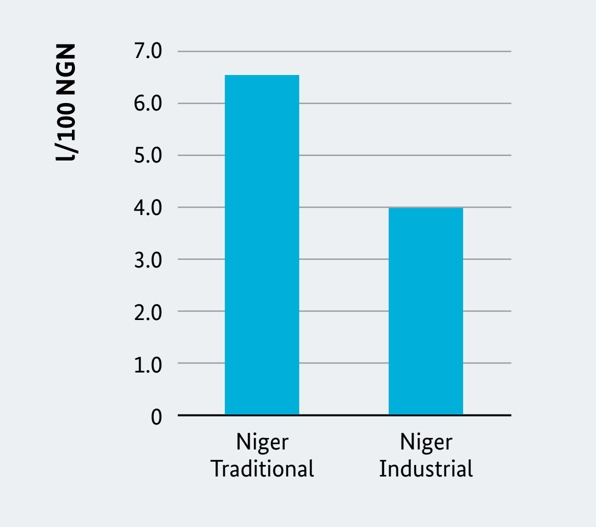

Figure 19: Water stress footprint [m³] of rice worth 100 NGN

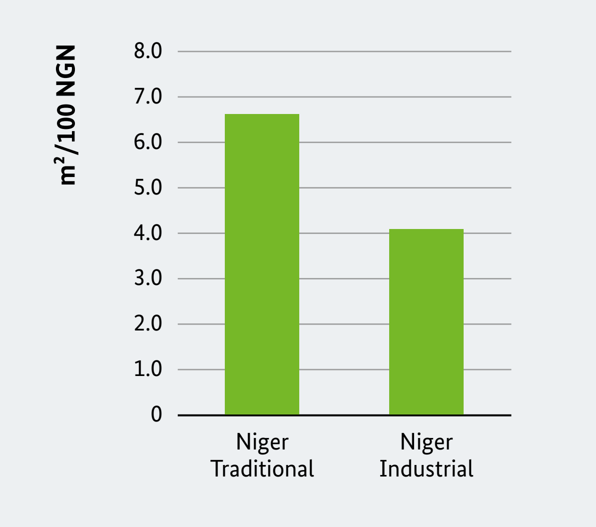

Figure 20: Land occupation of rice worth 100 NGN

4.4 Environmental Impact of Total Losses

To calculate the environmental impact of all losses along the value chain, the loss quantities as reported in Chapter 4.1 are multiplied by the impact of the product under study at the respective processing stage. Afterwards all impacts are summed up to result in the total impact in a given impact category.

The quantities lost along the rice value chain, the impact of the product per tonne and the total impact of the losses at the respective stage are listed in Table 11. The table summarises different processing steps and losses into three subcategories. The category 'paddy' refers to rice at field edge, i.e. after threshing and winnowing. Parboiled rice refers to dried rice after parboiling. Milled rice refers to rice after milling at market, incl. transport to market. Please note that the losses at marketing stage are not included, i.e. the results refer to losses cradle-to-shelf. [11]

The losses and related impacts are calculated for Nigeria as a whole, i.e. the average of the traditional value chain in Kogi and Niger is considered to be representative of the total national rice production. The industrial value chain has not been considered as no data was available on the market share of industrially processed rice in Nigeria. However, it can be assumed to be low as even the few existing industrial mills do not run at full capacity (CARI 2013). Additionally, the data for the industrial value chain in this study is based on a specific mill that had just started operation recently, so it is also questionable whether this mill adequately represents industrial rice processing in Nigeria.

The environmental burden per tonne of final product grows larger with every new loss at each successive stage in the process because all the impacts caused earlier in the process are added to the impact of the new stage. Each loss-stage is successively associated with a higher environmental burden, because impacts caused upstream in the value chain are all allocated to the product at the respective stage.

Figure 21 shows the contribution of the losses at different processing phases to the total GWP of losses in the rice value chain.

All losses occurring along the rice value chain add up to a GWP of 0.65 million tonnes of CO_2 eq. Although the environmental impact of rice per kg is still lower before parboiling (as paddy) compared to other processing phases (see Table 11), a comparatively large amount is lost at that stage. This is why the losses at this phase contribute most to the GWP of all losses.

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[11] Losses at marketing have only been included at a later stage in the study.

Processing step	Production	Loss total	Loss	GWP	Water stress	Land occupation	GWP of total loss	Water stress footprint of total loss	Land occupation of total loss
	million tonnes	million tonnes	%	tonnes CO_2 eq./ tonne	m^3/ tonne	ha/ tonne	million tonnes of CO_2 eq.	million m^3	million ha/year
Paddy	4.8	0.58	12	0.6	2.2	0.5	0.4	1.3	0.3
Parboiled rice	4.3	0.27	6	0.8	2.3	0.6	0.2	0.6	0.2
Milled rice	2.8	0.06	2	1.2	3.5	0.9	0.1	0.2	0.1

Table 11: Summary of environmental impact of rice PHL in Nigeria (production quantities of FAOSTAT, only traditional value chain considered)

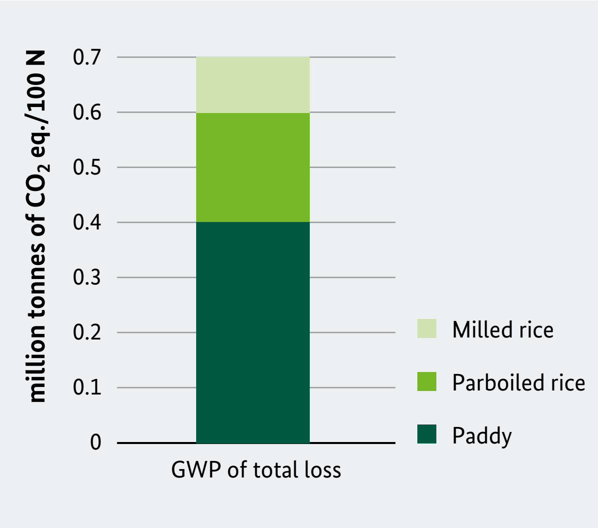

Figure 21: GWP of PHL of rice in Nigeria

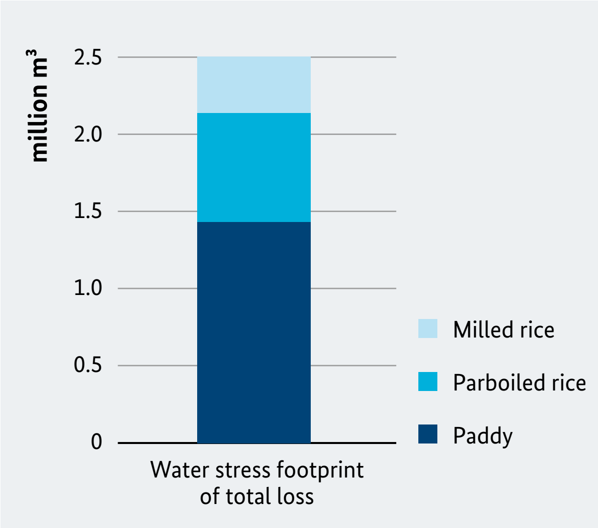

Figure 22: Water stress footprint of PHL of rice in Nigeria

Figure 22 depicts the water stress footprint of the losses of individual phases along the rice value chain.

All losses occurring along the rice value chain add up to a water stress footprint of 2.1 million m^3. The contribution of the losses at the various processing steps of this impact category is similar to the GWP.

Figure 23 shows the contribution made by the losses to land occupation at various processing phases. Taken all together, the losses account for a land occupation of 0.51 million hectares.

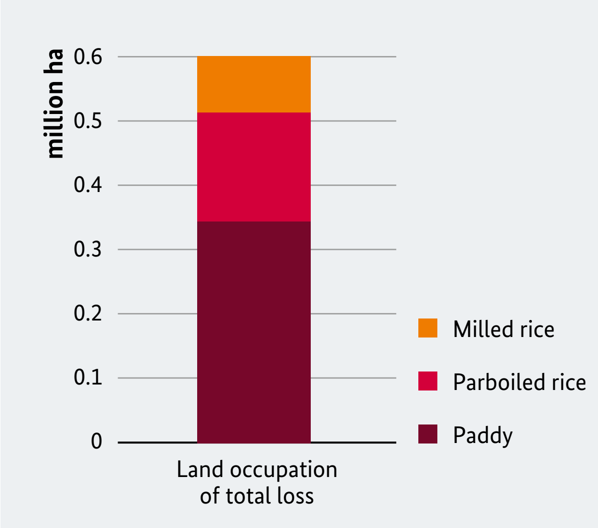

Figure 23: Land use (Occupation) of PHL of rice in Nigeria

5. Recommendations – Options for reducing food losses and their environmental footprint

About 20 to 25 per cent of the harvested rice in Asia is lost before it reaches the consumer's table (Balasubramanian et al., 2000). This study estimates a post-harvest loss of 24.9 per cent. The PHL lead to a substantial loss of revenue among farmers and therefore need to be addressed through appropriate reduction measures.

All measures reducing losses along the value chain will in consequence also reduce the environmental impact of the final product, because fewer resources will be needed and wasted to produce 1 tonne of final product. Furthermore, reduced food losses ultimately mean better food security. Making the production and processing chain of rice more efficient in terms of preserving more of the final product for consumption is not the only measure with a high potential for lessening environmental impacts. In order to find mitigation options with a specific focus on the environmental footprint, various scenarios were analysed. These scenarios use the LCA models deployed for the environmental impact assessment in previous chapters to test a number of hypothetical assumptions with regard to alterations in some key aspects in the value chain. First, the potential environmental benefit of an increased productivity (as intended by the CARI initiative) is discussed, followed by a description of the potential of improved stoves to mitigate GHG emissions. Finally, the substitution of rice currently imported from India with locally produced rice in Nigeria is tested for its environmental impacts.

5.1 Future Best Scenario – Potential Reduction of Environmental Impacts after the CARI Intervention

The CARI initiative (CARI, 2013) addresses important aspects for improving the rice value chain, which in Nigeria is largely inefficient and developing in few selected areas only. In order to assist the rice farmers, the programme is supporting both a sustainable increase in the intensity of small-scale rice cultivation and the development of inclusive business models. Such models improve access to equipment and services such as:

- Improved technology, seeds and other inputs for cultivation, threshing and harvesting;
- Appropriate parboiling and milling technology, also in order to achieve a product of high quality; and to promote the role of women within the value chain;
- Capacity building for farmers and millers.

This creates a more stable market for produce and consequently leads to a reduction in food losses.

In order to define the potential effect of the CARI initiative on the environmental impacts of rice as assessed in this study so far, a 'future best' scenario was laid out. The results calculated under this scenario were compared with the Niger industrial baseline scenario. The following assumptions were made:

- Yield increase from currently 1.9 tonnes/ha (Kogi) and 2.3 tonnes/ha in Niger to 4.5 tonnes/ha (CARI goal: 3–6 tonnes/ha);
- Optimised fertilisation (according to the removal of nutrients with the harvest);
- Improved access to pesticides (amount of pesticides applied doubled);
- Improved access to irrigation: farmers that use irrigation assumed to be 50 per cent (currently 3 per cent in Kogi and 24 per cent in Niger);

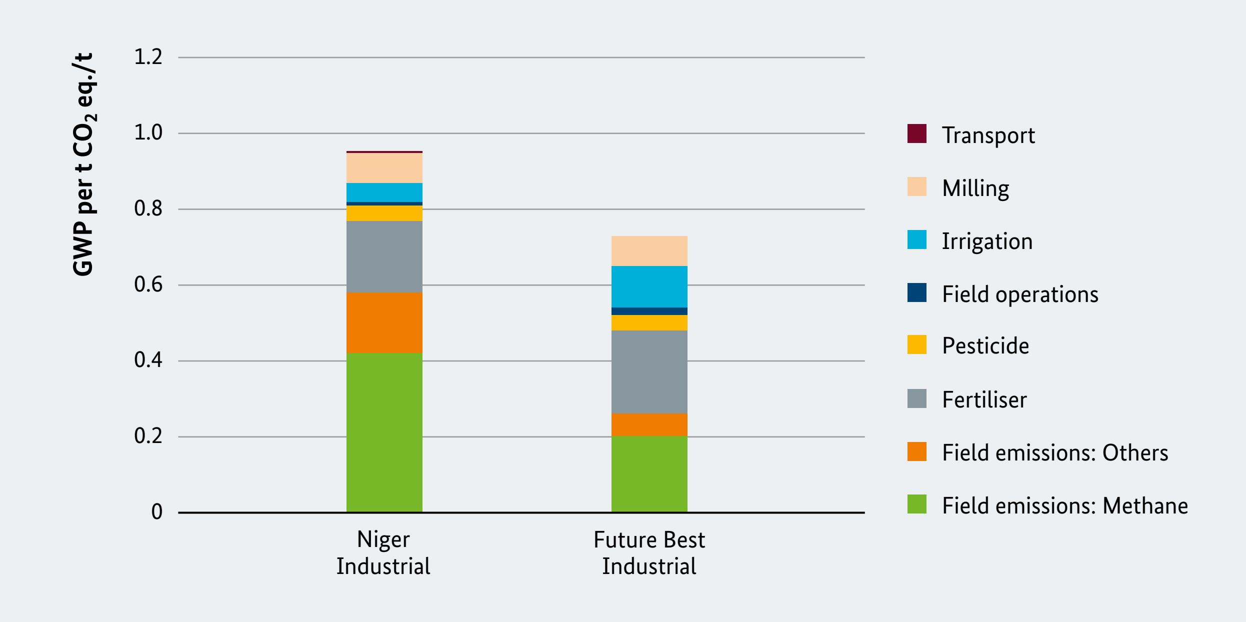

Figure 24: Contribution of different life cycle phases to GWP of 1 tonne of rice, comparison of 'Niger Industrial' and 'Future Best' scenario

- Losses during harvest, threshing and winnowing halved (due to training and improved access to technology);
- Industrial value chain considered (CARI goal: use industrial mills at full capacity).

Figure 24 compares the contribution of different life cycle phases to the GWP of 1 tonne of milled rice from the current industrial value chain (baseline scenario) and under the 'future best industrial' scenario.

It can be seen that an increase in productivity can potentially lead to reduced GHG emissions per tonne of final product (-24 per cent). If the yield is increased, field emissions are distributed over a larger quantity of rice leaving the field, hence reducing the emissions per kg (though increased fertiliser use will lead to higher absolute emissions on a per hectare basis). The increase of agricultural inputs and higher energy demands for irrigation do not even out this effect. Thus, from a global warming perspective, an increase in productivity can potentially lead to environmental benefits. The intended productivity increase of the CARI initiative could potentially lead to a reduction in GHG emissions of 1.4 million tonnes CO_2 eq., assuming a total production of milled rice of 2.78 million tonnes, all processed traditionally, compared to the same amount produced completely under the 'future best' scenario. These savings would represent a 1.8 per cent reduction of all GHG emissions in Nigeria.

However, it has to be stated that other important environmental aspects, such as eutrophication or the release of toxins into the environment, as well as social aspects of the intended productivity increase, were not assessed in this study. Such an assessment would be required before making claims about the positive impact of the planned initiative.

Figure 25 compares the results for the water stress footprint under the two scenarios.

Improved access to irrigation will necessarily lead to larger amounts of surface and ground water being consumed. With regard to water, the future best scenario does not represent an improvement (water consumption +100 per cent). However, as stated earlier, as the regions under consideration in this study are not classified as water stressed, in this case the trade-off between the use of water resources and yield increases might be resolved in favour of higher yields.

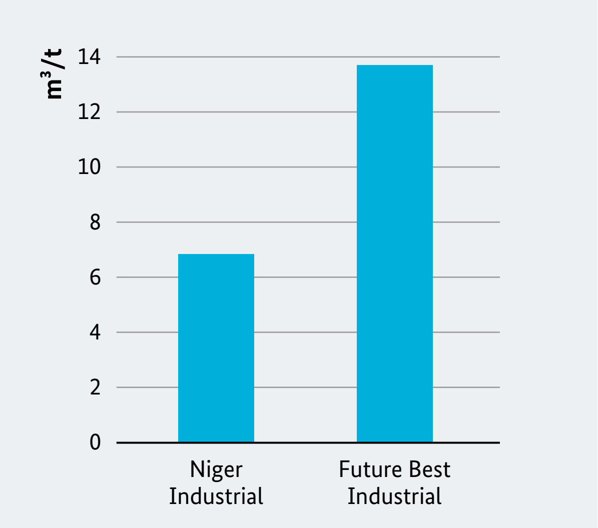

Figure 25: Water stress footprint [m³] of 1 tonne of rice, comparison of 'Niger Industrial' and 'Future Best' scenario

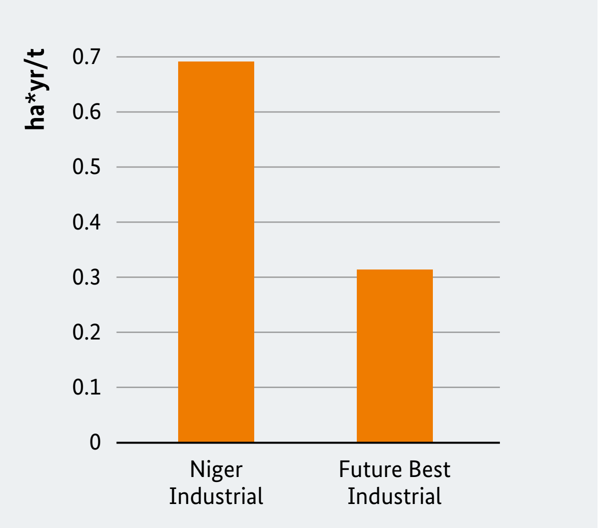

Figure 26: Land use (occupation) [ha*yr] of 1 tonne of rice, comparison of 'Niger Industrial' and 'Future Best' scenario

Figure 26 compares the results for land occupation under the two scenarios. Increased yield under the future best scenario will lead to less area required to produce 1 tonne of final product (-52 per cent).

Beside an increase in productivity, there are further possible reduction strategies during cultivation to specifically limit methane emissions. These include:

- Early incorporation of rice straw into the soil during the fallow period or no incorporation at all (the decomposition of organic biomass while the field is flooded is the source of methane emissions);
- The application of ammonium sulphate fertiliser can also reduce CH4 emissions to a certain extent (Dannemann, 2009);
- Alternate drying and wetting periods, or multiple aeration periods, are also an effective way to reduce GWP (see also IPCC, 2006).

5.2 The Reduction Potential of Using Improved Stoves for Parboiling

As shown in Chapter 4.2, emissions from parboiling contribute significantly to the GWP of rice in the traditional value chain. Parboiling in this case was assumed to be done over open fires (see also Figure 10). A variety of projects exist promoting stoves that burn biomass more efficiently and protect human health at the same time. A very promising approach is micro-gasification. Gasifiers currently provide the cleanest option for using biomass for cooking (Roth, 2014). Gasifiers make their own gas from dry solid biomass and allow users to cook with it. At the same time bio-char is created, a valuable material that can be used for various purposes (*ibid.*). Different biomass sources could be used in gasifiers. The possibility of using rice husk as fuel is of particular interest for the rice value chain. Hence, the stoves could improve the parboiling process with regard to the environment (e.g. through reduced emissions and less pressure on natural resources such as timber for fuel), economically (e.g. saved spending on fuel wood) and socially (e.g. improved health through avoided toxic emissions). It lies beyond the scope of this study to assess and quantify all of these impacts (although in general an LCA might be an appropriate tool to do so). However, at least for the GWP, the possible positive impact of using these stoves should be outlined.

Based on data from Akagi et al. (2011), it can be stated that emissions with GWP can be halved (per kg biomass burned) by using stoves instead of open fires. This assumption was used to calculate the 'stove average case' scenario (same amount of

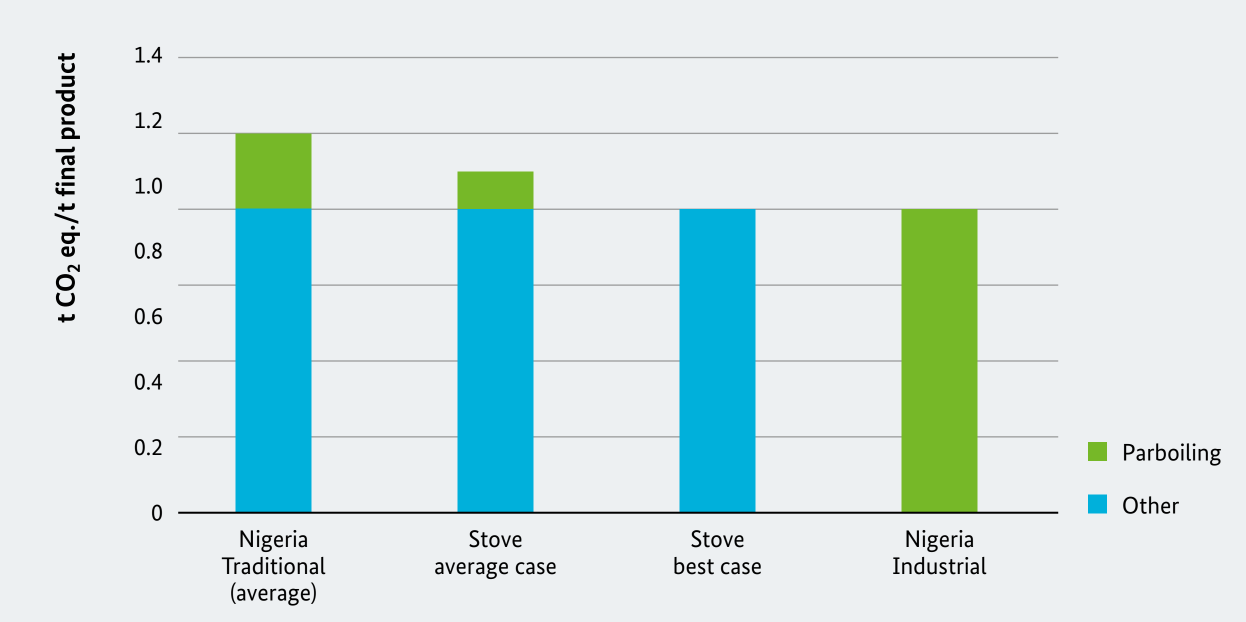

Figure 27: Potential reduction in GWP of 1 tonne of rice by using improved stoves for parboiling

biomass burned, reduced emissions). The emission with the largest effect on global warming from open combustion is methane. It is probable that these methane emissions will be completely combusted in micro-gasifiers (see also Roth, 2014). To address this point, a second scenario 'stove best case' (no methane emissions) is given. The results are shown in Figure 27.

If all methane emissions are avoided by improved gasifiers such as the micro-gasification stoves described in Roth (2014), the GWP of traditionally processed rice could be reduced by 18 per cent. In this case, traditionally produced rice would only have a slightly higher GWP than industrially processed rice (+5 per cent), at least based on volume (compare Chapter 4.3). Even if only half of the methane emissions were avoided (a conservative estimate), the GWP of the traditional rice value chain would still be reduced by 9 per cent. This is a clear indication that using improved stoves will reduce the environmental impact of the traditional rice value chain in Nigeria.

Although not quantified in this report, the possible positive effect of these stoves on biodiversity through the replacement of fuel wood with other fuel sources such as rice husks that would otherwise be wasted should be stressed. The separation of husks and rice bran is an important aspect in this regard. This would allow rice bran to be marketed as a valuable product and the husks to be used as fuel for parboiling rather than disposed of as waste. This would also prevent additional environmental damage caused by the storage of the milling waste.

5.3 Comparison of Environmental Impact of Domestic Rice Supply in Nigeria and Imports (Screening Assessment)

Despite its long tradition of rice cultivation, increased production and status as the largest rice producer in West Africa, Nigeria cannot meet its growing domestic demand for rice. As a result, the amount of imported rice has been increasing. According to FAOSTAT (2014) the largest rice exporter to Nigeria is India, both in quantity (23 per cent of total imports) and in value (11 per cent of total imports). The mission statements of various agricultural departments of the Nigerian government as well as of the CARI initiative describe the goal of replacing imported rice with domestic supply (through increased productivity in Nigerian rice cultivation). Reduction in PHL could also lead to increased local supply and thus reduce rice imports. In order to assess whether this goal can also be supported from an environmental point of view and set the results of Nigerian rice cultivation in a global context, the

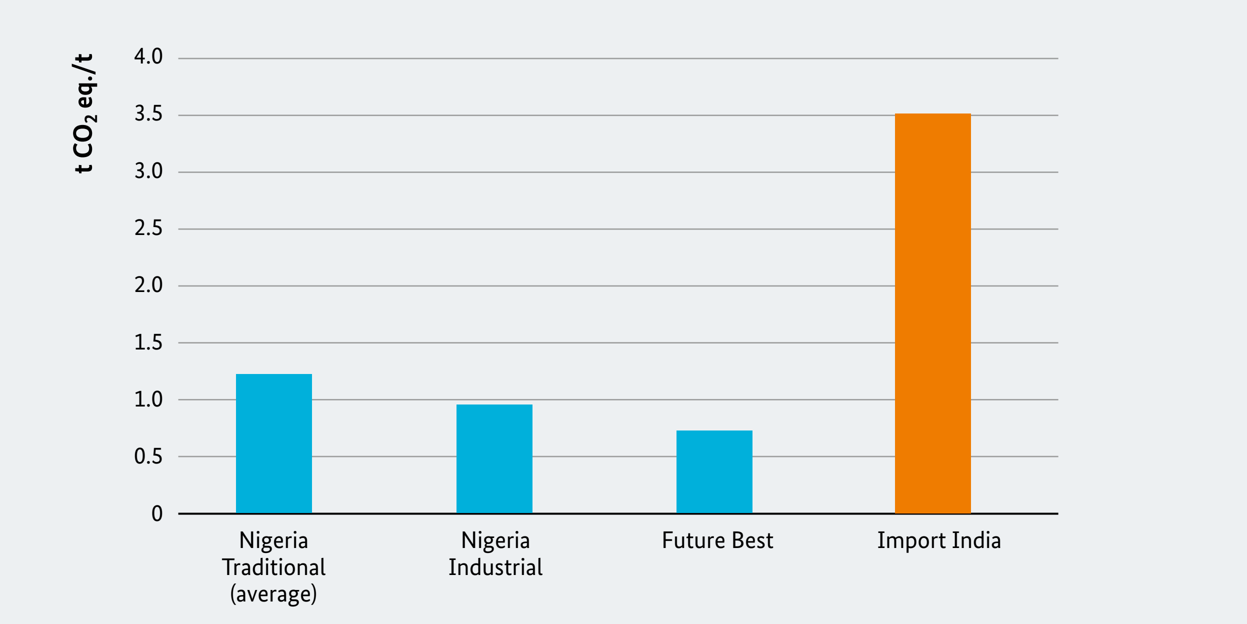

Figure 28: Comparison of GWP of domestic rice supply in Nigeria and imports (screening assessment)

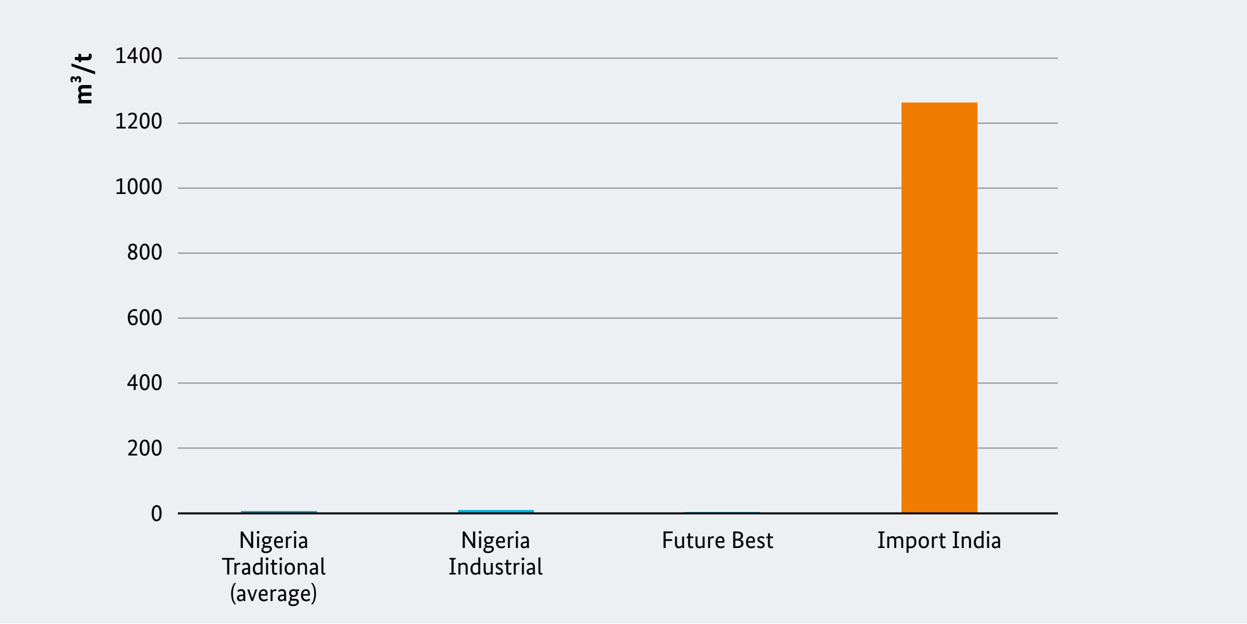

Figure 29: Comparison of water stress footprint of domestic rice supply in Nigeria and imports (screening assessment)

following chapter compares the environmental footprint of rice imported from India with the various Nigerian scenarios. The LCA data for rice cultivation in India was derived from Dannemann (2009). Two cultivation systems were investigated for India: deep water rice cropping and irrigated conventional, lowland rice cultivation. For the comparison in this study, the average of the two systems was calculated. As the system boundary in Dannemann (2009) is the field edge, the same processing was assumed as for the industrial value chain in Nigeria. Transport to Nigeria was estimated to be 13,000 km by ship. The results for the comparison of the GWP of domestic rice supply in Nigeria with imports are given in Figure 28.

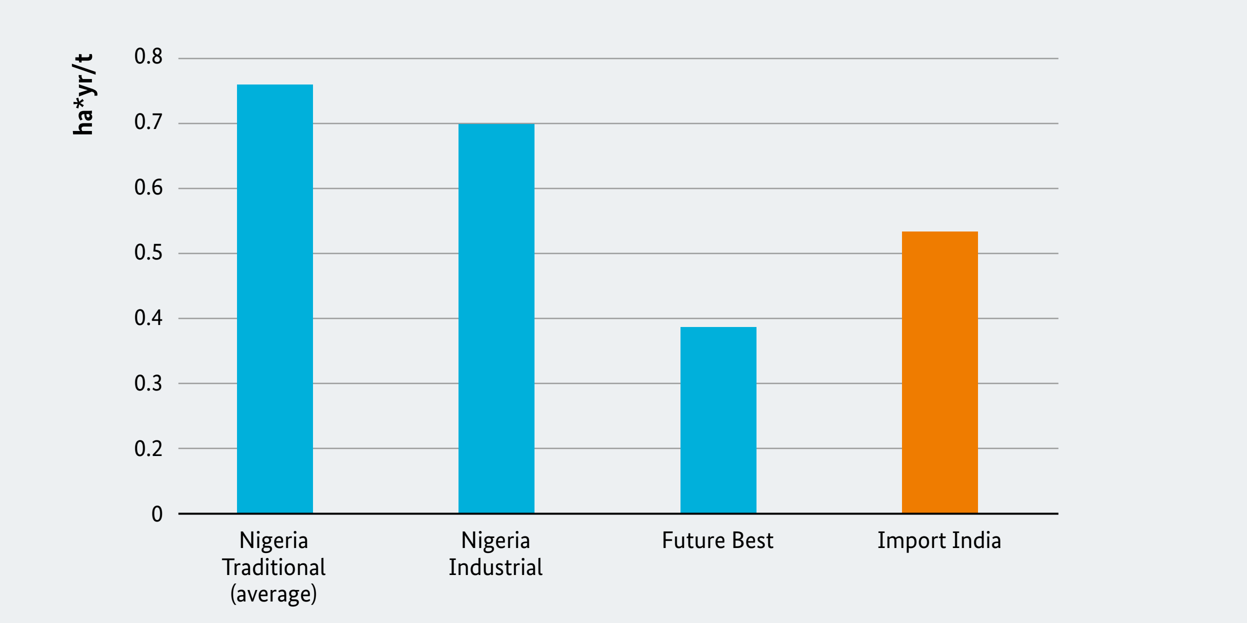

Figure 30: Comparison of land occupation of domestic rice supply in Nigeria and imports (screening assessment)

Imports from India reach Nigeria with a considerably higher GWP than the local supply. The main reason for this can be found in the different cultivation systems. The methane emissions from rice fields are directly related to the irrigation system and the duration of flooding. Both the deep water and the irrigated lowland cultivation systems lead to higher methane emissions compared to the mainly rainfed rice cultivation system in Nigeria. Transport to Nigeria adds only a minor contribution (5 per cent) to the GWP of rice imported from India. In spite of this, the results must be interpreted with care. The results for India can only be seen as a screening assessment, as they are based on secondary data and were not assessed with the same diligence as the values from Nigeria. Furthermore, possible differences in the quality of the final product are not considered. Additionally, as in the comparison of the current Nigerian rice production with a future scenario, only some specific aspects are investigated. Other environmental impacts as well as social aspects are not covered but would need to be considered to give the complete picture.

The Indian imports have also been screened for water stress. Values from Pfister et al. (2009) for rice cultivation in India were used for that purpose. The results are shown in Figure 29.

Both cultivation systems investigated in India are irrigated. This circumstance alone leads to much higher water consumption. Additionally, as the average WSI for India is 0.967 (severely water stressed), the consumption is weighted much higher, resulting in a large water stress footprint.

Figure 30 shows the comparison of land occupation of Nigerian domestic rice supply with imports from India.

As we have seen, the decisive factor for this impact category is the yield. As yields are higher in India, the land occupation is lower than in Nigeria. Only if the intended yield increases of the CARI initiative are achieved (future best scenario), will Nigerian rice be able to compete with Indian rice with regard to land occupation.

6. Environmental Footprint of Food Losses in Nigeria – Putting it into Perspective

The role of rice cultivation emissions should be put into a global perspective. Due to the methane emissions that occur while the rice fields are flooded, rice in general has a higher GWP than other staple crops such as maize, wheat or potatoes (on a kg or kcal basis). Rice cultivation alone contributes to 1.5 per cent of global GHG emissions: about the same as that of all air transportation (WRI, 2009). This is already a clear indication that combating food losses in rice value chains can have a large beneficial impact with regard to global warming. Given that rice is the staple crop contributing most towards human nutrition, the importance of addressing food losses in the rice value chain becomes even clearer.

The cultivation phase is the main contributor to GWP along the rice value chain. 80 per cent of all emissions caused until the final product is made occur on the field (even 91 per cent for the industrial value chain). That means that even losses occurring at an early stage in the value chain have a large environmental impact. This also means that tackling the large losses occurring at this stage (harvest losses 4.4 per cent, losses during threshing and winnowing 5 per cent) can contribute significantly towards an environmental benefit as well as improving to social and economic aspects.

The main difference between the traditional and the industrial value chain lies in the emissions from parboiling. In addition, the losses are lower in the industrial processing chain because all steps are done directly one after the other in a closed system and the quality of the resulting product is higher. However, improvements could be achieved in small scale processing value chains, if losses are reduced, improved parboiling techniques like micro-gasifiers are used, and processing steps that improve quality (e.g. de-stoning) are applied, which are also available on a smaller scale.

Looking at the GWP of the complete rice value chain, it can be seen that the food losses investigated in this study do indeed have a large environmental footprint. The GHG emissions into the atmosphere from losses in the rice value chain amount to around 0.65 million tonnes of CO_2 eq. per year. According to the World Bank (2013), the per capita emissions in Nigeria are 0.5 tonnes of CO_2 eq. per person and year. That would mean that the food losses in the rice value chain equal the emissions of more than one million Nigerians. Or, put differently, the emissions of around 430,000 cars in one year (7 litres of gasoline per km, 10,000 km per year). That also means that if it were possible to halve losses along the value chain, this would have the same effect as taking 215,000 cars off the roads for one year (with regard to GHG emissions). Building on data from the World Bank (2013), this would mean a reduction of 0.4 per cent of all GHG emissions in Nigeria. Although national GHG inventories have to be interpreted with care (with regard to system boundaries and assumptions), this means that reducing food losses along the rice value chain as well as increasing productivity in rice cultivation will contribute significantly to reducing GHG emissions in Nigeria. This conclusion is strengthened when considering that the rice currently imported from India is very likely to have much larger GWP than rice domestically produced in Nigeria.

Another environmental aspect considered in this study is water. Putting water use into perspective is complex. At the moment there is an ongoing debate in the LCA community on how to relate water consumption to human health, environmental health or resource depletion. The cause-effect chains are highly complex and very hard to express in numbers. Thus, no direct connection to these endpoints can be given in this report. To put the order of magnitude into perspective, we may use UNESCO's figure of 50 litres of water or 19 m^3 per person and day required to ensure their basic needs for drinking, cooking and cleaning (WWAP, 2009). The losses along the rice value chain account for a water stress footprint of 2.1 million m³ (the term refers to water that is lost for further uses). That means that the amount of water wasted with the losses could have potentially served around 110,000 people. Nevertheless, as rice cultivation is still mainly rainfed in the regions under investigation, and because these regions are characterised by a low WSI (Pfister et al., 2009), water does not appear as an environmental hotspot in the rice value chain in Nigeria. On the contrary, when the water stress footprint of rice in Nigeria is compared to the equivalent from India, the observation about the advantage of locally produced rice is further confirmed.

Land occupation is easier to set into perspective. In Nigeria around 2.7 million hectares are planted with rice in 2012 (FAOSTAT, 2014). The land required to grow the rice lost along the value chain amounts to 0.5 million ha. That means that land occupation through losses accounts for 19 per cent of cultivated area. Given the large variation between different years and possible discrepancies between area cultivated, yield, losses and production quantity within the values reported in FAOSTAT (2014) and in this study, the value corresponds neatly to the reported losses (20 per cent across the entire value chain).

The previous study on the environmental footprint of PHL in the cassava and maize value chain revealed that PHL in these value chains emit around 2.3 million tonnes of CO_2 eq. into the atmosphere and cause the deprivation of 2.8 million m³ of water[12]. The land occupied to produce the amount of rice lost along the value chain amounts to 1.7 million ha, i.e. losses account for 21 per cent of the area cultivated with maize and cassava. The production quantities in Nigeria of maize and cassava are still much higher than that of rice. Therefore, it comes as no surprise that the aggregated impacts of the PHL of these products are higher than for rice. Nevertheless, the environmental impacts of PHL of rice are within the same order of magnitude for some environmental impact categories.

Reducing food losses is an important measure in order to lessen the environmental impact along the rice value chain in Nigeria, but unlike other measures it is also vital for an improved food security in Nigeria.

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[12] Note that water deprivation was used in the previous study (GIZ, 2013). Due to the latest developments in methodology, the water stress footprint is used in this study, where water deprivation is divided by the global water stress index (see Annex A). The water stress footprint of the previous study would be 4.6 million m³.

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Appendix A: Description of Impact Categories

Global Warming Potential (GWP)

As the name suggests, the mechanism of the greenhouse effect can be observed on a small scale in a greenhouse. The same phenomenon occurs on a global scale. Short-wave radiation from the sun comes into contact with the earth's surface and is partly absorbed (leading to direct warming) and partly reflected as infrared radiation. The reflected part is absorbed by so-called GHG in the troposphere and is re-radiated in all directions, including back to earth. This results in a warming effect at the earth's surface.

In addition to the natural mechanism, the greenhouse effect is enhanced by human activities. GHGs in the atmosphere considered to be caused by, or increased through, human activity are, for example, carbon dioxide, methane and CFCs. Figure 30 shows the main processes of the anthropogenic greenhouse effect. An analysis of the greenhouse effect should consider the possible long term global effects.

The GWP is calculated in carbon dioxide equivalents (CO_2 eq.). This means that the greenhouse potential of an emission is given in relation to CO_2. Since the residence time of the gases in the atmosphere is incorporated into the calculation a time range for the assessment must also be specified. A period of 100 years is customary.

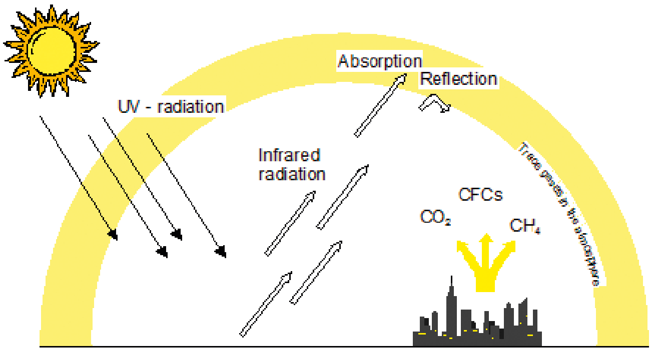

Figure 31: Greenhouse effect.

Water Footprint

TERMINOLOGY

Water use
Water use is understood as an umbrella term for all types of anthropogenic water uses. On an inventory level, water use equals the measured water input into a product system or process. In most cases water use is determined by total water withdrawal (water abstraction).

Consumptive and degradative use
Freshwater use is generally differentiated into consumptive water use (= water consumption) and degradative water use, the latter denoting water pollution:

Freshwater consumption (consumptive freshwater use) describes all freshwater losses on a watershed level which are caused by evaporation, evapotranspiration from plants[13], freshwater integration into products, and release of freshwater into the sea (e.g. from wastewater treatment plants located on the coastline). Therefore, freshwater consumption is defined in a hydrological context and should not be interpreted from an economic perspective, as it does not equal the total water use (total water withdrawal), but rather the associated **losses during water use.** Note that only the consumptive use of freshwater, not sea water, is relevant from an impact assessment perspective because freshwater is a limited natural resource.

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[13] Note: Typically, only water from irrigation is considered in the assessment of agricultural processes and the consumption of rain water is neglected. The rationale behind this approach is the assumption that there is no environmental impact of green water (i.e. rain water) consumption. Such an effect would only exist if crop cultivation results in alterations in water evapotranspiration, runoff and infiltration compared to natural vegetation. Additionally it remains arguable whether or not such changes (if they occur) should be covered by assessments of land use changes rather than in water inventories. However, rain water use is sometimes assessed in various methodological approaches or can be used for specific analyses. The GaBi software allows assessment of both water use including rain water ('Total fresh water use', 'total freshwater consumption') and without rainwater ('Blue water use' and 'blue water consumption').

Degradative water use, in contrast, denotes the use of water with associated quality alterations and describes the pollution of water (e.g. if tap water is transformed into wastewater during use). These alterations in quality are **not** considered to be water consumption.

The watershed level is regarded as the appropriate geographical resolution to define freshwater consumption (hydrological perspective). If groundwater is withdrawn for the supply of drinking water and the treated wastewater is released back to a surface water body (river or lake), then this is not considered freshwater consumption if the release takes place within the same watershed; it is degradative water use.

The distinction between freshwater use and consumption is crucial in order to properly quantify consumption, to correctly interpret the meaning of the resulting values, and for calculating water footprints (see ISO 14046 CD).

Assessment of Environmental Impacts – Water Footprinting

The water footprint of a system is a set of different calculations and should be used as an umbrella term rather than to communicate a single number. According to ISO 14046 (in progress) a water footprint consists of two parts: a water stress footprint caused by consumptive use and a water stress footprint caused by degradative water use.

Degradative use causes environmental impacts due to the pollutants released to nature. However, quality alterations during degradative use, e.g. the release of chemicals, are normally covered in other impact categories of an LCA, such as eutrophication and ecotoxicity. Methods to assess additional stress to water resources caused by reduced availability of water (due to reduced quality) are under development, but are not addressed in this study. So far, water footprinting focuses on the water lost to the watershed, i.e. water consumption. Water consumption is considered to have a direct impact on the environment (e.g. freshwater depletion and impacts on biodiversity).

In the assessment of the impacts of water consumption it is crucial where the water consumption takes place. In water abundant areas the effects of water consumption will have a very low impact, while in dry areas the impacts will be more severe. This difference can be addressed by applying the WSI developed by Pfister et al. (2009). The WSI is used to weight water consumption according to regional availability, i.e. a multiplication of consumptive water use with the water stress index (WSI_i).

The next step in water footprint calculations is a normalisation of the water deprivation with the global average water stress index (WSI_{global}). Thus the calculation builds on three figures: consumptive water use (CWU_i), the local WSI (WSI_i) and the global WSI (WSI_{global}). The resulting value is known as the ‘water stress footprint’ (Ridoutt and Pfister, 2010) and can be interpreted as normalised water consumption, i.e. the amount of water as if it were consumed on a global level. This normalisation facilitates the comparison of water consumption in different regions.

The Water Stress Footprint (caused by consumptive use)

$$WSF = \sum_i \frac{CWU_i \times WSI_i}{WSI_{global}}$$

WSI_i: regional water stress index
WSI_{global}: global average water stress index (value: 0.602)

Only results on impact level (i.e. after application of the WSI) should be labelled as water footprint. The simple aggregation of water inputs or inputs and outputs on an inventory level represents water accounting and should be expressed as such.

See the publication of Pfister et al. (2009) for details on the data on which the WSI is based and how it is calculated. The water stress footprint caused by consumptive water use is documented in Ridoutt & Pfister (2010).

There are at least two different frameworks for the calculation of water footprints. On the one hand there is the approach applied in this study as defined by the ISO, and on the other the water footprint as described by the Water Footprint Network (2014). Although the approaches differ they can also complement one another (Boulay et al., 2013).

Biodiversity

In the United Nation's Convention on Biological Diversity, the term 'biodiversity' is defined as 'the variability among living organisms from all sources including, inter alia, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part; this includes diversity within species, between species and of ecosystems'. The Millennium Ecosystem Assessment, a study commissioned by the United Nations Environmental Programme, emphasises the importance of conserving biodiversity in order to ensure an environmental balance and human well-being. It identifies terrestrial and aquatic habitat change, invasive species, overexploitation of wild populations, pollution and climate change as the most important direct drivers of biodiversity loss. Methods on how to assess impacts on biodiversity within an LCA framework are still under development (please refer to Appendix B for further information).

Appendix B: Qualitative assessment of impact on biodiversity

This chapter is based on the qualitative assessment of the impacts of PHL of maize and cassava in Nigeria on biodiversity (GIZ, 2013). Some specific aspects of the rice value chain are considered.

Biodiversity in the Food Supply Chain

Food production and the consumption of raw materials rely on living natural systems. The impacts of agriculture on biodiversity vary according to the production system, but all cultivation practices intervene in the ecosystems, e.g. by converting forests into agricultural cropland, by using water, by increasing soil erosion and by emitting GHGs. At the same time the capability of many ecosystems to cope with these changes is diminishing (UNEP, 2005). Food loss is linked to biodiversity, because even if a certain amount of food is not used or consumed, its production affects the biodiversity of ecosystems without directly benefiting human society.

Impact of Food Production on Biodiversity within an LCA

For environmental impacts such as those on biodiversity and land use the evaluation methodology in LCA is not yet fully developed. The assessment of these impacts is ‘recommended, but to be applied with caution’ (ILCD, 2011). Various approaches have been put forward. Curran et al. (2011) for instance suggest using existing LCA impact categories to assess the impact on biodiversity. According to Curran et al. (2011), the connection of LCA midpoint impact categories to biodiversity loss are as follows:

- **Land use change** – The UNEP (2005) states that in the past years, the increase in food demand has led to an intensification of cultivation systems. Both, the expansion of production areas and the production of biofuels has led to the conversion of natural or close-to-natural land use types into managed ones. This conversion of natural habitat to human use has been the main driver of biodiversity loss over the past decades.
- **Water use** – water polluted through anthropogenic activities not only reduces regional resource availability but also affects the functioning and diversity of water-dependent terrestrial and freshwater ecosystems.
- **Climate change** – Changing temperature, precipitation, and seasonality are expected to cause the extinctions of a large number of species over the next century. These changes in climatic condition are in turn exacerbated by anthropogenic GHG emissions.
- **Acidification and eutrophication** – These issues lead to a disruption of the natural nutrient balance, altering the habitat condition and the species composition in ecosystems, and are therefore responsible for a loss of biodiversity.
- **Ecotoxicity** – This refers to the potential of biological, chemical and physical stressors to affect ecosystems. Stressors can occur in the natural environment or can be introduced to ecosystems through human activity. Their concentration can reach levels high enough to alter the natural biochemistry, physiology, behaviour and interactions of the living organisms that comprise an ecosystem. The use of chemicals in farming has the potential to cause ecotoxicological effects by reaching organisms through the pathways of air, water and soil.

This study covers two of the impact areas mentioned by Curran et al. (2011), water use and climate change. Before discussing the results with regard to their impact on biodiversity, the following section offers a brief outlook on ‘land use change’ – to be added as indicator for the impact on biodiversity.

Land Use Change as an Indicator for Impact on Biodiversity

Land use change in Nigeria shows an intensification of cultivation systems. According to FAO Statistics (FAOSTAT, 2014), forest area in Nigeria has decreased at a constant rate over the past 20 years. At the same time the area on which rice was being cultivated increased. It cannot be clearly stated whether these increases are achieved at the cost of other crops or through deforestation. However, considering the decrease in forest area, it is likely that at least some of the increases in production and cultivated area of rice are due to the displacement and cutting down of forests. Additionally, the consumption of fuel wood for traditional parboiling is also expected to add pressure on forest resources.

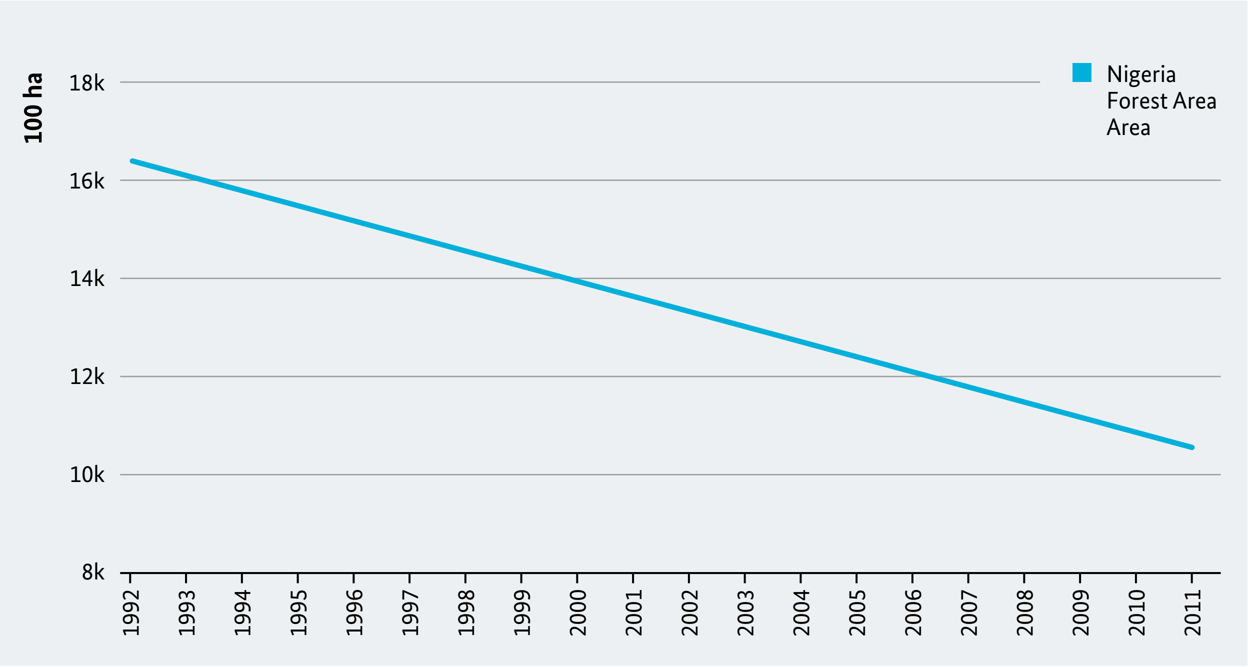

Figure 32: Developments in the size of forest area in Nigeria (between 1992 and 2011) Source: FAOSTAT (2014)

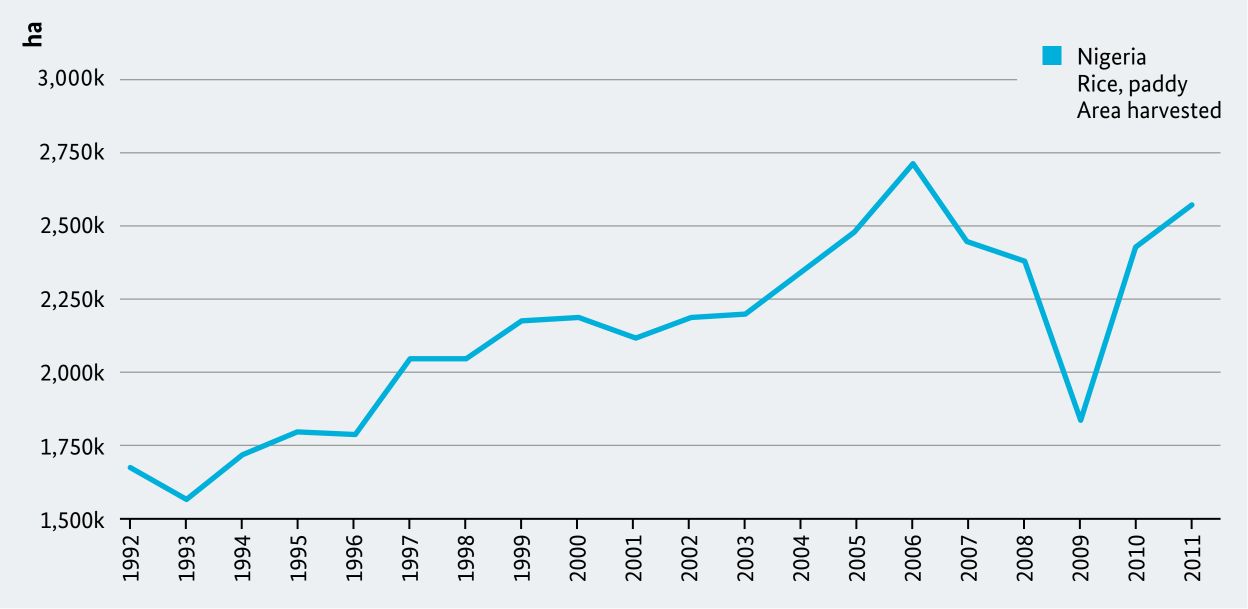

Figure 33: Area cultivated with rice in Nigeria (between 1992 and 2011) Source: FAOSTAT (2014)

Conclusion – Impact on Biodiversity

The impact assessment of production systems with regard to biodiversity is still in its nascent phase. This study therefore abstains from giving a quantitative assessment. A brief qualitative assessment based on the well-established impact categories follows.

As the results presented above indicate, food losses in the rice value chain contribute significantly to **climate change**. Impacts on biodiversity caused by climate change will only occur in the long term and will not be directly traceable to rice production in Nigeria. Still, agricultural production constitutes a twofold burden on biodiversity, with its impact on climate change and its changes in **land use.** Certain further impacts such as soil erosion potentially add to the pressure on the environment and biodiversity. Agricultural production therefore has a clear impact on biodiversity.

With regard to **water use** it was shown to be of less environmental concern compared to the impacts on climate change. This is mainly because the production systems under scrutiny are rainfed. Furthermore, even though water is used in processing, no large burden is caused in terms of toxicity or pollutants.

As a whole, taking the impacts on biodiversity into account can only aggravate concern about preventable environmental burdens caused by food losses.

Published by
Deutsche Gesellschaft für
Internationale Zusammenarbeit (GIZ) GmbH

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German Food Partnership (GFP)/Competitive African Rice Initiative (CARI)

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Design and layout
MediaCompany – Agentur für Kommunikation, Germany

Printed by
druckriegel GmbH, Frankfurt, Germany
Printed on FSC-certified paper

Photo credits
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As at
December 2014

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On behalf of
German Federal Ministry for Economic Cooperation
and Development (BMZ);
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