Food and Agriculture Organization
of the United Nations

Lessons learned on the sustainability and replicability of integrated food-energy systems in Ghana and Mozambique

PART 2: Analysis of case studies

FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS

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Part 1 of this study presents the core findings of the project; while part 2 presents the detailed analysis of the cases studied in Mozambique and Ghana

Part 1 was written by Anne Bogdanski, Manas Puri, Christa Roth and Olivier Dubois.

The IFES case studies presented in Part 2 of the study were written by Christa Roth (Ghana and Mozambique), William Quarmine (Ghana) and Helio Neves (Mozambique) and supervised by Anne Bogdanski.

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ABBREVIATIONS AND ACRONYMS

ADM	*Agro-Negócio para o Desenvolvimento de Moçambique, Limitada*
ADPP	*Associação de Desenvolvimento do Povo para Povo*
AF	Analytical framework
AFOLU	Agriculture, forestry and other land use
AIG	Asa initiative group
ANE	National Roads Administration
BAU	Business-as-usual
BBC	Bilibiza Biofuels Centre
BMM	Commodities Exchange of Mozambique
CAADP	Comprehensive Africa Agriculture Development Programme
CBO	Community-based organisation
CEPAGRI	Agriculture Promotion Centre
CES	Cooking energy system
CO_2eq	Carbon dioxide equivalent
CPO	Crude palm oil
CRF	Corporate responsible farmers
CSIR	Council for Scientific and Industrial Research
DINAB	National Directorate of Environment
DINAS	*Direcção Nacional de Agricultura e Silvicultura* (National Directorate for Agriculture and Forestry)
DNGRH	National Directorate of Water and Resource Management
EDM	Electricity of Mozambique
EFB	Empty Fruit Bunches
EnDev	Energising Development
EOZ	*Empresa Orizicola da Zambézia*
ETHOS	Engineers in Technical and Humanitarian Opportunities of Service
EU	European Union
FACT	Fuels from Agriculture in Communal Technology

FAO	Food and Agriculture Organization of the United Nations
FASDEP	Food and Agriculture Sector Development Policy
FDA	Agricultural Development Fund
FFB	Fresh fruit bunches
FFS	Farmers' field schools
FGD	Focus group discussions
FUNAE	*Fundo Nacional de Energia* (Energy Fund)
GAPI	*Gabinete de Consultoria e Apoio a Pequena Indústria*
GDP	Gross domestic product
GHG	Greenhouse gas
GHS	Ghana Shilling
GIZ	*Deutsche Gesellschaft für Internationale Zusammenarbeit* (German Federal Agency for International Cooperation)
GO	Government organisations
GSB	*Grupo de Saneamento de Bilibza*
GWP	Global warming potential
ICRISAT	International Crops Research Institute for the Semi-Arid Tropics
IFES	Integrated food-energy system
IIAM	*Instituto de Investigação Agrária de Moçambique in Manica* (Agricultural Research Institute of Mozambique)
INIR	National Irrigation Institute
INNOQ	National Institute for Standardization and Quality
INR	Indian Rupee
MASA	*Ministério da Agricultura e Segurança Alimentar* (Ministry of Agriculture and Food Security)
MEF	Ministry of Economics and Finance
MIRENE	Ministry of Mineral Resources and Energy
MOPHRH	Ministry of Public Works, Housing and Water Resources
MoU	Memorandum of Understanding
NAIP	National Agricultural Investment Plan
NAMA	National Appropriate Mitigation and Action

NDC	Nationally Determined Contributions
NEPAD	New Partnership for Africa’s Development
NGO	Non-governmental organisation
PFFB	Programa de Fomento da Produção da Cultura de Feijao –Boer
SACAU	Southern African Confederation of Agricultural Unions
UCAMA	Manica Farmers Union
UN	United Nations
UNAC	National Farmers Union
UNFCCC	United Nations Framework Convention on Climate Change
USAID	United States Agency for International Development

INTRODUCTION

There is an increasing agreement that, if done well, the production and use of biomass can significantly contribute to addressing three major global challenges, i.e. food security, sustainable energy for all and climate change – hence to achieving several SDG through bioeconomy. However, biomass is hardly a 'silver bullet' to achieve low carbon economy and contribute to the SDGs.

At the same time, there is already significant knowledge and experience on the risks and opportunities associated to biomass production and use, and on how to achieve it in a sustainable way. Combining different uses of biomass in a sound manner is deemed as a good approach in the development of sustainable bioeconomy, and integrating food and energy production is part of this approach. For this reason, FAO and others have considered the promotion of sustainable integrated food-energy systems IFES) as an important area of work. Anecdotal evidence and research projects suggest that sound IFES can be successfully developed. Yet their adoption by small-scale farmers or large-scale entrepreneurs remains challenging. Possible ways to overcome barriers are: (i) agricultural - through sustainable farming practices that reduce residue competition; (ii) institutional arrangements; and (iii) policy options that support the development and scaling-up of IFES initiatives. However, the promotion of such solutions and hence of sustainable IFES requires a robust and cost effective way to assess such systems as well as their potential for replication.

The above mentioned requirement was the justification for this project aimed at developing a cost effective and robust methodology to assess the sustainability and replicability of IFES, and test it in Mozambique and Ghana. The cases used in the analysis were:

In Ghana	In Mozambique
Utilisation of millet and sorghum stalks as cooking fuel	Intercropping pigeon pea with maize on the same field to produce food, fodder and fuel
Use of residues from palm oil processing for thermal energy generation	Production of heat energy by using rice husks to process rice
Maize Cobs as household cooking fuel and source of biochar	Jatropha production to protect food crop and produce biodiesel and soap

Part 1 of the report presents the core findings concerning the sustainability and replicability of the above-mentioned cases; whereas this part presents their detailed analysis

INTEGRATED FOOD-ENERGY SYSTEMS IN GHANA

USE OF RESIDUES FROM PALM OIL PROCESSING FOR THERMAL ENERGY GENERATION (ARTISANAL AND INDUSTRIAL LEVEL)

SYSTEM AND CONTEXT

BACKGROUND

Oil palm (*Elaeis guineensis*) has played a significant role in Ghana's economy since the 1800s when it was first traded internationally (Danyo, 2013). The crop is cultivated in the forest belt in Ghana - covering parts of Volta, Eastern, Central, and Western, Ashanti and Brong Ahafo regions (Gyasi, 1992). In Ghana, about 350 000 ha of land is cultivated with palm. Ghana produces about 2 million mt of fresh fruit bunches (FFBs) annually (Ofosu-Budu and Sarpong, 2013).

An estimated 80 percent of all oil palm farmers are smallholders. Two types of smallholder farmers can be identified. The first are the independent smallholders, who form the majority of smallholder oil palm farmers. These farmers do not have any contracts, which control their production practices or sales. Independent farmers record a yield of about 4mtha$^{-1.}$ The second type of farmers are out growers and cultivate the crop on their own private farms but have contracts with large estates linking some of their production and sales activities. Outgrowers in Ghana report an average yield of 7mtha^{-1}. There are also a few nucleus farms that are owned and managed by a processing company. Nucleus farms record an average yield of 7mtha^{-1}. Large estates have an even higher average yield of up to 12mtha^{-1}.

Every part of the crop has a culturally relevant use. For instance, fresh fronds have medicinal value, matured fronds are used to weave baskets and make brooms; the dead trees are a source of local alcoholic beverages etc. Perhaps the most important use of the tree in Ghana is the production of crude palm oil (CPO) and palm kernel oil (PKO). Ghana is a net importer of CPO. The country produces about 250 000 mt and imports approximately 60 000 mt of CPO annually. Oil processing is done at different scales that can be categorized into two; **Industrial processors** comprising large and medium firms, and **Artisanal processors**, comprising small firms and individual processors. According to Ofosu-Budu and Sarpong (2013), large plantations produce 55 percent of national CPO output; while medium-scale processors contribute 5 percent; and small-scale artisanal processors produce 40 percent of national output. Oil palm production and processing into CPO in Ghana presents a unique IFES scenario where processors, in spite of their scale, utilize the crops **residues for thermal energy generation that they need for the processing of the oil.**

STUDY OBJECTIVES

The literature identifies two oil palm residues, fibre and palm kernel shells, that can be used as fuel for processing of CPO in Ghana (Berget, 2 000; Ofosu- Budu and Sarpong, 2013). There is however not enough documented analyses of their use, sustainability and replicability. This report therefore presents and evaluates the sustainability and replicability of using oil palm fibre and palm kernel shells as fuel in processing of CPO in the Central region of Ghana. The study analyses two cases at different scales of operation, one at artisanal level and one at industrial level.

METHODOLOGY

SITE SELECTION

The study was conducted in the Central Region, which is the third largest oil palm producing region in Ghana, with some 16 percent of Ghana's total area under oil palm production (Angelucci, 2013). Within the Central Region, data were collected at two main sites for IFES cases at two different levels: Small-scale artisanal level and Industrial scale plants.

For the artisanal and small-scale palm oil processing, in Cape Coast Municipality is examined, which has about 19 000 ha of cultivated oil palm land and FFB output of 700 000 mt. This municipality is also the one where NGO ASA Initiative worked with local farmers under the regional Biochar Both the Plus Project and farmers started using the palm kernel shells as cooking fuel. This is potential unique oil palm IFES component. Two sites were visited: A group of artisanal processors of CPO were interviewed in the community of Enyinasi as one of the Biochar Plus Project sites of the ASA Initiative and a modern small-scale crude palm oil processing mill was visited at Kawyefi community. The mill serves a minimum of 50 artisanal processors daily during peak production periods.

An example at industrial level was found in the Twifo Hemange Lower Dakyira District, which has about 19 000 ha of cultivated oil palm with a total FFB output of about 890 000 mt. The case study was done at a large-scale industrial processor – Twfo Oil Palm Plantation (TOPP) that employs an IFES system to process CPO and other oil palm derivatives. The company has an installed CPO production capacity of 60mt per hour. It receives FFBs from an estimated 6 000 ha of land, of which 70 percent are cultivated by nucleus farmers and 30 percent are out grower or independent smallholders.

The case concerned only well-established palm oil plantations – hence no recent ones and no recent land use change related to palm oil production.

SETTING THE BOUNDARIES OF THE BASELINE AND IFES BIOMASS CHAIN

This IFES is observed at the processing level of oil. In this report the same IFES system (growing oil palm and using fibre or kernel residues for thermal energy) is described at the two levels of aggregation. At each level, the IFES system is compared to a 'business-as-usual (BAU)' which serves as a baseline. The IFES and BAU scenarios at the different levels are described hereafter.

- **Artisanal processing level**
  - IFES Case: Artisanal processors utilize only fibre or fibre-kernel pastes as fuel for all boiling activities during oil processing. Additionally those farmers participating in the Biochar Plus project can use palm kernel shells as cooking fuel in the ELSA gasifier stoves.
  - BAU Scenario: Artisanal processors rely on firewood or fossil fuel (diesel) for boiling activities in the oil processing and for household cooking and dispose of fibre and kernel shells.
- **Industrial processing level:**
  - IFES Case: Industrial processors use fibre and/or palm kernel shells to fuel a furnace which produces steam to (1) sterilize fresh fruit bunches and (2) to power turbines which generate electricity that is used to run all the machinery in the factory for the processing activities and the offices.
  - BAU Scenario: Processing factory, especially medium scale firms, rely on fossil fuel (diesel) or main grid electricity and discards fibre and kernel shells.

METHODS OF DATA COLLECTION

Data for this study were collected from the main stakeholders involved in oil production, both CPO from fruitlets and PKO from palm kernels in the study communities using a mix of participatory methods. We used individual interviews, key informant interviews, focus group discussions and participant observation to gather the data for this study. At the artisanal processing level, we interviewed the leadership of the ASA Initiative Group (AIG), also called Corporate Responsible Farmers (CRF). Women who processed CPO were interviewed as groups and individually. The research team visited a number of artisanal processing sites for first hand observation. At the industrial processing level, interviews were carried out with the marketing manager and mechanical supervisor of TOPP. The team also visited the processing plant to observe and understand the production processes and their linkage with the IFES.

SUSTAINABILITY ASSESSMENT

Sustainability of the IFES was assessed by comparing the IFES and BAU scenarios based on three measures of sustainability – social, economic and environmental. Following the IFES Analytical Framework (IFES AF), we develop a number of indicators for each of these components of sustainability, with which we compared the IFES and BAU (Bogdanski, 2014). Indicators were either impact (quantitative) or performance (process or qualitative) in nature.

REPLICABILITY ASSESSMENT

Content analyses of the data was carried out to assess the extent to which the IFES meets four replicability criteria described in the IFES AF –

1. presence of promoting or inhibiting project features of the IFES,
2. stakeholders that may promote upscale of the IFES,
3. alignment of the IFES with national food and energy objectives, and
4. availability of capacity for up scaling.

DESCRIPTION OF BAU AND IFES SCENARIOS

In this section, the value chains of the IFES and BAU scenarios are described. We begin by describing the BAU and IFES value chains at the artisanal processing level, before describing the same chains at the industrial processing level.

PRODUCTION

In the study communities, oil palm represents an important cash and food crop. It is mostly cultivated by smallholders on plots that are less than 5 ha in size. These independent smallholders are the main suppliers of the FFBs for this IFES. Interviews revealed that because of its capital-intensive nature, relatively wealthier and older farmers mostly grow the crop. Annually only weeding needs to be done.

- *Soil fertility management:* A combination of organic and inorganic soil improvement strategies are commonly carried out by small holders in the study area. When the crop is in its early stages, NPK (nitrogen, phosphorous, potassium) inorganic fertilizer is broadcast in a ring form around the base of the tree twice in a year to foster growth. Additionally, during the early stage of growth, the common practice is to mulch with biomass residue from older oil palm trees. When the crop starts flowering (after about 30 months), farmers mentioned that they apply a potassium-based fertilizer (Muriate of Potash), which contains 50 % Potassium and 46 % Chloride, to speed up fruiting.
- *Water management:* oil palm production by smallholders in Ghana mostly is rain-fed. In the study area, there are no oil palm irrigation systems for smallholders.
- *Weed management*: Weeding is done manually with cutlasses, at least twice in a year.

- *Pruning:* This activity was reported, in the key informant interviews, as the most important cultural practice for better fruit development. Farmers in the study area prune by regularly removing old, dead, damaged, or diseased fronds from their farms.

HARVESTING OF FRESH FRUIT BRANCHES (FFBS)

Independent smallholders harvest FFBs by cutting them from the palm tree with cutlasses or sickles. The harvested FFBs are gathered at an assembling point in the farm. In the lean season, one hectare of oil palm farm may yield a harvest of 100—200 kg, while the same plot could produce up to a tonne in the major season. Mostly, specialized labour is hired at a cost of GHS 0.40 (USD 0.10) per FFB for this activity. On the average, a harvester is able to cut and carry 200 to 300 FFBs per day.

COLLECTION AND TRANSPORT OF FFBS

At this point, two kinds of biomass are relevant for IFES analyses – (1) the FFBs which are later separated into empty fruit bunches (EFB), and fibre and nuts that are commonly used for fuel in the study area, and (2) the pruned fronds that can be used as fuel when properly dried. Even though the literature describes some uses of dried palm fronds for fuel in South East Ghana, we did not find any significant use in the study communities (Bergert, 2 000). The harvested FFBs are assembled along the in-field paths of the farms and the roadside. Subsequently, they are loaded into trucks or in tricycles and transported either to the homes of the farmers or to medium scale processing factories.

STORAGE OF BIOMASS

Once the FFBs are offloaded, they are stored mostly in the open air or under simple sheds. The storage process involves covering the offloaded FFBs with either waterproof material (plastic sheet or tarpaulin) or any other material like palm fronds or sometimes damaged zinc sheets. Fruits are stored between 3 days and 3 weeks before processing, depending on the pressure on the processing units. During the bumper season, storage may take longer because of bottlenecks at processing units.

BIOMASS PROCESSING AND STORAGE

The end-product of FFB processing is CPO, with fibre and kernels as by-products to be used as feedstock for bioenergy. The activities involved are as follows:

The separation of the fruitlets from the bunch can be done manually or mechanized .There are two general strategies used to loosen the fruits from the FFBs. The first is to extend the storage period. The longer the storage period the easier, it is to remove the fruitlets from the bunch because of rotting at the base. After a long period of storage, the fruitlets are easily removed by shaking or beating them with a baton. The second strategy is to quarter (cut) the FFBs into spikelets so that the fruitlets can be easily handpicked. Quartering is usually done when the fruitlets are to be urgently processed manually. When labour is hired for this process, the processors pay GHGHS 3.00 (USD 0.75) per 100 kg sack full of fruitlets removed from spikelets. For mechanized separation, the uncut FFBs are introduced into a machine with rotating metal pieces and a grate through which the fruitlets can fall by gravity and the empty bunches are expelled on the side. This machine needs to be powered by grid electricity or a diesel generator. This involves boiling of the separated fruitlets for 1-2 hours in large cast aluminium round pots with a capacity of 60 litres.

CRUDE PALM OIL (CPO) EXTRACTION AND STORAGE

Notwithstanding where the oil is processed (home or processing mill), the following steps are performed during the extraction process:

1. **Digestion**. CPO extraction begins with pounding of the sterilized fruitlets in either a mechanized digester or manually. The outcome of the digestion process is that the soft mesocarp of the fruit, which contains the oil, is removed from the seed coat or palm kernel (endocarp) to form a fibre-nut paste.

2. **Pressing**. The next stage is to use a metal press to squeeze the oil out of the fibre-nut paste. The liquid extract is a mixture of water, oil and impurities.
3. **Skimming**. After the oil is squeezed out, it is allowed to sit for a few hours to allow for water or any other impurities to settle before skimming the CPO from the top. When the oil is scooped from the top of the liquid extract, what is left is known as slurry.
4. **Boiling slurry**. Processors continue by boiling the slurry for a few hours. This activity brings more oil to the top of the boiling slurry which is continuously skimmed until the slurry has no more usable oil.
5. **Reprocessing fibre-nut paste**. Usually, the old fibre-nut paste is further processed by separating the nut from the fibre. The nuts are stored for onward sale or further processing into PKO, while the fibre paste is reloaded into the metal press and squeezed for more liquid extract. Once all extractable oil is squeezed out the fibre can be used as fuel to generate heat.

The crude palm oil and palm kernel oil are normally stored in large plastic drums or in plastic bottles. Key informant interviews with fruit processors at Kawyefi revealed that one 100kg bag of quartered FFB yielded one large plastic drum of CPO. It costs an average of GHS 140 (USD 35) to process a drum of CPO, which is sold at GHS 180 (USD 45) for a profit of GHS 40 (USD 45).

The main buyers of CPO are itinerant buyers who collect the oil from different processors for onward sale. Sometimes, cooperatives of CPO processors also purchase a good proportion of CPO in the study area. The peak period of purchasing is between March and May. Normally these buyers organize their own means of transportation for the CPO. When the CPO is sold as food, it is packaged in store in smaller bottles and sold in open markets.

END-USE

Crude Palm oil has two end-uses in Ghana – industrial non-food or as food for human consumption. Industrial end-uses of the CPO include soaps, detergents, cosmetics, plasticizers and coatings. For food purposes, CPO is refined into one of the leading vegetable oils in Ghana. Ofosu-Budu and Sarpong (2013) mention that CPO as vegetable oil constitutes almost 61 percent of the palm oil-related product demand in Ghana, and about 65 percent of the total demand in West Africa. Most households in Ghana prepare at least one palm oil based meal (soups and stews) per month. In the BAU scenario, the fibre cake and palm kernel by-products of the CPO processing are dumped. Processors would use firewood or mechanized processes powered by fossil fuel (diesel) or in rare cases grid-electricity where available for generating the heat energy required for all boiling activities.

COMPARISON OF BAU AND IFES SCENARIOS

COMPARISON OF BAU AND IFES SCENARIO AT ARTISANAL PROCESSING LEVEL

The value chain of the IFES and BAU is similar. The main difference is with regard to logistics and the use of biomass residues. In terms of biomass logistics, the BAU value chain differs from the IFES value chain in terms of purchase, transportation and packaging of fuel. In the IFES value chain, the fuel (fibre and kernel) are freely obtained as they are residues from the process on site, thus no transport is needed and there are no additional costs other than for storage to ensure the material does not get wet during rainfall. In the IFES scenario, the food and fuel end use depends on the type of processing equipment available, so different residues are used as fuel at different levels.

Empty palm bunches and palm fronds can be used as fuel for oil processing or they are dumped or used in the fields as mulch.

Kernel and fibre: If the kernel cannot be separated from the fibre, fibre-cakes including the palm kernels are used as fuel. But if there is a machine that can separate the kernel from the fibre, then the main fuel for the oil processing is the pure fibre cake and the kernels are further processed to obtain PKO either on site (if the required machinery is available) or sold to PKO processors,

Kernel shells: After pressing the PKO, the palm kernel shells remain. These can be used as fuel in specific applications: These kernel shells can be used for household cooking in the ELSA gasifier stoves introduced by the ASA Initiative. These stoves produce char from the kernels that can be sold as fuel to blacksmiths who use them in their forges. If there is no demand or technology to use them as fuel, the kernel shells are dumped. Recently ASA started experimenting with the use of the empty palm bunches as fuel for oil processing in larger gasifiers from old oil drums, applying the same concept as in the ELSA stoves. This process creates very valuable biochar from the bunches, which can be used as an ingredient in the bio-fertilizer for the fields. This technology is not yet fully developed to be rolled out.

The comparison of BAU with IFES at the artisanal processing level has been presented in Table 1.

Table 1: Comparison of business-as-usual (BAU) with integrated food-energy system (IFES) at the artisanal processing level

	BAU	IFES
BIOMASS PRODUCTION		
Land prep	Land is prepared in May. It involves clearing, burning of residues on the field. Mostly manual.	
Planting	Planting on flat soil. Seedlings commonly used. Mostly manual, using family labour	
Cultural practices		
Soil fertility management	• Organic: mulch-using residue from the oil palm crop. • Inorganic: NPK applied twice a year. Muriate of Potash applied at flowering.	
Water management	Rainfed	
Weed management	Weeding with cutlass twice a year	
BIOMASS LOGISTICS		
Harvesting	• Fruits containing fruitlets harvested by hand with cutlasses and sickles. • Residue (fibre and kernel shells) are harvested together with fruitlets	
Collection and Transport	Fruits (with residue) are transported to processing sites in trucks	
Yield	About 100 kg – 1 tonnes of FFBs are harvested per ha There is no data on residue yield at this stage	
Storage	Stored at factory sites between 3 days to 3 months without processing.	
BIOMASS PROCESSING		
Loosening	Fruitlets (still containing residue – fibre and kernel) are removed by beating the FFBs or by quartering FFBs into spikelets and fruitlets removed manually.	
Sterilization	Fruitlets (still containing residue – fibre and kernel) are boiled for a number of hours	

Table 1 (cont'd): Comparison of business-as-usual (BAU) with integrated food-energy system (IFES) at the artisanal processing level

CPO extraction	• Boiled fruitlets are **digested** by pounding to remove fibre containing oil from kernel. Resulting paste is **pressed** to squeeze out liquid. Oil is **skimmed** from the liquid. The remaining slurry is **boiled** again to skim more oil from the top. • The by-products (fibre and palm kernel) are separated. The Kernel is cracked either manually or mechanically to release nuts for PKO processing			
	BIOMASS (FOOD AND FUEL) LOGISTICS			
	FOOD	**FUEL**	**FOOD**	**FUEL**
Packaging	• Crude Palm oil packaged in large drums or in small bottles	Firewood is packed in the open at processing sites while diesel is stored in drums	Same as BAU	Fibre by-product are stored under sheds at the processing sites
Transport	When sold to itinerant buyers or cooperatives, buyers pays. When sold in the market processor bears the cost.	Organized by processors	Same as BAU	Free
Sale	CPO = GHS 180 (USD 45)	Diesel = GHS 4 (USD 1.00) per litre Firewood = = GHS 1.5 (USD 0.38) per kg	Same as BAU	Free
	FOOD AND FUEL END USE			
Food end-use	Processed CPO is a key vegetable oil for household meals and the main source of non-animal fat in the Ghana diet, thus an important contribution to food and nutrition security.			
Cooking system	**Stove:** improved 3 stone stove that fits the 60 liter boiling pots **Fuel**: Firewood for boiling		**Stove:** improved 3 stone stove that fits the 60 liter boiling pots **Fuel:** fibre only or fibre-kernel paste	
Fuel end-use	Fibre dumbed Kernel sold at GHS 3 (USD 0.75) per head pan to KPO processors or GHS 10 (USD 2.50) per 50 kg fertilizer bag		Fibre/fibre-kernel paste used as fuel Kernel sold at GHS 3 (USD 0.75) per head pan to KPO processors or GHS 10 (USD 2.50) per 50 kg fertilizer bag	

COMPARING THE BAU AND IFES VALUE CHAINS AT THE INDUSTRIAL PROCESSING LEVEL

We observed that at the industrial level, the IFES is utilized only by large-scale processors, while medium processors employ the BAU scenario (MOFA, 2010). Comparison of BAU with IFES at the industrial processing level has been presented in Table 2.

Biomass production

At the industrial level of processing, both the IFES and BAU receive FFBs from three sources: (1) nucleus farms which are owned and operated by the estates, (2) independent smallholder and (3) outgrower schemes who have contracts with the plantation. Production follows the same processes described earlier (Section 3.1.1) with two key differences. First, industrial processors with nucleus farms prepare their land mechanically. Secondly, industrial processors normally develop their own planting materials in nurseries equipped with irrigation systems.

Biomass logistics

Biomass logistics are similar for both IFES and BAU scenarios at the industrial processing level. Up to 11mt of FFBs are harvested from nucleus farms of the industrial processors. Harvesting is carried out by estate workers and transported in trucks on weekly bases to fruit ramps. At the fruit ramps, FFBs are queued for sterilization.

Biomass processing

Similar to the other stages of the value chain, the IFES and BAU scenarios are the same for the processing of the biomass. Processing of Crude Palm Oil (CPO) at the industrial level is fully mechanized and the treatment with heat for sterilization comes in at an earlier stage, as the FFB are sterilized **before** debunching. This requires more thermal energy thus also more fuel compared to sterilizing only the fruitlets after debunching, as more mass needs to be heated up, but it makes the entire processing chain more hygienic. The main activities in the industrial processing of CPO begin with carting of FFB to Sterilizing Cages. Next, the FFBs are sterilized with steam under pressure. Thereafter, the sterilized FFBs are conveyed to bunch strippers to remove fruitlets. The empty fruit bunches are then conveyed to the nucleus farms to serve as mulch. The freed fruitlets are moved to a digester, which pounds the fruitlets into a wet fibre-nut paste. From there, a number of screw presses are used to squeeze out the oil from the fibre-nut paste. The fluid from the pressing is passed through screens to rid it of debris before it is stored in Settling Tanks. After the remaining debris settles in the tank, the oil is passed through a clarifying centrifuge and stored in storage tank. The sludge from the settling tanks is centrifuged again and the recovered oil returned to the storage tank.

Most industrial oil mills also produce PKO, so in a next processing step the palm kernels (also called palm nuts) are separated from the fibre in a Depericarper after they have been digested. Kernels are cracked open using a ripple mill and then stored in a nut bin awaiting onward processing into PKO. The crushed hard palm kernel shells remain as residue.

Food and fuel logistics

In both BAU and IFES scenarios, the produced CPO is stored in large storage tanks and moved to their final destination in tank trucks. The final CPO product is either exported or sold to local manufacturers. A tonne of CPO is sold between GHS 350 - GHS 400 (USD 87.5 – USD 100) in the local market. The BAU and IFES scenarios differ in their fuel logistics. In the industrial IFES scenario, the fibre and the cracked shells are used as fuel in the boiler which generates steam for electricity and other processing activities. After the separation from the kernel the fibre is conveyed into a Cyclone device for cleaning and then onward into a buffer before being fed into the boiler. Sometimes the fibre is merely heaped on the compound. The lightweight and small empty cracked kernel shells are also conveyed to the boiler and simultaneously fed into the boiler with the fibre.

In the BAU scenario, processors rely on national grid electricity or use of diesel generating set. When electricity is used, the BAU value chain could pay at least GHS 14 (USD 3.5) per KW. Every litre of diesel used to power crude oil processing will cost the processor at least GHS 4 (USD 1.00). With regards to the IFES chain, the palm fibre with calorific value of 19.055 kcal/kg and palm kennel shell with calorific value of 18,884 kcal/kg are freely obtained. Conservatively, it is estimated that a ton of biomass feedstock would have cost TOPP at least GHS 14 ($45.00) if they were to buy from other suppliers (Gabienu, 2012).

Food and fuel end-use

Majority of industrial CPO (whether from IFES or BAU chains) end up in export markets. The estimated daily price of quality exportable industrial CPO is GHS 2 800 (USD 700) per tonne. Exporters or large manufacturers of food products (cooking oils, margarines) detergents and cosmetics buy those that are sold locally. In the BAU scenario, the fibre cake and palm kernel by-products of the industrial CPO processing activities are normally dumped or are incinerated without recovering thermal energy or sold. The fibre is sold in urban markets as a firestarter for charcoal stoves, while the palm kernel shells are sold to itinerant buyers, or blacksmiths for their forges. In the IFES chain at TOPP, the by-products are primarily used as fuel in the factory boiler to produce steam. The steam is used for all heat applications in the oil processing chain (sterilization of bunches, boiling of oil) and it powers a turbine that produces all the electricity of the factory. Thus the factory is self-sufficient in processing energy, both heat and electricity by using the residues from the oil processing. TOPP only buys fuel for transport vehicles. Surplus shells and kernel waste are used to fill up roads on the plantations and the empty bunches go back on the fields as mulch.

Table 2: Comparison of business-as-usual (BAU) with integrated food-energy system (IFES) at the industrial processing level

	BAU	IFES
BIOMASS PRODUCTION		
Land preparation	Land is prepared in May. It involves clearing, burning of residues on the field. Mostly manual.	
Planting	Nucleus plantation. Planting on flat soil. Seedlings from own nursery.	
Cultural practices		
Soil fertility management	• Organic: mulch using residue from the oil palm crop. • Inorganic: NPK applied twice a year. Muriate of Potash applied at flowering.	
Water management	Rainfed	
Weed management	Weeding with cutlass twice a year	
BIOMASS LOGISTICS		
Harvesting	• Fruits containing fruitlets harvested by hand with cutlasses and sickles. • Residue (fibre and kernel shells) are harvested together with fruitlets	
Collection and Transport	Fruits (with residue) are transported to processing sites in trucks	
Yield	About 100kg – 1 tonnes of FFBs are harvested per ha There is no data on residue yield at this stage	
Storage	Harvested FFBs stored at fruit ramp awaiting sterilization.	
BIOMASS PROCESSING		
Sterilization	Sterilize the FFBs with steam	

Table 2 (cont'd): Comparison of business-as-usual (BAU) with integrated food-energy system (IFES) at the industrial processing level

Loosening	- A mechanized stripper loosens the fruitlets from the empty bunches. - The empty bunches (a by-product) are transported to the nucleus plantation to serve as mulch.			
CPO extraction	- Sterilized fruitlets are conveyed into a digester to separate the oily fibre coat from the kernel. The digested pulp is covered through a screw press. The oily discharge from the press, containing water and fruit debris, is passed through screens and settling tanks. The oil phase from the settling tanks is passed to a clarifying centrifuge. The sludge, or heavy phase, from the settling tanks is centrifuged and the recovered oil returned to the settling tanks.by pounding to remove fibre containing oil from kernel.			
PKO extraction	- The by-products (fibre and palm kernel) are separated from each other. The kernel is further processed in palm kernel oil.			
	Palm kernel shells and fibre are usually discarded.		Palm kernel shells and fibre are usually discarded.	
BIOMASS (FOOD AND FUEL) LOGISTICS	**FOOD**	**FUEL**	**FOOD**	**FUEL**
Packaging	- CPO and PKO are packaged in large tanks		Same as BAU	From digester, kernels are separated from fibre in a depericarper. Fibre is cleaned in a cyclone and transported to the boiler. Kernels are cracked open in a ripple mill. The nuts are stored in a nut bin, the cracked heaped on the compound.
Transport	Crude palm oil is transported in large tank trucks.		Same as BAU	Free, only conveying within factory compound.
Sale	CPO = GHS 350-GHS 400 per tonne	Diesel = GHS 4 (USD 1.00) per litre Electricity = GHS 14 (USD 3.5) per KW	Same as BAU	n.a., not sold normally
BIOMASS (FOOD AND FUEL) END USE				
Food end-use	Processed CPO is a key vegetable oil for household meals. CPO and KPO are used for soaps and detergents			
Cooking system				
Fuel end-use	Fibre and kernel shells are incinerated		Fibre/fibre-kernel paste used as fuel	

SUSTAINABILITY ASSESSMENT

In this section, we analyse the major benefits that make the IFES likely to be sustainable at both the artisanal and industrial processing levels. The IFES (growing oil palm and processing it into palm oil by using its biomass residues for fuel) was found to be an improvement of the BAU scenario on all measures of sustainability - social, economic and environment.

SOCIAL PILLAR

Social pillar of sustainability was assessed by the criteria of food security, energy access, health and adaptive capacity to climate change. We found that, in terms of the social pillar, the IFES has advantages over the BAU scenario in the area of food security and energy access adaptive capacity at all levels of aggregation (Table 3).

Table 3: Social indicators of sustainability of IFES at the artisanal level

Note: if there is no difference between BAU and IFES, the fields in the table are merged)

Criterion	INDICATORS		BAU	IFES
	Impact	Performance		
Food security	Land size (ha)		Nucleus farms = 4 000 – 5 000 Outgrower = 1 000 – 13 000 Independent = 3 000 – 3 500	
	FFB Yields (mt/ha)		Nucleus farms = 9 – 12 Outgrower = 4 Independent = 2 - 5	
	Rural household expenditure associated with IFES energy component (USD)		If firewood used, 1kg = 4 KW = USD 0.38 If diesel used, 4 KW = USD 0.34	USD 0.00
Energy Access	For oil processing	Availability of fuel *[Not available /short supply/ adequate]*	Firewood = Adequate Diesel = Adequate	Kernel shells and fibre = Adequate
		Access to fuel *[Not accessible / difficult / easy]*	Firewood = Difficult Diesel = Easy, but expensive	Kernel shells and fibre = Easy
	For household cooking	Primary fuel use in rural households	Firewood and Charcoal, complemented by LPG	
		Use of palm kernel shells	n.a., as no stove technology available	Palm kernel shells used in ELSA stoves partially substitute other fuels

Table 3 (cont'd): Social indicators of sustainability of IFES at the artisanal level

Health		Generation of smoke *[Low/Medium/High]*	Firewood = Low Diesel = Low	Kernel shells and fibre = High if used in current shielded 3-stone fires. If used in gasifier technology then there is little smoke.
Adaptive capacity to climate change and variability		Number of source of income.	• Sale of FFBs • Sale of CPO • Sale of palm kernel	

Food security

At the artisanal processing level, the most significant food security proxy indicator is "household expenditure savings". Processing CPO with the IFES leads to savings by households in form of reduced expenditures on fuel. To clarify this point, we assume that a BAU processor will utilize 1kg of fire wood to carry out all boiling activities on a batch of FFBs being processed. Conservative estimates put the price of firewood at GHS 1.5 (USD 0.38) per kg. According to Roth et al (2014), a kilogramme of wood contains 14 MJ of useful energy. If that would need to be generated by electricity, this would require about 4 KW of electricity, depending on the equipment used. Suppose the processor wishes to use diesel to generate 14MJ, it will cost him about GHS 1.34 (USD 1.00) plus maintenance costs (1 litre of fuel run through a generator produces 3 KW of energy). However, when an artisanal processor applies the IFES, the cost of fuel is free.

Concerning industrial processors, a similar expenditure of saving is made by subscribers of the IFES. For the same measure of heat, equivalent to 4 KW of energy, the BAU scenario will pay commercial grid electricity rate of GHS 17 (USD 4.25)[1] The IFES processor will however only spend on labour for operation and routine maintenance costs since the biofuel is free. In another estimation, Gabienu (2012) puts the savings per tonne of using own fibre and kernel shells with the IFES system at GHS 180 (USD 45). Some of these savings trickle down to the smallholder farmers who are linked to industrial processors in terms of higher prices of FFBs and expansion of social schemes etc.

Energy access

We measure energy access by two indicators – the availability of the main fuels used and the ease with which these fuels can be accessed by processors.

At the artisanal level, the IFES' main advantage over the BAU is the ease with which the fuel is acquired. We find that whereas the kernel shells and fibre are easily available (through the processing activities), firewood is not always easily accessible. This is because, even when they are not purchased, processors must incur transport cost (walk distances sometimes) of acquiring firewood. A similar argument can be made for the advantage of the IFES over BAU scenario at the industrial processing level. The fuel of the IFES at this level is easily available and the supply is reliable and at the control of the processor. Grid electricity, used by BAU processors for instance, is often unreliable in Ghana.

ENVIRONMENT PILLAR

To assess environmental sustainability, we developed indicators to analyse whether or not the utilization of the IFES affects soil health, the forest or the environment in terms of carbon emissions (Table 4). For both the artisanal and industrial processing levels, the significant environmental sustainability criteria

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[1] http://www.ecgonline.info/index.php/customer-care/services/tariff

which distinguish the IFES from the BAU scenarios was “climate change mitigation”. For this criteria, we found the following proxy indicators relevant –dependence on fossil fuels and forest friendliness.

Climate change mitigation

For all the levels of oil palm processing, the BAU scenario threatens the environment more than the IFES. First, the IFES does not depend on fossil fuels. Secondly, where firewood is used to power certain activities of CPO production, there is the danger that continual usage without conscious replacement of forest resources will eventually result in forest degradation or even deforestation. This is particularly so in communities where wood is scarce. Although in the study communities, wood resources are relatively available, this danger remains, as the sources of firewood are not sustainably managed.

Soil health

The data revealed that both the BAU and IFES users, at any level of aggregation, apply residue from the oil palm crop (especially EFBs) as mulch. We further discovered that there is additional benefit from bio-fertilizer containing biochar for soil improvement using residue from the crop during processing, especially at the artisanal level. The NGO, ASA Initiative is at the trial stage of developing specialized stoves that use EFB as fuel for oil processing. The technology comprises of a drum kiln which burns the EFBs to char while providing heat energy for all boiling activities during processing. ASA has proven the feasibility of small-scale biochar production in the ELSA gasifier cookstoves, but the quantities obtained from cooking are very small (about 200-300 g of char per meal cooked) and the char obtained from palm kernel shells is not very suitable for bio-fertilizer production Thus the effort to explore the larger versions using EFB, which gives a much better light-weight biochar that can easily be crushed for the use in the bio-fertilizer.

Table 4: Environmental indicators of sustainability of IFES at the artisanal level

Criterion	INDICATORS		BAU	IFES
	Impact	Performance		
Soil health		Organic fertilizer applied to crop (Yes/No)	Yes	
		Inorganic fertilizer applied to crop (Yes/No)	Yes	
Pollution (pesticides)		Organic pesticides applied *[Yes/No]*	No No	
		Inorganic pesticides applied *[Yes/No]*	Yes Yes	
Climate change mitigation		CO$_2$ emission		
		Carbon balance after food and energy production (Positive/Negative/Neutral)	Neutral	Neutral
		Clean-burning fuel (Yes/No)	No	No
		IFES depends on fossil fuel (Yes/No)	Yes (Diesel)	No
		IFES depends on renewable natural resources (Yes/No)	Firewood – Yes Diesel – No	Yes
		Energy component is forest-friendly (Yes/No)	Firewood – No Diesel – Yes	Yes

ECONOMIC PILLAR

To assess the economic sustainability of the IFES, two indicators were essential – gross margins of processors and energy use efficiency. For both indicators, the IFES performed better than the BAU scenarios, especially at the artisanal processing level (Table 5).

Table 5: Economic indicators of sustainability of IFES at the artisanal level

Criterion	INDICATORS		BAU	IFES
	Impact	Performance		
Profitability	Gross margin using different fuels		1 drum of CPO = GHS 25 (USD 6.25).	1 drum of CPO = GHS 40 (USD 45).
Resource use efficiency (Biomass)		Share of used biomass (percent) (as opposed to biomass burnt or left to decay)	0 %	>20 %

Profitability

The profitability of the IFES and BAU scenario is assessed by looking at the gross margins. This measure is appropriate because it provides a quick assessment of costs and returns without including fixed costs. At the artisanal level of processing, we observed that the IFES CPO producers could earn at least 60 percent more gross margin than BAU processors. Discussions with processors revealed that on average, a bag (this is a volumetric measure referring to bags like used for 50 kg of maize or fertilizer, thus referred to as a '50 kg bag' even if it does not contain 50 kg of fruitlets) of fresh fruitlets processed under the IFES, yields 1 drum of CPO, which earns a gross margin of GHS 40 (USD 45). For the same quantity of fruitlets, the BAU CPO processors must pay for the use of fuel. To paint a clearer picture, we impose a simplifying assumption that it will take at least 20 kg of firewood to process 1 sack of fruitlets into 1 drum of CPO. At a conservative rate of GHS 1.5 (USD 0.38) per kg, this will add an additional cost of GHS 15 (USD 3.75) to the production process. Thus, leaving the BAU CPO processor with a gross margin of GHS 25 (USD 6.25).

Resource use efficiency

The IFES improves resource use efficiency compared to BAU scenario in both, industrial and artisanal processors. For instance, at the artisanal level, we observed that IFES processors utilized between 1 and 20 per cent of their own generated residues as fuel. At the industrial processing level, the IFES processors utilize up to 100 % of their own generated biomass, and go on to obtain more biomass from other independent farmers for utilization as fuel. This is not the case for BAU where none of the biomass is utilized. An added benefit of this high resource use efficiency is that it reduces the types and volume of waste from processing activities. This makes waste management more cost-efficient as they save the extra cost of disposing of the by-products.

REPLICABILITY OF THE IFES

In this section, we discuss the conditions under which the IFES can be replicated. We consider how the features of the IFES, stakeholders surrounding it, the policy environment and existing human and technical capacities create the conditions for replication of the IFES.

WHERE AND HOW THE IFES CAN BE REPLICATED?

Replication at the artisanal processing level:

The part pf the IFES of using residues for oil processing is replicable within all communities along the oil palm belt. Since it is a naturally emergent IFES, the likelihood is that it is applied at various levels by artisanal processors in all oil palm growing communities in Ghana.

For the use of palm kernel shells for household cooking specialised gasifier stoves like the ELSA stoves developed by ASA under the Biochar Plus programme with input from the University of Udine in Italy must be made available and accessible. So far ASA has trained only few artisans to produce the ELSA stoves under their supervision to ensure an acceptable quality. If the cooking energy IFES has to be replicated, either more artisans have to be trained with the consent of ASA in other areas or other gasifier stove models have to be developed or imported. There are many models to choose from (see ROTH et al 2014) but the ELSA stove has proven to be an appropriately priced stove that has been adapted to the Ghana cooking requirements. Thus it would be recommended to replicate this stove model of which over 2 000 have been successfully sold and train people who to use it.

Replication at the industrial processing level:

Available data shows that the IFES is used among only large scale processors. Medium-scale processors are therefore the potential population who can take up the IFES. This will however require support in terms of funding, technology transfer and training of human capacity.

ENABLING OR CONSTRAINING FEATURES OF THE IFES

We find that the IFES has many features that could ease its uptake by BAU processors.

Natural resource potential: The oil palm tree is available in all communities within Ghana's oil palm belt. It is the second most important cash crop in Ghana, hence the crop has high prospects (Danyo, 2013). For instance, it has been said that, barring exchange rate fluctuations, Ghana has the lowest cost of oil palm production in West Africa (Ofosu-Budu and Srpong, 2013). This high prospect for expanding oil palm production creates an enabling environment for the replication of the IFES across the oil palm belt.

Renewable energy technology potential: Another enabling feature of the IFES is that it is supported by adequate technology. The food component of the IFES is strongly supported by both the Oil Palm Research Institute (OPRI) and the large estate who continuously develop new technologies to enhance the improvement of oil palm production. At the artisanal level, at present, the energy component needs very little technology.

Even so, there is potential to improve the energy component of the IFES, while benefiting the farming systems of households. This potential has been demonstrated by the ASA Initiative's improved processing stoves with biochar as by-product. A feature of the IFES at the artisanal oil processing level which threatens the replicability of the IFES is that the fibre fuels still contain oil and produce smoke when not used in an appropriate stove. The new drum-size stoves being tested by the ASA Initiative could potentially address these problems, as they allow a mix of Empty Palm Bunches and oil-containing fibre to be used as fuel resulting in a relatively clean combustion, provided the EFB have been sufficiently dried before use as fuel.

Clarity and credibility: In its present state, the IFES has enough clarity and credibility to facilitate scaling it up in other communities. We found no evidence that both the food and energy component of the IFES was complicated to use or yielded uncertain results. Best production practices of the oil palm are straightforward and easy to understand, and barring any natural disasters yield desired results. The energy component of the IFES is also simple to use, notwithstanding the level of processing.

Even though at the industrial level, a much complicated boiler-turbine technology must be installed, once it is operational, its use become easy and results are consistent and reliable. There is also the option to install a boiler only to generate heat only and omit the more complex electricity generation.

Legitimacy: At the artisanal processing level, the IFES is indigenously developed to meet the need for cheaper energy sources and owned by its users. At artisanal level the introduction of gasifier stoves is introduced from the outside, but it has been adapted by ASA in a long participatory process involving the communities so that they now perceive the ELSA stove as their own. The development of drum-size burners for oil processing is likely to be seen as a legitimate further development of the ELSA stove. The energy component at the industrial processing level is also introduced. The technology is normally purchased. Consequently not all industrial processors have a boiler with or without electricity generation. Various suppliers exist whose technologies are in use since long years so that there is trusted experience available.

Ease in assessing IFES results: The results of utilization of the IFES are easy to observe at all levels of processing within the first year of adoption. Hence future effort to transfer the IFES to other communities will be relatively easier since potential beneficiaries will be able to see results for themselves. For instance, in the last decade, Ghana has experience shortages in electricity supply. The industrial IFES users, could clearly observe that the use of the residue to generate its own electricity had saved them millions of GHS in alternative energy (diesel) cost or production foregone. At the artisanal level, also, interviews with processors indicated that they were able to observe the tangible economic of using the IFES.

Business Model (Funding): This IFES' potential for replication can be observed in its self-emergent nature. At the artisanal processing level, there is no need for funding to support any component of the IFES. At this level, technology for production of oil palm is available and only needs to be disseminated. Also, there are no complicated stoves or machines to accompany the energy component of the IFES. Replication will just require effort in capacity building and extension services to processors. External funding may be needed to pay for the development of stoves and drum kilns if the energy component of the IFES is to be upgraded with the ELSA stoves for cooking or the new gasifier technologies for oil processing being developed by the ASA Initiative. At the industrial processing level, the IFES is accompanied with expensive technologies. The present the model of funding is through public-private partnerships. The TOPP estate is, for instance, jointly owned by the government and Unilever. Such partnerships provide a viable means by which the IFES can be taken up by medium scale processors.

Alignment and linkage: Another positive aspect of the IFES, which positions it for replication is that it aligns with the interests of CPO processors in Ghana. Whether they are artisanal or industrial, CPO processors are interested in reliable and cheap energy sources to enhance cost minimization. As earlier discussed, the application of this IFES addresses these expectations of the processors.

Complexity, coordination and behavior changes: Once the IFES is subscribed to, its application is routinized. Particularly at the artisanal level, there is no need for processors to be organized to utilize the IFES; neither do they need to undergo further behavioral changes to adapt to the IFES as there are no complexities regarding the use of fiber or kernel shells in the current modified 3-stone fires. Initially, industrial processors would have to train technicians to operate and maintain the boilers and turbines. But once trained the operation of the machines become routine. This simplicity creates the environment for replicability of the IFES. There is however a drawback, especially at the artisanal level. Users of the IFES are still exposed to health risks as the fibre fuels still contain oil and produce smoke when not used in an appropriate stove. The adoption of gasifier stoves will add complexity when introduced as they require behavior change in the operation. It will also require artisans to adopt the production of the stoves.

Acceptability in local knowledge systems and culture: In general, we observed that the IFES has widespread use among artisanal processors. Even among industrial processors, up to 50 % of large estates apply the IFES. This high rate of acceptability of the IFES is basically due to the availability of the biomass, the fact that they don't have alternative uses and uses do not need to further process them (with any technology) before they can be used to generate energy.

ROLE OF STAKEHOLDERS AND INSTITUTIONS IN THE REPLICATION OF MAIZE PELLET IFES

The main stakeholder groups and their **current roles** within this IFES is described in this section.

Artisanal processing level stakeholders

Stakeholders who are directly involved with the IFES are farmers, processors, local artisans and small-scale mill owners.

- Oil palm farmers are the main stakeholders who are involved in the production and supply of FFBs which contain the biomass.
- **Artisanal processors** are responsible for processing of the fruitlets into CPO. In the process, they generate the palm kernel shells and fibre for the production of heat energy**.**
- Small scale mill owners could be individual or a processor cooperative. They invest in machinery such as crusher, miller to speed up the processing of CPO. The artisanal processors can use the facilities of the small mills at a fee for each machine used. Artisans can thus decide which part of the processing they want to be done more conveniently by the machinery at the mill or with more manual labour elsewhere.
- **Local Artisans (welders)** are involved in the production and maintenance of equipment and utensils for the processing of CPO. The main manufacturers of equipment and machinery for palm oil production are GRATIS Foundation, which has offices in the Cape Coast Municipality.

Stakeholders who are not directly involved in the production and use of the pellets include:

- The **Oil Palm Research Institute (OPRI)** is the main supplier of oil palm production technologies.
- In the study communities, **Twifo Oil Palm Plantation** is a major supplier of planting material.

Industrial processing level stakeholders

At the industrial processing level, the direct stakeholders identified were farmers, TOPP and Unilever, Ghana. The TOPP is the main operator of the IFES. It produces its own oil palm in nucleus farms and processes it into CPO using by-products from the processing as fuel. Unilever are the joint owners of TOPP and responsible for managing the company. Unilever also receives the majority of the CPO produced from TOPP for the manufacturing of its products. The indirect stakeholders are OPRI and the Government of Ghana as they are the joint owner of TOPP.

THE EFFECT OF GHANA'S POLICY ENVIRONMENT ON POTENTIAL REPLICABILITY OF THE IFES

This section assess how government policies on oil palm, energy and climate change have created an enabling environment for the scaling up of the IFES.

Oil palm policies

With regards to the food component of the IFES, there is an adequate supporting government policies to sustain oil palm production. These policies are outlined in the government's current agricultural policy document FASDEP II. According to the FASDEP II, the priority for government is to support the supply of high-yielding planting material and improved agronomic practices to producers. The approach adopted by the government is to attract private sector investment to expand outgrower schemes in Ghana. In their estimation, this approach will put farmers in a position where they are supported to expand production. The government plans to link this private sector interest with supporting research institutions.

Economic perspective

The government of Ghana has shifted its economic policy focus towards supporting and partnering the private sector business to enhance productivity. To this end, a number of taxes and import tariffs have been removed. These tax cuts include agricultural inputs and machinery. This new policy direction, together with the oil pam production policies, make investments in the oil palm sector attractive. Medium scale processing therefore have the opportunity to seek the right support to procure the needed boiler-turbine technology to operate the IFES at the industrial level.

Energy policies

The relevant energy sector policies in Ghana are outline in two documents - The Strategic National Energy Plan (SNAP) and The Renewable Energy Act, 2011. These policies generally seek to reduce firewood use while promoting alternative fuels. As described earlier, this IFES seeks to achieve the same goal by decreasing the dependence on relatively expensive wood and fossil fuels for processing of CPO. We therefore do not see any policy challenges when it comes to the replication of this IFES.

Climate policy

One of Ghana's climate change priorities is to reduce the pressure on forests and mangroves for wood fuels. This IFES fits into the policy environment in the sense that is outcome is to reduce the pressure on firewood and fossil fuels. As such the IFES has the potential to be used as a tool by policy makers to address climate change issues. This provides potential for wide-scale replicability of this IFES.

THE EFFECT OF HUMAN AND TECHNICAL CAPACITY ON REPLICABILITY OF THE IFES

At the artisanal level of the IFES, replication will depend partly on the capacity of farmers to sustain the production and supply of the FFBs as well as the capacity of the processors to generate enough bioenergy from the FFBs. We observed that these skills and capacities are present, not only in the study community, but throughout the oil palm belt of Ghana. However, what may be lacking is local farmers' capacity to raise improved planting material. Also the management skill of artisanal processors is often low and requires much capacity building in terms of effective management of the bioenergy resource.

What is needed to promote cleaner burning and more efficient gasifier stoves is the training of artisans or larger manufacturers in the production of such stoves, be it the ELSA stove for cooking or the drum-size burners once fully developed. The latter also still requires technical assistance for the refinement of the technology, both in human and technical capacity, which will also require some source of funding. Ideally the existing technical and human capacity created at ASA could be built upon if funding would be made available to them for this technology development.

At the industrial processing level, highly trained labour is required. Presently, the users of the IFES have adequate human and technical capacity to continue the use of the IFES. However, for other industrial processors to take up the IFES, they have to build the capacity of their workers. This might add to the initial cost considerations of the IFES and negatively affect its replicability.

CONCLUSIONS

The oil palm IFES presented in this report was studied among CPO processors, out of which some also further elaborate PKO. We distinguished between artisanal and industrial processors in this study. The IFES involves the cultivation of oil palm (food component) and the use of its biomass (fibre and kernel shells) as fuel in the processing of CPO and PKO (energy component).

In the study area, we observed that the IFES emerged naturally among artisanal processors in response to the need for cheaper energy and as a means of waste management. Whereas the idea of the IFES is not new to the industrial processors, new technologies has to be procured before the IFES can be fully utilized. Hence at this level, it is partly indigenous (idea) and introduced (technology).

This study has described, into detail, the value chain of the IFES and BAU scenario at both the artisanal and industrial levels. Based on pre-selected indicators, the IFES was compared with a BAU scenario in order to assess its sustainability.

We conclude that the IFES is sustainable at both levels of aggregation (artisanal or industrial). This is because the IFES can be clearly distinguished from the BAU scenarios in the following ways:

- The IFES potentially improves rural farm household food security through savings on energy expenditure.
- When CPO is produced with the IFES, the gross margins after sale can be up to 60 percent more than when it is produced under the BAU system.
- The IFES provides its users with readily available and reliable supply of bioenergy for processing activities.
- The IFES helps to mitigate climate change by reducing the reliance of processors on both climate unfriendly fossil and/or forest-based fuels.
- The IFES improves resource use efficiency because processors utilize their own generated residues as fuel which also reduces their waste.
- At least at the artisanal level, the IFES has the potential to be upgraded with modern gasifier technology for expanded benefits through further resource efficiency plus the creation of biochar for the production of bio-fertilizer. This can be applied on food crops or on palm plantations to increase yields.

We further conclude that the IFES, whether in its current state or upgraded, is potentially replicable across the oil palm belt in Ghana. Replication is possible because, with the exception of complaints of smokiness at the artisanal processing level with the current technologies, we did not find any feature of the IFES which inhibits its use. Furthermore the policy environment is enabling and there is adequate stakeholder support for the IFES.

Among artisanal processors, since the IFES is indigenous, replication will depend mainly on increased processor education and capacity building. At this level of processing, we conclude that replication will also depend on the number of added benefits that comes with the use of the IFES.

With regards to added benefits, in its present form, the IFES does not directly influence household's farming systems. However, when it is enhanced through ASA Initiative's modern drum kiln burner and sterilization stoves, there could be potential benefits in terms of biochar residue for further use as bio-fertilizer in farms. Another added benefit which can influence uptake of the IFES among artisanal processors is the introduction of the ELSA stove as an emerging top-lit up-draft (TLUD) micro-gasifier stove for home cooking that can utilize crushed palm kernel shells as fuel, which otherwise are discarded. So, while the IFES supports CPO processing, the TLUD stoves will support home cooking still using residue from the oil palm tree.

At the industrial level, we find that the IFES has not been adopted by the medium scale processors. This is largely due to cost considerations. The accompanying technology is expensive. However, replication can be greatly enhanced if medium scale processors take advantage of the new economic era of public-private partnerships and reduction of taxes to acquire the boiler and if appropriate turbine technologies for electricity generation.

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MAIZE COBS AS HOUSEHOLD COOKING FUEL AND SOURCE OF BIOCHAR

SYSTEM AND CONTEXT

BACKGROUND

Agriculture has always been important to Ghana's economy. The sector contributes 19 percent to Ghana's annual Gross Domestic Product (GDP), and remains the chief source of livelihood for about 51 percent of Ghanaian. Some 27 percent of urban and 83 percent of rural households operate at least one agricultural activity.[2]

Maize is Ghana's most important cereal, with several socio-economic benefits to society. The crop contributes about 55 percent of cereal output and 3 percent of the total agricultural value in Ghana (Angelucci, 2012). Currently, Ghana produces about 2.5 million tonnes per annum at a compounded annual growth rate of 8 percent and consumes 3 million tonnes annually, revealing a deficit of about 500 000 tonnes.

A number of reasons make maize production an appropriate case for the integrated food-energy systems (IFES) assessment. First, the crop is Ghana's leading staple food cereal. Second, the crop yields adequate biomass for household energy. For instance, from conservative estimates, a production rate of 2.5 million tonnes per annum yields approximately 40 billion pieces of empty maize cobs or 8 million tonnes of biomass annually. According to Darfour and Rosentrater (2016), in Ghana maize cobs are sometimes used as fuel to reduce drying energy and save firewood use. The use of corn cobs for energy does not interfere with soil fertility issues as cobs are traditionally removed from the field anyway, while the straw is left on the field to rot or burn. The potential of scaling up any maize IFES case is therefore high considering that maize is grown by at least 32 % (2.1 million) of Ghanaian households.

STUDY OBJECTIVES

The Energy Commission of Ghana has estimated that there are 553 000 tonnes of maize biomass produced in Ghana annually, with a potential energy of output of 17.65 - 18.77 MJ/kg.[3] Yet, specific cases of maize IFES are not systematically documented. The objective of this report is to document a specific maize IFES case where the empty maize cobs are converted into pellets for use as fuel for domestic cooking purposes. Additionally, the report analyses the sustainability and replicability of this IFES case.

METHODOLOGY

SITE AND CASE SELECTION

An identified IFES case for this study involves the production of pellets from empty maize cob to be used as a fuel in clean burning cooking stoves. This innovation is promoted by the ASA Initiative

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[2] *http://www.statsghana.gov.gh/docfiles/glss6/GLSS6_Main %20Report.pdf*

[3] *http://energycom.gov.gh/files/SE4ALL-GHANA %20ACTION %20PLAN.pdf*

Group (AIG), a Non-Governmental Organisation that is generally dedicated to economic empowerment of women in the central region of Ghana. AIG was the implementing organisation in Ghana of two regional research projects led by the University of Udine (Italy) and funded by the ACP-EU Cooperation Programme in Science and Technology programme: the BeBi Project (2009-2013)[4] and the follow-on Biochar Plus Project (2014-2016)[5]. The IFES elements of pellet fuel production combined with a biochar producing stove were developed under these projects.[6] The selection of AIGs maize pellet IFES for this study is appropriate because maize production is important in the Central Region. The region contributes 12 % of Ghana's total maize output. Additionally, cooking fuel is expensive in the region. For instance the region has the highest charcoal price per kilogramme in Ghana (GHS 0.95 or USD 0.24). The study was conducted at Nyinesin in Cape Coast Municipality, where the AIGs pelletisation activities are carried out.

Cape Coast Municipality covers a land area of 12 200 ha with 8 000 ha (65 %) arable land but only 3 500 ha arable land has been cultivated at present. Climatic conditions of the municipality are favourable for maize production. The temperature of the municipality ranges between 25° C and 32° C. The hottest months are in February and March, just before the main rainy season, while the coolest months are between June and August. Cape Coast is a fairly humid region with average relative humidity varying between 85 % and 99 %. The municipality has an average annual rainfall between 750 mm and 1 000 mm. The vegetation of the Municipality is mainly comprised of secondary forest with thickets and shrubs growing to an average height of 4.5 m. Major tree crops include oil palm, cocoa and citrus. The main food crops are cassava, maize and plantains.

SETTING THE BOUNDARIES OF THE BASELINE AND IFES BIOMASS CHAIN

The analysis in this report is conducted at the system level. This means that the unit of analysis is not the individual or household but two maize-based systems that are compared:

- the Business As Usual (BAU)scenario where only maize is produced and biomass residues from maize like the empty cobs are generally discarded or only occasionally used as cooking fuel in open fires, where they burn to ash.
- the integrated food-energy system where in addition to food production there is an energy component producing cooking fuel out of biomass residues: empty maize cobs are processed into pellets to serve as cooking fuel in special clean-burning gasifier stoves called ELSA stoves for households.

The ELSA stove was developed by the University of Udine, and was later modified and adapted to be used in local conditions by AIG. The ELSA stoves are pyrolitic gasifiers that do not burn the pellets to ash but they convert them into biochar, which is a key ingredient for bio-fertilizer, which is then be applied to maize fields. The combination of pelletized fuels and the ELSA stove for food preparation and the subsequent use of the biochar to enhance food production are the main features of integrating food and energy in one system. The stoves are an integral part of the biochar value chain, which is an additional self-reinforcing loop of synergy between food and energy production characterising this IFES case.

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[4] *BeBi: Agricultural and Environmental Benefits from Biochar use in ACP Countries (2009-2013); FED/2009/221814;*

[5] *Biochar Plus: Energy, health, Agricultural and Environmental Benefits from Biochar Use: building capacities in ACP countries (2014-2017) - FED/2013/330-236; Biochar Plus was implemented in Ghana by AIG with the aim to absorb and use biochar technologies by (1) producing and selling fuel produced with locally available biomass (pellets); (2) producing, collecting and distributing the biochar; and (3) receiving carbon credits and selling them in the international carbon markets. https://sites.google.com/site/biocharplusproject/home*

Through the group discussions, we collected historical data from IFES adopters on the BAU system before and after the introduction of the IFES. With this comparison, we were able to assess the sustainability and replicability of the selected maize cob IFES.

SUSTAINABILITY ASSESSMENT

A list of indicators was developed for each of three sustainability pillars, as suggested by the IFES Analytical Framework (IFES AF) (Bogdanski, 2014). Indicators were either impact (quantitative) or performance (process or qualitative) in nature. Comparing indicators for the BAU and IFES systems, the sustainability was assessed.

REPLICABILITY ASSESSMENT

Replicability of the IFES was assessed through descriptive analyses of the extent to which the IFES meets four replicability criteria designed in the IFES-AF, i.e.

1. Presence of promoting or inhibiting project features of the IFES,
2. Stakeholders that may promote upscale of the IFES,
3. Alignment of the IFES with national food and energy objectives and (4) availability of capacity for up scaling.

METHODS OF DATA COLLECTION

Data for this study were collected by the two consultants, William Quarmine and Christa Roth, in November 2016 using a mix of participatory methods. Key informant interviews were held with the leadership of the AIG Group (AIG) also called Corporate Responsible Farmers (CRF). We also visited the pellet production site of AIG and held group discussions with women cooking with the pellets on the ELSA stoves.

DESCRIPTION OF THE CASE STUDY

DESCRIPTION OF BAU SCENARIO

Maize is the leading cereal produced in the Cape Coast Municipality, mostly by smallholder farmers. Nearly every farmer grows maize to ensure their own supply, surplus maize is sold making maize one of the major crops grown in the area after oil palm, cocoa, cassava, plantains, and citrus. Farmers in the municipality are also involved in animal husbandry[7]. There are few large-scale institutional farming activities. For example the Ministry of Agriculture piloted a block farm project where farmers were assisted to grow about 1 200 ha of maize under ideal conditions, although the land has now been earmarked for sugar cane production for the nearby sugar factory.

Land preparation

Traditionally in the study community, maize is grown over two seasons within a calendar year. During the major season (May – July), land preparation begins in May. In the minor season (September to November), land preparation starts from September. Land preparation involves clearing, burning of residue and tilling with basic tools like cutlasses and hoes.

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[7] http://mofa.gov.gh/site/?page_id=1453 reports that there are more than 100 000 poultry birds, 18 000 sheep and 24 000 goats.

Planting

Maize is generally planted in rows. Some studies show that in the Central region of Ghana (including Cape Coast), only 50 % of farmers have adopted row planting (Regasa, 2012). Maize is not planted in ridges. During planting, the traditional process is to make two holes next to each other with either a cutlass or a stick. In one of the holes, up to 3 maize kernels are buried, while fertilizer is mostly put in the other adjacent hole.

Harvesting

Maize is harvested by hand by breaking the dried ear or cob off the stalk. The stalks are later cut down and left on the field. Traditional farmers either burn the fields or leave the stalks to rot on the field to serve as mulch.

Collection and transport

Maize is transported on the cob from the fields to farmers' homes through carrying in baskets, bicycles or in tricycles depending on how far availability of money or infrastructure will allow.

Drying

Maize cobs are sundried on the ground outside the houses. Drying is often insufficient, leading to mould development during storage.

Storage

Maize is stored either unshelled on the cob or shelled depending on the needs of the farmer. Harvested unshelled cobs are packaged in stacks in household barns or stored in closed rooms at a temperature of about 25° C. Postharvest losses by mould and weevils are common.

Shelling and cleaning

Shelling is mostly done manually or by hand or small tools designed by artisans in the community. For smallholders, the most common method of cleaning the shelled maize grain is winnowing. This involves letting the grains drop from a height and allowing natural air to carry the chaff and foreign materials out of the grains.

Processing and end use

Only a small proportion of maize is consumed unprocessed, e.g. roasted on the cob. The majority of maize-based foods are prepared from maize flour. Shelled maize grains are commonly converted into flour with a mechanised maize mill. The traditional method of pounding the grain with the pestle and mortar is labour intensive and not very common any longer. Maize flour is processed as need arises and stored until consumption for longer periods of time in kitchens or separate store rooms. Empty maize cobs are dumped or temporarily stored in the yard outside the house. Maize is the most important grain food staple in Ghana. Maize flour is prepared into various staple dishes like porridge, *kenkey and banku* differing in consistency and degree of fermentation[8].

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[8] *Maize dough is prepared mixing milled maize flour into a paste and leaving it to ferment for a few days. Porridges (Koko) are prepared by boiling a thin mixture of fermented maize dough with water. Banku is prepared by continuously stirring a thicker mixture on the fire until it reaches a semi-solid consistency and moulded into balls. Kenkey has a more solid consistency. It is prepared first mixing cooked and non-cooked fermented maize dough into a semi-solid consistency. After that the mixture is moulded into balls and wrapped in leaves or maize husks. The balls are then cooked to taste.*

Maize residue end-use

After shelling, the empty maize cobs are traditionally dumped or occasionally used in their natural shape as cooking fuel in open fires where they burn to ashes.

Cooking system

For the BAU, maize-based foods are prepared on different stove types depending on the production method and the available fuels: firewood is commonly used in the traditional three-stone stove, charcoal mostly in the common coal pots, while LPG requires special gas stoves. More liquid foods that do not require heavy stirring are often prepared on LPG stoves (if available) or coal pots. Solid foods whose preparation require heavy stirring and mingling are prepared on sturdy stoves like coal pots or three-stone fires. The woodfuels are the main cooking fuels. While firewood is sometimes collected, charcoal has to be purchased. Some households complement woodfuels by LPG, but no household uses LPG as a sole source of cooking fuel, as it is too expensive and some traditional meals cannot be prepared on the gas stove. LPG is mostly used for small quantities of food or reheating or when speed and ease of use are a priority e.g. for the preparation of breakfast in the morning.

DESCRIPTION OF IFES SCENARIO: MAIZE COB PELLET PRODUCTION

The system was introduced as a comprehensive package with multiple benefits, hinging around the two major elements:

- Utilisation of the biomass of the dry maize cob for the production of clean-burning pellets for use in the advanced ELSA gasifier cook stoves. The ELSA cook stoves convert the pellets into char while creating a gas that provides the clean flame for cooking.
- Downstream utilisation of the charred pellets from the advanced ELSA stoves to be used as biochar mixed with organic manure in the bio-fertilizer to improve soil fertility for increased yields of maize or other crops.

Biomass production

The farmers associated with the AIG, who are the pioneering subscribers to the IFES system, produce maize in much similar manner as the traditional farmers in the community. There are however a number of differences worth mentioning that were introduced through the extension work by the AIG.

Soil fertility management

The AIG has introduced the idea of making bio-fertilizer by mixing organic and if available animal manure with biochar. The bio-fertilizer is prepared in pits ca. 2x2 m and 1 m deep, coated in plastic sheets to retain moisture inside. The recommended formula for the bio-fertilizer is by volume 2 parts biomass, 2 parts biochar, 2 parts poultry dung (to add nitrogen to the mix), 1 part top soil that was removed when digging the pit. The manure mixture is left to mature for 3 months until it can be applied on the fields. This soil amendment partially contains the same elements as NPK fertilizer, although the nitrogen content is lower, depending on the type of animal manure in the mix. The bio-fertilizer can retain soil water, nitrogen and other plant nutrients and maintain them available for the plants for a longer time. This improves soil fertility and enhances plant growth similar to expensive industrial fertilizer. Yet it saves money as the ingredients are locally found or produced.

Trials on demonstration plots have been conducted, however, yields have not been quantified as the harvesting was mixed up between the demonstration plots and no useful data could be generated. Despite the lack of ‘facts and figures’, the farmers have seen with their own eyes the benefits of the organic fertilizer on the plant growth on the demonstration plots. They are convinced about the positive effects encouraged so that they have started doing their own pits. So this year the farmers will begin using biochar fertilizer on their maize farms. Then data on increased crop yield on farmers' fields can be generated.

Water management

The biochar helps to retain water in the soil much longer and thus manage rainwater much more efficiently. Thus there is less stress by the plants due to rainfall variability. Additionally the AIG and its members have directed their focus on improving water access through the digging of wells. In the community, a hand-dug well costs up to GHS 2 000 (USD 500). At present, the Corporate Responsible Farmers have the means to pay for these wells. However, interviews reveal that the hand-dug well will serve other farmers in the group. The water access is seen key to improve production of manure and maize and will allow people to farm vegetables and other crops to diversify their diet and increase their cash crop basis.

Weed management

Although the members of the AIG are yet to apply the biofertilzer on their own farms, they claim to have observed a change in the types of weeds on the demonstration plots. They distinguished between 'hard weeds' that are common on the untreated soil and labour intensive to remove from the hard soil, while the softer soil of the bio-fertilizer-treated demonstration plots produced softer weeds that are easier to be removed and managed. This can also be an effect of the reduced compaction, better drainage and aeration of the soils.

Harvesting

Harvesting methods are not different between IFES and BAU farmers. However, the AIG IFES farmers are much more climate-conscious. As such, after harvesting the maize, they leave their stalk residue on the field without burning to cover the soil to preserve moisture and recycle organic material back into the soil. With this practice, they increase the soil carbon content and reduce smoke creation thus reducing air pollution and emissions of climate relevant particulate matter through the burning.

While the IFES has similar maize collection, transportation and storage processes as the BAU farmers, the empty maize cobs are treated differently. The IFES farmer collects and stores empty maize cobs for palletisation. They have a pellet production unit at one of the Corporate Responsible Farmers about 20 km North of Cape Coast on the road to Twifo Praso. There is also some space for storage of empty cobs and produced pellets.

Residue processing (pellet production)

The pellet production room of the AIG is the centre for manufacturing the pellets. Converting maize cobs to pellets has several advantages: the calorific value per kg of the biomass remains the same, but compacting the maize cobs reduces the volume. Loose maize cobs are around 100 g per litre, while about 600 g of densified pellets can fit in the same volume, thus transport costs are reduced. The pellets also have a lower moisture content and more predictable burning properties, making them an ideal fuel that can burn very cleanly with very low emissions in the ELSA stoves.

The process of production of pellets involves first crushing the empty maize cobs into smaller sizes. Next, the crushed cob are ground into powder so that they particles can easily fit through the die holes of pelletiser. The rollers of the pelletiser force the powder through the die holes with 6 mm diameter which give the pellets its unique shape. The pellets break off at a length of ca. 1-3 cm. In principle any other biomass residue can be used to blend into the pellets. The original idea in 2010 by AIG was to utilise the abundantly available maize cob supply from the large government plantation that would otherwise have been wasted. This source is no longer available and these days AIG blends maize cobs with saw dust, mainly to make up for the seasonally aggravated scarcity of the maize cobs.

The pelletizer was given to AIG as part of the EU-funded BeBi project in August 2012 through the assistance of the University of Udine. The project has employed one person to run the pelletizer. The current output of the pelletizer is between 100 – 200 kg per day. This output would not serve more than 100 households on a regular basis if they would rely entirely on the pellets as cooking fuel.

The output of the current machine is limited, but it could be increased significantly if the project had a crushing machine. As of December 2016, the pelletizer played the double role of crushing the cob biomass and pelletizing, which slows down the processing speed and output. Conservative estimates from the group suggest that approximately 6 000 kg of pellets have been produced and sold since the beginning of the production in 2014.

An advantage of pellets is that they are a standardised fuel with well know and predictable burning properties in a gasifier stove. That makes a big part of the clean burning, as the engineering lies partially already in the fuel, and the ELSA stove is designed to match that specific fuel. Thus, the good results with high efficiency and almost no or very little smoke.

Pellets packaging and transport

Maize cob-based pellets are packaged in 2 kg bags. They are stored in the pellet production room of the AIG, and sold to owners of the ELSA cook stoves. The AIG sell the pellets directly to customers at a price of GHS 1.7 per kg (ca 0.42 USD). This price is slightly subsidized, as it does not include the full cost of transportation. Transportation is currently supported by AIG as they piggy-back the transport of pellets on their regular trips when they visit communities where their activities are held. This is fine in the current stage, where the fuel is produced in small quantities and the pellets still need to be promoted and awareness raised on this new fuel type. In future if a larger pellet mill can be procured and pellet output scaled up considerably, the full distribution costs will have to be factored into the pellet price.

Residue end-use

The main difference in cooking systems between the IFES and BAU system is that the IFES is associated with an external technology – the ELSA gasifier stove. The pellets cannot be used in any other of the existing stove technologies, thus an appropriate biochar-producing gasifier stove to suit the fuel and the local cooking habits was developed as part of the research projects BeBi and BiocharPlus. The University of Udine and the spin-off start-up company Blucomb designed and fine-tuned the biochar-producing ELSA stove together with the local implementation partners in Ghana, Sierra Leone and Togo. After many loops and feedback rounds between the researches, AIG and the users, the current ELSA stove was developed.

Cooking system

In Ghana these stoves are available in single and double burners. A single burner ELSA stove is sold at GHS 120 (USD 30), while a double burner goes for GHS 140 (USD 35). The stoves are manufactured by specially trained selected local artisans following specifications given them by AIG. Although the stoves can burn any type of chunky small-size dry biomass (e.g. wood chips, shells and husks of nuts like cashew, groundnut etc.) in the Cape Coast mainly two fuel sources are mainly used – pellets from the AIG and palm kernel shells, which are abundantly available among the oil palm farmers in the area. All of the users interviewed during the field work were producing their own palm kernel shell, which they used as a free fuel in the ELSA stoves. They only relied on the maize cob pellets in the rainy season when no palm kernel shells were available. In more urban areas where people don't process palm oil, households rely entirely on the maize cob pellets as a convenient fuel to use as a substitute for LPG. Women in the AIG mentioned that they use the ELSA stoves to prepare dishes with preparation times up to 1-1.5 hours, which is the time one filling of a fuel container would last on average.

All of them still complement the ELSA stoves with firewood and charcoal stoves (coal pots), or in some cases additionally LPG. Although they said that cooking on the ELSA stove was similarly convenient as cooking on LPG and that it nearly replaced the cooking they would do with LPG. The artisans have produced ca. 4 000 ELSA stoves under the supervision and quality control of the AIG. All have been sold through AIG to about 4 000 homes in the Cape Coast Municipality for which the pellets or palm kernel shells serve as fuel.

According to the women using the ELSA stove, maize cob pellets are in high demand during the raining season when they don't have access to the substitute, their dried palm kernels shells. The women argued that comparatively, pellets are better than charcoal in terms of pricing and convenience of cooking. The added advantage of the pellets is that, if well managed, they can become a source of biochar for home gardens. The charred pellets are gathered and added to other charred biomass for the manufacture of bio-fertilizer, which is used to improve soil fertility.

BAU AND IFES COMPARISON

This benefit of the maize cob pellets mostly applies to users in rural areas who have own gardens to cultivate. Group discussions revealed that char created from the palm kernel shells was not appropriate for use as biochar, as they still contain oil residues and don't decompose easily. Nevertheless those are the properties that make the charred palm kernel shells highly appreciated by blacksmiths as fuel for their forges. So if the ELSA stove owners don't reuse the char in their own coal pots, they can sell it to blacksmiths and create added value from a free fuel source (Table 6).

Table 6: Comparison of business-as-usual production of maize with the maize cob pellet fuel and biochar IFES.

	BAU	**IFES (pellet fuel biochar)**
BIOMASS PRODUCTION		
Land preparation	Land clearing, burning of residues on the field, some use weedicide, or no tilling, they use only cutlass (Ghana word for *panga*, *machete*), just before rains, twice per year (April main season, Sep-Nov short season),	
Planting	Planting on flat soil, row planting, use cutlass to make planting holes, up to 3 seeds per station, fertilizer into the planting station or adjacent hole next to planting station	
Cultural practices		
Soil fertility management	NPK application is not frequent. Few farmers apply recommended dosages of fertilizer.	NPK usage is reduced or entirely substituted through the application of bio-fertilizer containing biochar, chicken manure and organic matter. Biochar assists to retain nutrients like K, P, Ca and Mg in the soil for prolonged accessibility for the plants.
Water management	Rainfed	AIG facilitates additional water access by hand dug-wells for limited irrigation for its members.

Table 6 (cont'd): Comparison of business-as-usual production of maize with the maize cob pellet fuel and biochar IFES.

Weed management	Weeding with cutlass and hoe, depending on need	Weeding techniques same as BAU, but farmers reported that weeding was easier as the soil is softer when bio-fertilizer is applied due to higher water retention and lighter soil structure which makes weeds easier to remove.[9] They also claimed that the weeds are of a different type and softer than the traditional.
Pest and disease management	Apply chemicals when needed, common pests are armyworm, grasshoppers	Techniques same as BAU, but less need for treatments as biochar reduces soil-borne diseases. Farmers noted that plants are generally healthier (also vegetables) and less prone to disease, so less pest management needed.
BIOMASS LOGISTICS and PROCESSING: GRAIN		
Harvesting	By hand, break off cob.	
Collection and Transport	Transport cob (filled with corn) from field to house on the head by farmer, in little tricycle or bicycle if the infrastructure and the money allows, sometime carrying in a group	
Yield	About 1.83 tonnes/ha	Increased yield, but no exact data yet.
Storage at farm	Storage in barns on the cob for own consumption	
Shelling	Shelling of grain by hand	
Packaging	Grain sold in 100 kg bags to vendors at farm gate, local markets and wholesalers	
Transport	By buyer, sometimes by farmer to market	
Sale	Average maize price = GHS 2 (USD 0.50) per kg	
BIOMASS LOGISTICS and PROCESSING: BIOMASS RESIDUES		
Harvesting	Stover is left in the field to rot or is burnt on the field.	So far stover is not processed into pellets, as only corn cobs are used. But the potential is there to add the stover and increase the biomass availability to process into cooking fuel
	Cobs are transported with the grain to the farm house, no extra transport	
Yield	n.a.	The total biomass residue is about 44 % of the gain harvest, out of which half is empty cob and half stover. Depending on the variety the cob has estimated weight of 0.4 tonnes/ha, the stover could add another 0.4 tonnes/ha.
Collection and Transport	n.a.	Empty cobs are transported to the pellet production site of AIG
Storage at farm	n.a., cobs are not stored	Storage of cobs in pellet production room of AIG
Cob processing into fuel	n.a.	Corn cobs are pelletized at the production centre. AIG acquired a pelletizer from Italy through the BeBi project in 2010 with a maximum output of 200 kg of pellets per day.

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[9] Graber E.R. 2014, Carbon Management, Vol. 5, Issue 2, p. 169-183

Table 6 (cont'd): Comparison of business-as-usual production of maize with the maize cob pellet fuel and biochar IFES.

Packaging	n.a.	Pellets are packaged in 2 kg re-sealable plastic bags to protect them from moisture.
Transport	n.a.	Pellets are transported to the retail stations with the project pickup when it is going anyhow, transport not yet fully factored into the price of the pellets
Sale	n.a.	GHS 1.7 (USD 0.43) per kg
FOOD AND FUEL END USE		
Food end-use	Eaten as is, or milled into flour, human consumption	
Cooking system	Stoves: three stones for firewood Coal pot for charcoal LPG if available and affordable	Stoves: three stones for firewood Coal pot for charcoal LPG if available and affordable ELSA stove for pellets (single or double burner)
Fuel end-use	Occasionally maize cob used in open fire for cooking family food by farmers at the house, rest dumped	Pellets are purchased by owners of the ELSA stove and used for cooking family food at the their houses
Fuel by-product after cooking	Ash after full combustion, no residual calorific or commercial value	Bio (char) remains as product of the partial combustion in the pyrolytic ELSA stove. The char still has a high heating value and can be used as fuel for further cooking in a coal-pot or it can be sold as fuel to blacksmiths. Biochar is also an important ingredient in the bio-fertilizer. When buried in the ground it recycles several nutrients into the soil and acts as carbon storage. It increases water retention and cation-exchange capacity of the soils thus increasing soil fertility. People without ELSA stoves sometimes buy biochar to produce bio-fertilizer on their own.

SUSTAINABILITY ASSESSMENT

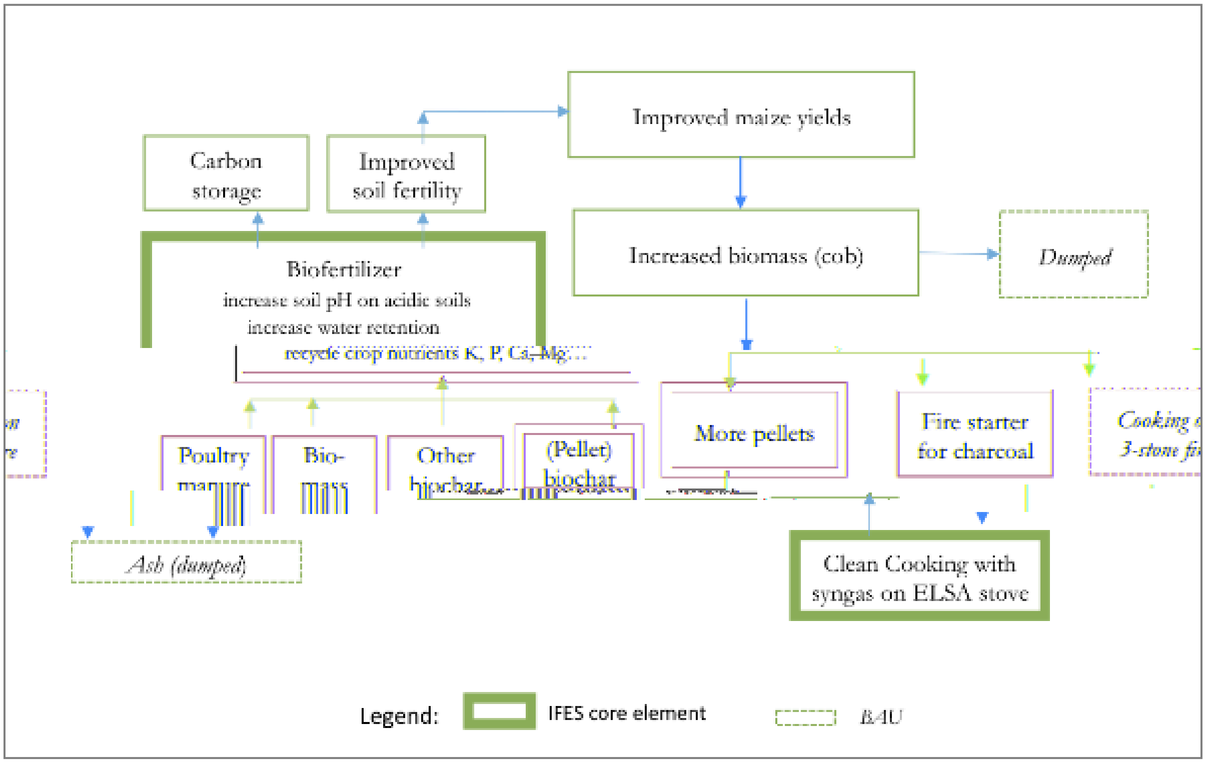
In this section we assess the sustainability of the IFES chain compared to the baseline scenario (BAU). The IFES value chain differs from the BAU in the following core elements:

- The utilisation of the biomass of the dry maize cob for the production of clean-burning pellets to substitute the more expensive cooking fuels charcoal or LPG.
- The introduction of the clean-burning ELSA gasifier cook stoves to utilise the pellets and complement or replace traditional charcoal coal pots and LPG stoves. The ELSA stoves convert the pellets into syngas which is used for cooking similar to LPG and as a by-product of cooking the biochar remains.

- ➢ The downstream utilisation of the biochar created as a by-product of the clean cooking with the ELSA stoves. The biochar can be applied as is or better mixed with other ingredients to bio-fertilizer. It can be applied as soil amendment especially on acidic soils to increase the pH and water retention capacity, to recycle crop nutrients, to serve as carbon storage. This leads to improved soil fertility and increased yields of maize or other crops.

In the BAU the maize cobs are either dumped or occasionally used as cooking fuel in 3-stone fires where they burn to ash that gets dumped without returning nutrients to the field. The main distinguishing features of this IFES from the BAU are visualised in Figure 1 below:

Figure 1: Main distinguishing core elements of the IFES versus the BAU



The sustainability was assessed according to different indicators grouped into three pillars: social, environmental and economic.

SOCIAL PILLAR

The social pillar of sustainability was assessed by the criteria of food security, energy access, health and adaptive capacity to climate change. We found that the IFES is an improvement over the BAU in all social criteria (Table 7).

Food security

While there is no difference in the land size, the application of biochar can potentially positively affect the maize yields resulting in an overall increase in food security. However, data to quantify the yield increase will only become available for Ghana after the next harvest. Yet data from other countries suggest a potential increase by 50 percent or more through the application of biochar on the fields.

The most appropriate proxy indicator for food security in this context was 'household expenditure savings'. To illustrate this point, we compared the cost of cooking an average meal with the ELSA stove (IFES) and charcoal coal pot (BAU). With the ELSA stoves, subscribers of the IFES mentioned that they can get 1-1.5 hours of cooking time out of 1 kg of pellets, depending on the wind conditions[10]. Depending on the meal type also, the average preparation time is 1.5-2 hours, so to cook an average meal they would need 1.0-1.5 kg of pellets at a cost of GHS 1.70 per kg (USD 0.46). This translates to a total cost per meal between GHS 1.70 (0.43) - and GHS 2.55 (USD 0.64).

It was revealed during group discussions that for an average meal on their conventional charcoal stove (coal pot) they would need to invest between GHS 3.00 (USD 0.75) and GHS 4.0 (USD 1.00) or 1.5 - 2 of the small charcoal bags that sell at GHS 2. Conservatively, this would translate into a minimum average saving of GHS 1.3 (USD 0.33) per meal. This is consistent with the statement of the women during discussions that they could save at least GHS 500 per year on charcoal when using pellets.

LPG was not a main cooking fuel for none of the participants, so it was difficult to estimate the savings compared to the pellet use, but the women estimated that cooking on LPG is at least 30 percent more expensive than charcoal, which would compare to an estimated fuel cost above 1 USD per average meal.

Palm kernel shells are an alternative fuel for the ELSA stoves when pellets are in short supply. When using their own (free) palm kernel shells those savings could easily amount to GHS 1 000 (USD 250.00) or more in a year. However, women who use the ELSA stove had not done that calculation, as this is also difficult to quantify as they also use firewood for cooking and not entirely charcoal.

The cost of the ELSA stove was not factored in as in the perception of the women it did not matter so much. The advantages of the ELSA stove and the convenience of its use outweighed the initial investment. The ELSA stove perceived to last longer than the coal pots that need to be replaced at least once per year.

Table 7: Comparison of social indicators of sustainability between the BAU and IFES systems

Criterion	INDICATORS		BAU	IFES
	Impact	Performance		
Food security	Land size (ha)		< 2ha	
	Yields of maize (tonnes/ha)		1.83 (not measured, taken from MoFA statistics)	Increase observed but not yet quantified, estimates indicate potential increase up to 50 %
	Rural household expenditure associated with system (USD/kg)		Cost per average meal: USD 0.75 with charcoal > USD 1.0 with LPG	Cost per average meal: USD 0.43 with pellets on ELSA stove or 0 for palm kernel shells
Energy Access	Number of alternative fuel sources		3: charcoal, LPG and firewood	At least 6: additional to charcoal, LPG and firewood people can use pellets, woodchips and palm kernel shells in the ELSA stove

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[10] *The primary air supply in the stove regulates the speed of the pyrolysis process in the stove that converts the pellet fuel into char and the gases that are burnt in the flame, providing the useful heat for cooking*

Table 7 (cont'd): Comparison of social indicators of sustainability between the BAU and IFES systems

Health		Generation of smoke (Low/ Medium/High)	Coal pot – Medium LPG stove –Low	ELSA stove - Low
Adaptive capacity to climate change and variability		Availability of mechanisms to address rain failure (Yes/No)	No	Yes [increased water retention through biochar fertilizer assists to mitigate effects of drought]

If there is no change between IFES and BAU, then the fields in the table are merged. Grey shaded cells indicate a significant advantage. This also applies to the following tables in this chapter.

Energy access

In terms of energy access, subscribers of the IFES system have at least three additional sources of fuel compared to those with the BAU system. The ELSA stove can burn a variety of small-sized fuels cleanly. It gives users more flexibility to utilise available fuels and residues. As at the time of the study, households that owned ELSA stoves were alternating between the maize cob pellets and the palm kernel nuts. A few people in vicinity of carpenters used woodchips as fuel.

However, a detailed assessment would need to be done to assess the trade-offs of switching the stove and fuels. This is because whereas charcoal and pellets are both available and accessible, pellets are more affordable. Nevertheless, from an initial assessment, it seems that IFES may have an advantage over BAU scenario on energy access.

Health implications

The energy component of the IFES is generally cleaner than the alternatives under the BAU. To assess this, we rated the extent to which the fuels and stoves under each system exposed women who utilize them to smoke (Table 2). Burning charcoal in coal pots produces relatively higher amounts of smoke and harmful carbon monoxide compared to burning pellets in ELSA stoves. Cooking with LPG produces the least amount of smoke, but the emissions are in the same range as burning pellets in ELSA stoves.

Adaptive capacity to climate variability

Another advantage of the IFES over the BAU is in the area of adaptive capacity to manage climate variability. The members of the AIG, who were the main users of the IFES had through the activities of the AIG (including soil fertility management, water management, training etc) developed mechanisms to cope with crop failure due to climate variability. In particular, these include the use of biochar manure to retain soil moisture and nutrients, as well as digging of wells to irrigate farms.

ENVIRONMENTAL PILLAR

The three criteria used to assess the environmental sustainability of the IFES were soil health, pollution from pesticides and climate change mitigation potential. There was a marginal difference between the IFES and the BAU in terms of soil health and pesticide pollution and a clear advantage of the IFES in terms of contribution to climate change mitigation (Table 8).

Soil health

As mentioned earlier, the IFES is part of a package of activities introduced by the AIG. The process starts with the idea of improving soil fertility under maize production with biochar-based fertilizer. With this improved yield, more maize biomass residue can be harvested, more organic matter can be mulched in the soil and more maize cobs are available for pellet production. The charred pellets are in turn used as an input for the production of bio-fertilizer. Hence, soil fertility increases as compared to the baseline scenario. While it was impossible to quantify the improvement due to the absence of data, farmers already observed an increase in maize yields, which prompted more farmers to prepare and apply bio-fertilizers on their fields. From literature and the observations from other sites in the regional BeBi programme it is known that biochar improves soil health, reduces soil-borne diseases, and regulates water availability through retention in the soil and reducing soil water evaporation. Rainwater infiltration rates are increased through the incorporation of bio-fertilizer and the risk of soil erosion reduced. Additionally with the IFES there are less changes in soil temperature which leads to enhanced soil microbe activity and plant nutrient availability, hence more crop production. Conclusion: the application of biochar-based soil amendments creates a self-enhancing positive feedback cycle that is likely to counteract soil deterioration and preserve if not increase soil fertility sustainably in the long run. Therefore we conclude that this IFES will be sustainable in the long run.

If the charred pellets are not used as input for bio-fertilizers, they are burned to ash in coal pots in which case no carbon is sequestered as all CO_2 is released into the atmosphere and no additional soil health benefit is obtained.

Climate change mitigation

We found the IFES to be more environmentally sustainable than the BAU. When looking at maize cobs, the IFES and the BAU lead to different carbon balance results. So for instance in the BAU, if the maize cobs are burnt to ash in open fires or dumped and allowed to rot, all the carbon that the maize plant assimilated from the atmosphere in the 4-6 months of growth will be returned in the form of carbon dioxide back to the atmosphere. This would be a carbon-neutral process from a short-term perspective. However, in Ghana charcoal is mostly made in unimproved earth mound kilns with a low charcoal yield of under 20 percent and depending on the production technique around 5 to 6 tonnes of wood are needed to produce 1 tonne of charcoal. Over 50 percent of the primary wood-energy is lost in the process of making charcoal Given that in BAU, charcoal is the primary fuel used for cooking, GHG emission from charcoal making are also accounted for. FAO (2017) estimates that around 5.7-9.0 Kg of CO_2eq are emitted to produce 1 kg of charcoal in traditional charcoal kilns, which is the case in Ghana.

Biochar is a climate solution

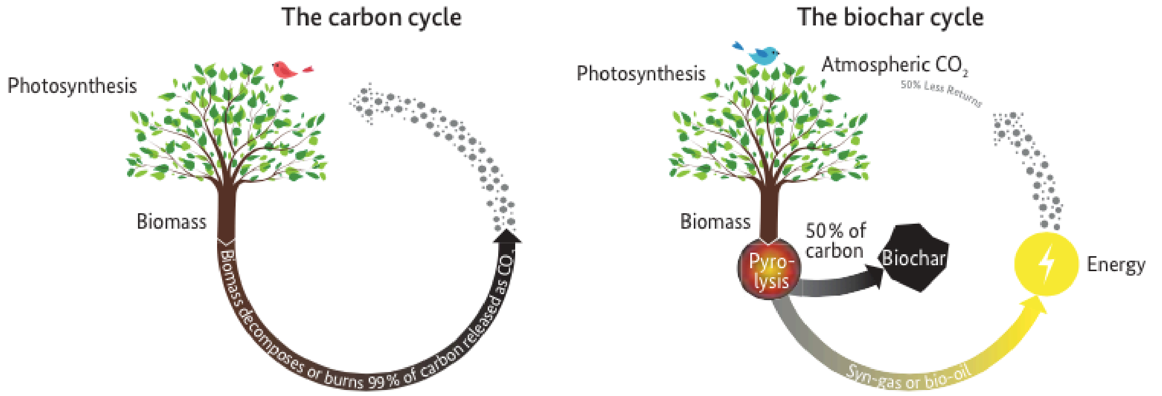
Because plants pull carbon dioxide out of the air when they grow, if you convert part of a plant's carbon to biochar and put it in the soil, you are reducing the amount of carbon dioxide in the atmosphere. This is called Biochar Carbon Capture. But be careful, your biomass must be sustainably grown and harvested and your biochar production process must be clean, or you might make more carbon dioxide than you bury as biochar.

The process of making biochar releases energy. It is a form of burning or thermal con- version without oxygen that is called pyrolysis. If you can use that energy to substitute for energy from fossil fuels, that is another way that biochar can reduce carbon in the atmosphere. You can use your biochar stove to cook dinner instead of using a gas or electric stove.

Biochar is good for soil

Biochar is like permanent compost—a source of soil carbon that supports soil life, but unlike compost, it does not break down quickly. Compost may last for several years in your soil (and compost is needed as a food source for plants), but biochar will last for decades or centuries. Think of biochar as the "bones" of soil. At a microscopic level, biochar is formed from fused carbon rings that are very stable. This carbon ring structure is like a scaffold that nutrients and minerals hold on to so they stay in the soil where plants can find them. In the Amazon rainforest, people added biochar to soils over thousands of years to help grow food crops in the poor tropical soils. Tropical soils can grow giant rain forests, but when the forest cover is removed, rain washes the soil away. Biochar helped people stabilize the soil for agriculture. A lot of the biochar is still there, thousands of years later. Even today, farmers value these old, black Terra Preta soils for their increased productivity compared to the nearby red soils.

Source: Wilson 2013, Make Your Own Biochar Stove, www.biochar-ebooks.com



Most carbon returns to atmosphere
Green plants use solar energy to remove CO_2 from the atmosphere via photosynthesis and store it as chemical energy in biomass. When biomass decomposes or burns, this process is reversed and nearly all CO_2 returned to the atmosphere.

Up to 50 % of carbon stays in the soil
Pyrolysis destroys the structure of the biomass. One half of the carbon is converted to woodgas and the other half remains in the created char. If the char is buried in the soil as biochar, most of the carbon stays there and is sequestered as biochar.

Source: adapted from Wilson (2013), based on Biochar Solutions Inc. (2011), printed in Roth (2014)

Over a life cycle of a tree the carbon balance is neutral, but in the view that most charcoal is made from unsustainably managed biomass, meaning that a tree cut for charcoal making is normally not replanted, all the emissions add to the CO_2 in the atmosphere. When LPG is used as cooking fuel, all CO_2 emitted from this fossil fuel adds to the total CO_2. However, GHG emissions are reduced even more if fossil fuel is replaced by sustainably grown biomass. When pellets are used in the ELSA stove, in the pyrolysis process only the syngas is released which is burnt cleanly with negligible emissions other than CO_2. Furthermore, no black carbon or other climate relevant particulates or gases are emitted from the cooking process. The charred pellets remain as a by-product. If they are brought back to the soil, the carbon balance of the cooking process is actually negative, as the carbon bound in the charred pellet (about 50 % of the overall carbon in the plant) is stored in the soil and sequestered from the atmosphere for at least 50 years (Roth 2014). This means that the method of burying char in the ground actively removes carbon from the atmosphere, as it is unlikely that the char will be transformed to ash, releasing the remaining carbon through combustion, which requires both heat (temperatures above 600° C) and plenty of air (oxygen), none of which will reach required levels in the soil.

Table 8: Comparison of environmental indicators of sustainability between the BAU and IFES

Criterion	INDICATORS		BAU	IFES
	Impact	Performance		
Soil health		Organic fertilizer applied to crop (Yes/No)	No	Yes
		Inorganic fertilizer applied to crop (Yes/No)	Yes	Yes
		Management practices to improve soil fertility (Yes/sometimes/No)	Sometimes	Yes
		Management practices to increase soil carbon (Yes/sometimes/No)	No	Yes
Pollution (pesticides)		Organic pesticides applied (Yes/No)	No	No
		Inorganic pesticides applied (Yes/No)	Yes	Yes
		Management practices to manage pests (Yes/No)	No	No
Climate change	Potential CO_2 released (kg CO_2/kg fuel)		Charcoal – 7.5 LPG – 3	
		Carbon balance after food and energy production (Positive/Negative/Neutral)	Neutral or positive, depending on amount of non-renewable biomass used for charcoal production and fuelwood	potentially negative if biochar is buried
		Clean-burning fuel (Yes/No)	Charcoal – No LPG – Yes	Pellet -Yes
		IFES depends on fossil fuel (Yes/No)	Yes (LPG)	No
		IFES depends on renewable natural resources (Yes/No)	Charcoal – Yes LPG – No	Pellets -Yes
		Energy component is forest-friendly (Yes/No)	Charcoal – No LPG – Yes	Pellets -Yes

Thirdly, while the charcoal fuels of the BAU could potentially lead to deforestation, the pellets used under the IFES does not affect forest resources.[11] As mentioned by Amuah (2011), Charcoal production in Ghana persistently puts pressure on the forest resources of Ghana.

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[11] This is particular true for areas where wood resources are scarce. In the Cape Coast Municipality, wood resources are not scarce compared to other ecological zones in Ghana. Yet the danger remains.

ECONOMIC PILLAR

Two criteria are assessed here – profitability and feasibility. We found that the IFES has advantages over the BAU in the areas of profitability for both the promoter and the user of the system and feasibility of use (Table 9).

Profitability (for promoter of IFES)

The question to address here is whether the energy components of two systems are profitable from the perspective of a promoter. We address this question by first looking at the gross margins earned from sale of one stove (ELSA for IFES and Charcoal coal pot for BAU). We find that there are positive gross margins sellers of both stoves. However, charcoal coal pot sellers make more returns (20 percent) compared to ELSA stove sellers on sale of stoves.[12] Next, we look at the gross margins earned from sale of fuel (Pellets for IFES and charcoal for BAU). The returns on maize cob pellets is higher than that of the charcoal.

From the perspective of the AIG, that promotes the IFES in the study area, the IFES may be more economically viable because it creates alternative streams of income in terms of the production and sale of the improved ELSA stoves and maize cob pellets. With over 4 000 of these ELSA stoves and 6 000 kg of pellets sold already, a market for the maize cob pellets IFES system is clearly emerging. If this market is sustained, there is potential of creating alternative means of livelihood for artisans (stove producers, stove repairers and pelletizer machine repairers) and pellet retailers in the study area.

Table 9: Comparison of economic indicators of sustainability between the BAU and IFES systems

Criterion	INDICATORS		BAU	IFES
	Impact	Performance		
Profitability (retailer)	Stove– retail prices (profit margins) [USD (% margin)]		1 burner charcoal coal pot = 4.5 (20 %)	1 burner ELSA = 25 (≤ 10 %) 2 burner ELSA = 35 (NA)
	Fuel - retail prices (profit margins) [USD (% margin)]		1 kg charcoal = 0.24 (≤ 15%)	1 kg pellets = 0.46 (21 %)
Feasibility of use		Energy component has alternative fuel (yes/No)	Coal pot – No LPG – No	ELSA - Yes

Feasibility of use and maintenance (for users of IFES)

From the perspective of the user, the IFES may be an economically feasible option when compared to the BAU. The first illustration of this point is that the ELSA stove and pellets present households with a cheaper and faster option for cooking compared to the coal pot and charcoal. Secondly, The BAU stoves do not have alternative fuels. When the households face shortages in charcoal or LPG, they do

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[12] We use retail prices as a proxy to measure how much it cost to invest in the energy component of the IFES.

not have any other alternative fuels. However, when the households run out of pellets, the IFES allows them to gather free palm kernel nuts for use as fuel in the ELSA.

This analysis reveals that, it is feasible and attractive to replace or maintain the ELSA stove as the benefit of continuous use of the stove is economically interesting. Although the cost of purchasing an ELSA stove (GHS 140 or USD 35) is relatively higher than the coal pot (GHS 18 or USD 4.5) the attached benefits make it attractive. Even if people use the stove with the palm kernel shells and not the pellets, the ELSA stove would not exist if it hadn't been introduced by the AIG in the course of the maize pellet intervention.

REPLICABILITY OF THE MAIZE PELLET IFES

The study identified several project features of the IFES, as has been introduced by the ASI Initiative that make it easier to upscale these systems in other communities throughout Ghana.

ENABLING FEATURES OF THE MAIZE PELLET IFES

Natural resource potential:

One of the reasons why the IFES scenario has replicability potential is that maize cob is freely available in the communities where the IFES is promoted. The biomass is also available in all rural agricultural communities in Ghana. Therefore, maize cob palletisation is possible in all regions in Ghana. The IFES does not compete with any aspect of the maize plant (the grains and the husk). For instance, the maize grains are used for food for both households and livestock, while the husks are utilized for preparing and preserving food. Additionally, other seasonally available materials, like sawdust or other agricultural residues that are too bulky for transport can be used with or in place of maize cobs in ELSA stoves for energy production.

Renewable energy technology potential:

One of the advantages of the IFES is that maize is a national priority crop, as such has a long history of support with technological innovations (Regasa et al, 2013). The national agricultural research priorities continue to focus on the improvement of maize production. Moreover, maize is not only widely available but also grown by the majority of farm households across the country.

Replication is also dependent on the development of appropriate and accepted stoves for the pellets, be it the ELSA stove or other similar clean-burning gasifier stoves for pellets. Only pyrolytic gasifiers operating without forced-air blowers will not burn the fuel to ash but conserve the char. Otherwise the energy-provision component will still be there, but the biochar component will fall away. This depends on the needs and preference of users in other areas where the IFES is to be replicated.

We found that the design of the ELSA stove presents a challenge to the replicability of the IFES. The ELSA stove is a top-lit up-draft (TLUD) gasifier where the fuel is filled in one batch and the lit at the top. The challenge with TLUD gasifiers is with ignition. Due to the way the fuels are filled into the stove, top surface of the entire fuel should be ignited as evenly as possible, yet pellets are hard to ignite. We identified that AIG, together with AIG had adopted a fire starter technology where some dried wood flakes are soaked wax so that the wax can penetrate into the wood. Another commonly used fire starter is dried palm nut fibre. Another way to develop fire starters is by soaking some of the pellets in liquid fuels with low ignition point like kerosene, gasoline or diesel. Cooking oils do not work.

Certain ELSA stove features do not meet the cooking specification of women. For example, some majority of the women in the interviews wanted shorter stoves to be able to do heavy stirring on the stove. Yet when made aware that a shorter stove would mean a shorter cooking duration they then preferred to go for that. Still there is room to have an additional shorter ELSA model to complement the range of ELSA stoves, currently available as single or double burner in the same height.

Additionally, the women complained that after a couple of years of use, the stove began to deteriorate, yet, they do not have contacts with any of the artisans that repair the stoves. They need to consult AIG leadership before their broken down stoves are repaired. This challenge can be overcome by training more artisans and over time develop a properly functioning market for the ELSA stoves. The biggest challenge is the quality control of the stoves to ensure that the artisans adhere to the prescribed patterns and quality standards for the stoves which are crucial for the proper functioning of the stoves.

The technology for palletisation is available in Ghana and utilized at various levels of production. The affordability and feasibility of the pellets lend them for easy adoption by households and hence potential upscale to other communities. One disadvantage of the palletisation process is that it is capital intensive to start, but where the market exists, returns are high enough to cover these initial costs in a few years. .

Clarity and credibility:

Presently, the AIG is the only organization that produces and sells both the ELSA stoves and the pellets. One of the reasons for the success of the IFES in the study area is the credibility of AIG. The NGO has worked with households in the study areas on many beneficial food, energy and microfinance activities over the years. This has given them credibility and won them some trust. Hence the IFES is seen as another beneficial component of AIG's general development activities. The strong support system provided by the NGO, in terms of organization and training, makes the acceptance of the IFES easy for women in the study communities.

Legitimacy:

The IFES is not indigenous to the study area. It was introduced to the area by an external project consortium who were involved in the Biochar Plus Project. Even though the AIG is promoting the IFES, it is working together with other partners like University of Udine, to push the idea. This notwithstanding, we have observed that AIG has done a great job in involving the local farmers and transferring ownership of the IFES to households.

Ease in assessing IFES results:

The IFES will be easy to introduce to other communities because it is simple to use and its benefits are easily observed. Group demonstrations revealed that women who subscribed to the IFES were able to easily measure the benefits of the IFES. They did not need external help to calculate tangible economic and health benefits of using the IFES. This is so because, especially for the energy component of the IFES, women in households were able to see the clear difference between the BAU and the IFES after a few cooking sessions.

Business model (funding)

The project did not start as a profit-focused business and is currently entirely based on the support of the EU-funded AIG. This fact notwithstanding, the IFES has the potential of being economically viable given the current patronage. This means that unless a private stove and pellet market and value chain emerge, a similar organization is required for replication in other communities. It also means that for any organization to successfully promote the IFES, they will require external (government or donor) funding to cover the procurement and operation of pelletizers.

Alignment and linkage:

The IFES has further potential for replicability because it aligns with national and local policies as well as the priorities of rural households in Ghana. At the national level, Ghana's energy priorities include the promotion of clean energy and improved cook stoves. The IFES therefore fits perfectly into this priority. At the local level, group discussion revealed that food security and convenience of cooking systems are the main priorities of households. The IFES system positively addresses these concerns of rural households.

Complexity, coordination and behaviour changes:

The food component of the IFES value chain does not require much complex organization. The technology is available and production is routinized. The energy component however has activities that need to be carefully coordinated. These include procurement of pelletizer, production of pellets, sale of pellets, and production and sale of ELSA stoves. All these activities are presently facilitated by the NGO, AIG. Also, if the IFES is introduced to other communities, the capacity of artisans to build, repair and improve on the gasifier stoves and pelletizers need to be built. Due to the fact that the feasibility of the IFES is dependent, in part, on the benefits derived such as biochar, households who are introduced to the IFES may have to be trained on the benefits of biochar for their farms and home gardens.

Acceptability in local knowledge systems and culture:

We found generally high levels of acceptability of the IFES among the AIG members, especially the women. Also, the 4 000 plus maize cob pellet IFES subscribers is an indicator of the acceptability of the system, even if not all are exclusively using the pellets as fuel in their ELSA stove, but without the ASA project the ELSA stove would not have been made available. From the perspective of the users of the maize cob pellets, all the aspects of this IFES depend on raw materials that were already locally available, but are now transformed into a new shape: the maize cobs to pellets, and the local metal to the ELSA stove. Both elements need to be in place for the IFES to function in the designed way.

Nevertheless, we observed a number of complaints about the IFES which could threaten replicability but can all be addressed to ensure the continuation. For instance, women interviewed complained that pellets are not always available. This is due to the limited capacity of the only small pelletizer. Its output of maximum 200 kg per day is not sufficient to serve more than 150 users on a regular basis. This looks like a mismatch to more than 4 000 ELSA stove users, but can be explained with the fact that most users in the rural areas use own palm kernel shells as fuel, which is residue from their palm oil processing with extremely good burning properties in the ELSA stove. These women use the pellets preferably in the rainy season when the palm kernel shells are not available. In future, to scale up this particular IFES, a larger pelletizer will be needed as well as a larger storage space to build up stocks for the rainy season. Another element is the moisture-proof packaging to prevent the pellets to absorb moisture, as moist pellets don't burn well in the stove.

ROLE OF STAKEHOLDERS AND INSTITUTIONS IN THE REPLICATION OF MAIZE PELLET IFES

We have identified relevant stakeholder groups and their **current roles** within this IFES:

Stakeholders who are directly involved in the production and use of pellets for household energy are the AIG (AI); local artisans; the AIG farmers group (AIG); and women in the community.

- The AIG is the lead stakeholder that coordinates all the activities involved with organization of the production of maize, collection of maize cobs and pelletisation. The NGO is also the sole trader of ELSA stoves and the distributer of the maize cob pellets.
- The AIG works with **local artisans (welders)** to produce the ELSA stoves. The NGO is the custodian of the stove designs, while the artisans manufactures them.
- The **AIG Farmers' Group** are the producers of the maize. The group employs one person to operate and manage the pellet-making machine.
- The ELSA stoves and pellets are sold to women in the households within the communities. They are the **end-users** of the pellets.

Within these directly involved stakeholders, two **champions** have emerged which we list separately as their engagement is crucial for the success of the project. Ms Veronica Kitti, as head of the AIG, and Mr. Paul Ainnoo as head of the AIG Group. Mr. Ainoo, is referred to as a Corporate Responsible Farmer (CRF), a role assigned to farmers who emerge as champions of innovation among the groups that work with AIG. Together, they have offered leadership for the stakeholders who are not directly involved in the production and use of the pellets include:

- The **European Union** (EU) as donor of the project
- The **project consortium** with the University of Udine (UU), University of Cape Coast (UCC), the international biochar community. These stakeholders were crucial in the development of the entire system and introduction of the technologies for both pelletizer and stoves. The maize cob pellets IFES was introduced by the AIG as partner of the BEBI project (from 2011-2013) followed by the Biochar+ programme (2014-2016), both funded by the European Union and lead by the University of Udine. As part of the work, the University of Udine provided the pelletisation machine. University of Cape Coast is a local collaborator with University of Udine. They hosted the projects locally and oversaw the scientific research component of the various stages of the biochar projects. There is a general collaboration on biochar with other universities in Ghana such as University of Ghana, Kwame Nkrumah University of Science and Technology (KNUST) and University of Development Studies. A Ghana Biochar Association is under formation and expected to come to existence in early 2017 to create a platform for all biochar-related stakeholders to exchange experience and lobby jointly for the potential role of biochar in climate change adaptation and mitigation.
- The **media** are regularly engaged by AIG to assist in raising awareness of the stoves, pellets and biochar in general.

THE EFFECT OF GHANA'S POLICY ENVIRONMENT ON POTENTIAL REPLICABILITY OF THE IFES

Presently, there is a conducive policy environment for the promotion of the IFES.

Maize production policies

The maize pellet IFES fits perfectly in the national agriculture policy. Ghana's food and Agriculture policy document "Food and Agricultural Sector Development Policy" (FASDEP II) aims, among other things, to improve maize productivity through fertilizer subsidies, mechanization programmes, block farms programme and the buffer stock scheme. This suggests that the environment for producing the biomass for pellet production across all maize producing regions in Ghana remains conducive. It also means that in the foreseeable future, the biomass stock is not going to run out.

Energy policies

In principle, any effort to replicate the IFES will not face any energy policy bottleneck. At the national level, two policy documents - The Strategic National Energy Plan (SNAP) and The Renewable Energy Act, 2011 provide the policy framework for the expansion of the IFES in Ghana. These policies generally seek to reduce firewood use while promoting alternative fuels.

The SNAP for instance aims to (1) reduce wood fuel energy intensity by 10 % and 50 % by 2020 in rural and urban areas respectively; (2) achieve 10 percent penetration in the use of improved efficiency cook stoves by 2020 and (3) reduce the wood fuel share of energy demand to 40 percent by 2020. The Renewable Energy Act, 2011 seeks to:

- promote production and use of improved and more efficient wood fuel technologies such as cook stoves and charcoal production techniques;
- promote the use of alternative fuels such as biogas, LPG, and wood-briquettes for cooking and heating, and
- support sustainable regeneration of woody biomass resources through legislation and fiscal incentives for reforestation, particularly in "stools".

Cookstove policies

Whereas the energy policy is generally favourable to the IFES, there are challenges with cookstove polices in Ghana. Cookstoves have been a central component of government's energy policies since the 1960s. The government, through research institutes and international collaborators, have developed and promoted a number of cook stoves over the years. However, much of their efforts focus on the improvement of the BAU cookstoves – coal pots and LPG stoves. In particular, the government is pushing for the mass use of LPG[13].This focus on charcoal stoves and LPG has meant that the market for gasifiers and micro-gasifiers are yet to become mainstream in Ghana.[14]

Climate policy

The IFES ties in with national climate change policies plans. The objective of the Ghana's climate chance policies are twofold. First, the nation plans to "minimise the loss of carbon sinks by reducing activities that lead to the destruction of natural ecosystems, especially forest degradation and deforestation". The second objective is to "enhance carbon stocks through programmes that restore degraded forests and other natural ecosystems". According to the Ghana Climate Change Policy, the approach to achieving this policy objective is through reduction of the pressure on forests and mangroves for wood fuels through the promotion of improved efficiency in cook stoves among others. The country plans to develop programs towards sustainable wood fuel production and development of alternative biofuel sources for domestic energy supply.

The IFES provides a clear contribution to the national focus of reducing GHG because the maize pellets are a cleaner alternative to charcoal in terms of CO_2 emissions. Additionally, the IFES aligns the national goal of increasing carbon sinks because it is connected to biochar production and has a negative overall carbon balance compared to the BAU.

THE EFFECT OF HUMAN AND TECHNICAL CAPACITY ON REPLICABILITY MAIZE PELLET IFES

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[13] https://cleancookstoves.org/binary-data/RESOURCE/file/ 000/ 000/334-1.pdf

[14] http://www.energycom.gov.gh/files/Barriers %20to %20Renewable %20Energy %20Technology %20Transfer %20in %20Ghana(2015).pdf

The success of the MCP- IFES is linked to the leadership provided by the AIG. In this instance the competence level of the leaders of the AIG is a key driver of the IFES. In Ghana the NGO sector is a thriving with several competent non-profits who can adopt and adapt the AIG model or partner with them to introduce the IFES in maize production communities.

The current success of the IFES and future up scaling is also linked to technical support from the university (research) and donor community. Ghana has an active donor community who can potentially support the IFES. Already, the SNV, Global Alliance for Clean Cookstoves, GIZ and UNHCR are experimenting with different aspects of the IFES such as pelletization, briquetting in Ghana. We observe that the AIG model of promoting the IFES is dependent on the organizing strong farmer organizations. This is dependent on the quality of leadership provided by group leaders. We observe that the leaders of the AIG (Corporate Responsible Farmers - CRF) provide strong leadership competence in terms of organizing the group and keeping its operations running. These CRFs have successfully run the AIGs because they are of relatively high education, have large farm holdings, selected by the group themselves.

At the production end, there is local capacity in stove making and pellet production which can be disseminated. The AIG team have been trained in pellet making under the ACP/Science and Technology Programme. The experience and leadership of the AIG and community leaders explain the adoption the IFES in the study community.

CONCLUSIONS

The maize cob pellet IFES is an innovation, introduced to communities in Cape Coast Municipality, which has not been systematically documented. This report has outlined the various components of the IFES, assessed its sustainability and provided the grounds for replicability.

In its current state, the IFES comprises of the utilisation of dry maize cob for the production of clean-burning pellets to be used in the advanced ELSA gasifier cook stoves. The ELSA cook stoves convert the pellets into char while creating a gas that provides the clean flame for cooking. The system thrives by being part of an interconnected system of value chains (biochar manure, vegetable production, oil palm kernel) which are coordinated by an NGO -AIG.

On several sustainability indicators, we found the IFES to be an improvement over the BAU. These include:

- Social sustainability
    - IFES saves households expenditure on cooking
    - IFES improves health through less smoking of energy component
    - IFES expands energy access by adding to household energy mix one more available, accessible and affordable cooking system.
- Environmental sustainability
    - IFES generates less emissions
    - IFES has a soil improvement potential
    - IFES is less dependent on fossil fuel and forests resource
- Economic sustainability

- Energy component of IFES is potentially feasible for the suppliers, if they could be supported to cover initial cost.
- IFES has many potential benefits for users (example improvement in farming systems, availability of even cheaper fuels), making it feasible to use.

We found a number of reasons why the IFES can be replicated in other communities in Ghana. First, the features of the IFES make its use throughout Ghana (especially maize growing-communities) easy and convenient. Secondly, the IFES fits in perfectly into the maize, energy and climate change policy environment, with potential to be adopted as a mechanism for improving agricultural production while addressing climate challenges. Finally, we observe that there is adequate human and technical capacity to provide the needed support wherever the IFES is replicated in Ghana.

Whereas the IFES is sustainable and could take advantage of the many internal opportunities and external threats for scaling up, successful replication depends on the method by which it is promoted. In this study, we identified two business models to promote the IFES – through a non-profit or via market forces.

If the IFES will be coordinated by a non-profit organization, an overarching institution is required to coordinate the production of stoves and pellets. Additionally, Funds are required to procure and maintain the technological (biomass crusher, pellet machine, improved stoves) and the organizational (farmer groups) components. This institution needs a trading model to get the IFES to rural farm families. In the case of the AIG, the model of using a multifaceted NGO which works with farmer organization on improving soil fertility has proven to work in the municipality. At present the University of Udine and the EU are funding aspects of the IFES system. With a market base of 4 000 stove users and subsidized pellet prices, it is unclear if the AIG is able to procure new technology without the donors support. We conclude that, if the IFES is to be spread through this NGO approach then, the more connection points to other areas and value chains, the better it seems to be.

If the IFES is coordinated through a more decentralized marketing chain. In this approach replicability might be enhanced through private sector investment into the fuel production as a business. The profitability of a fuel production enterprise is strongly linked to the prices and availability of alternative cooking fuels. This might vary from region to region and economic feasibility needs to be assessed case-by-case. If market forces is allowed to spread the IFES, policy makers need to create awareness and build capacity of value chain actors to see the possibility and economic viability to enter the pellet production market.

Whether or not the IFES is promoted by an NGO, there ought to be adequate community artisans (welders, machine builders and machine operators, and mechanics). This does not inhibit potential introduction of the IFES to any community in Ghana, because all Ghanaian communities have adequate artisans who can be fallen upon.

The basis of any future replicability of the maize cob pellet IFES is the extent to which the improved stoves are acceptable to women in rural households. We found convenience and its relative advantage over coal pot and gas stoves as the main drivers of acceptability and use by women in the study area.

The IFES fits perfectly into the national policy environment. There is need for government policy makers to direct more attention to the emerging gasifier stove sector. These gasifier stoves create room for woody farm biomass to be pelletized and present an alternative to conventional wood fuels.

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UTILISATION OF MILLET AND SORGHUM STALKS AS COOKING FUEL

SYSTEM AND CONTEXT

BACKGROUND

There is high demand for wood fuels (firewood and charcoal) in northern Ghana (i.e. the Northern, Upper East and Upper West regions). For instance, Antwi et al (2010) mention that wood fuels constitute up to 65 percent of total energy demand in Ghana. The average northern Ghanaian household consumes about 440 kg of charcoal annually, slightly more than the national average of 334 kg per year (Energy Commission, 2012). According to Ayamga (2015), in parts of northern Ghana, households consume up to 1,157 kg of firewood for cooking yearly. This high demand for wood fuels has placed pressure on forest or wood resources in northern Ghana, which supplies up to 10 percent of Ghana's wood fuels.[15]

Through integrated food energy systems (IFES), this over dependence on forest resources for cooking fuel can be curtailed if households would utilize biomass from their farms as additional sources of energy (Bogdanski, 2014). Sorghum (Sorghum bicolor L.) and millet (Pennisetum glaucum L.) are two of the most important staple cereals in northern Ghana whose residues are used by several households in the region as cooking fuel (Freeman and Boateng, 2012).Sorghum and millet are mostly cultivated in northern Ghana because they do well under the savannah agro-ecological climatic conditions. In total the two crops are cultivated on a land area of 550 000 ha, out of which 350 000 ha are under sorghum and 200 000 ha under millet. Whereas Ghana produces up to 250 000 tonnes of sorghum annually, the yearly output of millet is about 350 000 tonnes.

Households in northern Ghana take advantage of the woody characteristics of sorghum and millet stalks to burn them for fuel. It is estimated that per each kg of sorghum crop the stalk yield is 3.5 kg while 1 kg of millet produces 5.5 kg of stalks (Ayamga et al, 2015). Because the stalks have alternative uses as fodder etc., not all produced stalks are available for fuel. The Energy Commission (2011) estimates that 150 000 tonnes of millet and 136 000 tonnes of sorghum are available annually to be used for fuel. A large proportion of these stalks end up supplementing wood fuels from natural forests as household fuels in northern Ghana.

To improve upon the continuous use of the sorghum and millet stalks for fuel, while easing the pressure on forest resources, it is important to understand the system of production of the cereals and converting the biomass residue into fuel.

STUDY OBJECTIVES

The purpose of this study is to provide a detailed documentation of an integrated food-energy system (IFES) which involves the utilisation of stalks from sorghum and millets to substitute firewood cooking fuels in the Northern and Upper East region of Ghana. The study analyses the sustainability and replicability of this IFES case.

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[15] *http://www.crc.uri.edu/download/GH2014_SCI010_SNV_FIN508.pdf*

METHODOLOGY

SITE AND CASE SELECTION

The study was conducted in the Northern and Upper East regions of Ghana (Table 10). The two regions were selected because they represent the sorghum and millet belt in Ghana. Within each region, four communities were sampled to collect data for the study. In the Northern region, the study team visited Nyankpala, Kulaa, Gaagbini and Walewale. In the Upper East region, the survey was carried out in Nakpasalig, Kalini, Anangfobisi and Dua Tadonjo. The Northern region has a dry climate because it is close to the Sahel and Sahara, but with wide variation in temperature ranging from 14 °C at night to 40 °C in the day.

The region is characterized by one rainfall season from July to November. The average annual rainfall during this period is 750 to 1 050 mm. In the Upper East region, temperatures range between 14° C at night to 35° C. There is only one rainy season in the year, normally from May to October with an average annual rainfall between 800 mm and 1 100 mm.

Table 10: Sampled communities

	District	Community
NORTHERN REGION	Tolon Kunbungu District	Nyankpala
	Sagnerigu District	Kulaa
	West Mamprusi District	Gaagbini
UPPER EAST REGION	Nabdam District	Nakpasalig
		Kalini
	Bongo District	Anangfobisi
		Dua Tadonjo

SETTING THE BOUNDARIES OF THE BASELINE AND IFES BIOMASS CHAIN

In this study, two systems are described – the IFES and a Business As Usual (BAU) scenario. The two systems are described as follows:

- The IFES comprises the production of millet and sorghum and the use of their stalks as fuel for household cooking to substitute or complement firewood to various degrees, which often comes from mostly unsustainably managed forest resources. This IFES concerns the fuel supply only, without replacing the conventional three stone stoves as cooking technology.
- The BAU scenario with which the IFES is compared covers the production of sorghum and millet, but households have to rely on firewood for cooking because stalks are either sold or left as fodder.

SUSTAINABILITY ASSESSMENT

The IFES Analytical Framework (IFES AF) – is used to analyse the sustainability of integrated food-energy systems (Bogdanski, 2014). The framework proposes three pillars of sustainability (1) social, (2) environmental and (3) economic. To analyse the sustainability based on each pillar, we developed a number of indicators. The indicators were either impact (quantitative) or performance (process or qualitative) in nature. Sustainability was assessed by comparing indicators for each of the two scenarios.

REPLICABILITY ASSESSMENT

The IFES AF presents four criteria with which the replicability of an IFES can be assessed – (1) presence of promoting or inhibiting project features of the IFES, (2) stakeholders that may promote upscale of the IFES, (3) alignment of the IFES with national food and energy objectives and (4) availability of capacity for up scaling. Within each criteria, we discuss how specific factors promote or inhibit the future uptake of the IFES.

METHODS OF DATA COLLECTION

Eight communities were selected based on the recommendations of the Regional Offices of the Ministry of Food and Agriculture (MoFA), according to the prevalence of the IFES crops and practices and the availability of MoFA staff to organise meetings with community members. The selection was deliberate to document specific IFES cases and not supposed to be a representative sample of the region. Field work was carried out in November 2016 by the consultants William Quarmine and Christa Roth.

Data was obtained from these selected communities through focus group discussions with 10-20 farmers in each community. Males and females were both represented on the focus groups. Additional to focus groups discussions, individual interviews were held with staff of the MoFA, Savannah Agricultural Research Institute (SARI) and GIZ.

DESCRIPTION OF THE CASE STUDY

VALUE CHAIN OF THE BAU SYSTEM (BASELINE)

Biomass production

Sorghum and millet are the 'compound crops' in northern Ghana. This means that they are often planted on the available fields near the farmhouses, but are not restricted to them. Land is still available in abundance in Northern Ghana. The limiting factor of the size of the cultivated fields is more commonly the available labour resources for cultivation. They are traditionally cultivated by males, but the residue is harvested by females. Average farm sizes are no more than 1.5 ha which produce a maximum output of 4 bags of grains (i.e. the equivalent volume of the prevalent 100 kg fertilizer bag)[16].

Land preparation and planting

Land preparation for cultivating millet and sorghum begins in May. Residues are cleared with cutlasses after which farmers plough the land into ridges. Three varieties are usually planted– early maturing millet, late maturing millet and sorghum. Over the years, sorghum and millet farmers have developed a traditional pattern of staggering the crops to maximise yields to reduce risk if one variety fails. On the same plot of land, the farmers begin with early maturing millet followed by sorghum and late maturing millet. Planting is carried out in rows and involves using hoes to make holes in which up to four seeds are buried.

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[16] *In the absence of scales it is common practice by farmers to measure crop yield in volume. The units 'bag' are based on the most prevalent bags in which industrial fertilizer is sold which can either be 50 kg or 100 kg bags. The weight of the bag filled with grain varies per grain type but seems to be consistent enough within the grain varieties to be accepted as units even for trade.*

Cultural practices

- *Soil fertility management:* Focus group discussions revealed that soil fertility in the study communities have degraded over the years. Use of inorganic fertilizers in sorghum and millet fields is however scarce. Two organic fertilizer strategies are common. First, after harvesting, the stalks and other residue from the crops are left on the field for use as fodder for animals. In the grazing process, animal droppings are left of the fields. The animals normally leave the stalks and feed on the softer residues. Once the animals are satisfied, the leftover stalks are collected and the remaining softer residues and animal droppings on the field are ploughed into the soil. Second, the farmers use crop rotation as a way of maintaining the fertility of the soil. The prevalent strategy is to plant one legume between grain crops. Some farmers reported yet another interesting strategy that can substantially increase soil fertility by planting two different legumes after each other or simultaneously e.g. groundnut and pigeon pea (Cajanus Cajan). Some farmers claimed that this double-legume crop rotation could triple sorghum and millet yields as compared to no legumes and no fertilizer application.

- *Water management:* Sorghum and millet cultivation in the study areas are rainfall dependent. There is no irrigation as the crops are rather drought-tolerant.

- *Weed and pest management*: We observed no cases of weedicide use. The normal practice is to weed intermittently under the sorghum and millets with cutlasses and hoes. Farmers reported that insects attack their sorghum and millet crops, yet pesticides are hardly used. Usually, these insects are left untouched until the rains when they are washed off.

Biomass harvesting and storage

- Harvesting

Grain harvesting is done manually by removing the panicle (ear) of the crop with sickles or small hand knives. In rare cases, the stalks are cut down, but the common practice is to harvest the grain without breaking the stalks which are harvested later. This is done manually by cutting them with cutlasses. Individual stalks are then polished buy removing all the leafy husks around them. Respondents estimated stalk yields at 12 donkey carts per hectare. To find the actual average stalk yields, we make two simplifying assumption:

a. we adopt the measurements of Anabire's (2014), who calculated that 1 kg of sorghum crop yield 3.5 kg of stalks while 1 kg of millets produces 5.5 kg of stalks (Ayamga et al, 2015),

b. we use Quaye's (2014) estimation of sorghum and millet yields of 580 kg/ha and 490 kg/ha respectively in the Northern Region.

From these two scenarios, we estimate stalk yields in the study area to be about 2 030 kg/ha for sorghum and 2 695 kg/ha for millet.

- Collection and transport

The harvested sorghum and millet panicles (containing the grains) are gathered in the farm and transported to the house for drying. Transportation of harvested sorghum and millet ears to the houses is done either with donkey carts (depending on the distance of the farm to the house and quantities transported), baskets or head pans. Harvested stalks are collected by women. They are transported to the homes either by carrying them on the heads or loading them on donkey carts or tricycles (if available).

- Storage

Generally, the grains are stored for human consumption and for sale. The majority of farmers in the study areas store their gains (on the panicle or threshed) at home in traditional storage structures. The main storage facility in the region are mud silos. Others means of storing the grains include jute sacks and polypropylene bags. The stalks are normally left on the field before they are processed, by stripping off all dead husks until the woody part remains. When processing is completed, they are bound together and leaned against the walls of the house.

Biomass processing

- Drying

For both sorghum and millet, the tradition is to sun-dry the grains either on the panicle or as threshed grains. The purpose is to reduce the moisture content to allow for easy threshing and cleaning as well as preventing post-harvest losses through mould development. Harvested stalks are sun dried first on the field before harvesting, then at the house where they are kept in a way to be exposed to the sun for further drying.

- Threshing

Threshing is carried out to remove the grain from the harvested panicle. For most small farmers, threshing is carried out by beating the dried sorghum and millet panicles with sticks.

- Cleaning

Through the cleaning process, farmers are able to remove all contaminants from the main grains. Some of the contaminants include sand, small stones, chaff and animal droppings. Cleaning of the harvested sorghum and millet grains is done through winnowing. In this process, sizeable quantities of grains are thrown up in the air or dropped from a height to allow the wind to blow off the light contaminants. Also, during this stage, the winnowed grains are put in a basket or container and vigorously shaken. This process allow the lighter grains to settle at the top while heavy contaminants stay at the bottom. Cleaning of the harvested stalks is done by removing all dried husks and leaves from the stalk until it is left with the woody part.

- Packaging

When packaged for sale, sorghum and millet grains are mostly put into jute sacks or woven polypropylene bags (e.g. recycled fertilizer bags). In the markets they are displayed in saucepans and measured by volume. On the average, a kilogramme of both sorghum and millet sells at GHS 2 (USD 0.50) per kg to non-farm households and middlemen who sell them onward at higher prices in the non-sorghum production areas (especially, southern Ghana). With regards to stalks, they are bundled by tying a collection of them together with a rope.

Biomass (grain and residue) end-use

- Grain-end-use

Sorghum and millets have three main end-uses. The majority of household grow the crops for food. The other two uses are animal feed and industrial purpose. When used for food, the grains are milled before they are used either in fermented or unfermented form to prepare porridges and other solid foods. Industrial use of sorghum as a local substitute for barley for beer brewing is growing in Ghana. Some farmers have contracts with breweries to supply sorghum. Local sorghum-based breweries have also traditionally existed in Ghana and artisanal beer brewing is a very common and lucrative income-generating activity.

- Cooking system

To cook sorghum-and-millet-based foods, most households visited utilized the traditional three-stone stoves. In the BAU scenario, they utilize only firewood as fuel. We found that while most households have small kitchens, cooking is mainly done outside in the open (but within the compound). This is usually the case because households must cook in large portions and also because the kitchens are normally overheated. On rainy days however, cooking is done in kitchens.

- Fuel residue end-use

Firewood is the main fuel for 3 stone-stoves in the BAU scenario. Stalks are sold either for construction (roofing and fencing), or are used in IFES households as fuel. All the communities visited have a forest nearby at varying distances. In Nagkpasalig in the Nabdam District of the Upper East Region, we discovered that the community had banned the cutting of trees in natural forests. Firewood collectors (often women and children) are only permitted to collect fallen branches and twigs.

In other communities, like Anangfobisi in the Bongo District of the Upper East Region, farmers had planted their own acacia woodlots as a source of firewood. In general, the majority of farmers reported that firewood is scarce and women have to walk long distances to collect them for free. In this processes, they collect the firewood on three days in a week, spending close to an hour or more in the process. A day's collection of firewood lasts for about two to three days. If they are to purchase the firewood, a donkey cart or tricycle load cost an average of GHS 50 (USD 12.5).

THE SORGHUM-MILLET BASED IFES VALUE CHAIN

This IFES has emerged naturally over the years in response to the rising need for fuel and firewood resources (Table 11). The IFES has the following elements:

- It involves the cultivation of sorghum and millet for food and the utilization of their stalks for fuel. Varieties that produce thicker stalks are preferred over varieties that are bred by research institutes for increased yield but with thin stalks.
- The stalks are utilized to different extents. In its purest form, the entire firewood fuel of households is substituted with sorghum and millet stalks. This group of IFES utilizers are few. The majority of households in the study communities however mix various quantities of firewood and stalks.
- The IFES does not involve the replacement of the stove use for cooking in households, just the fuel. A change in the cooking technology could additionally save fuel.

The value chains of the IFES and BAU scenario are similar, except for the end use of the fuel. This is because with both system, the grains and stalks are needed. Whereas the IFES household utilizes the stalk for fuel and could possibly sell the excess, the BAU households either leave the stalks on the farm as fodder or manure. Some farmers also reported to simply burn the stalks on the field, sell them or let others harvest the stalks for fuel. This difference leads to the separate cooking system paths for the IFES and BAU households described earlier in this section.

COMPARISON OF BAU AND IFES SCENARIOS

Table 11: Comparison of the value chains of the BAU scenario and the IFES

	BAU IFES
BIOMASS PRODUCTION	
Land preparation	Season starts in April/May. All old crops are cleared. Soil is ploughed into ridges.
Planting	Planting in ridges with hoes. Up to 4 seeds are planted in one hole. Sorghum and millet are planted around the house compound.
Soil fertility management	Inorganic fertilizers are hardly used for compound farming. Residue is ploughed together with animal dropping into the soil. Crop rotation – two legumes planted after each other before cereals.
Water management	Rainfall dependent
Weed management	Weeding with cutlass and hoe, depending on need
Pest and disease management	Mostly no pesticides used. Some sorghum and millet varieties are attacked insects. The insects are washed away during the rains.
BIOMASS HARVESTING AND STORAGE	
Harvesting	**GRAIN:** By hand by breaking panicle off the stalk by hand or with small knife **RESIDUE:** Cut with cutlasses.
Collection and Transport	**GRAIN:** transported to mud silos in pans or baskets, or on donkey carts **RESIDUE:** stalks are transported to houses by head or in donkey carts.
Yields	**GRAIN:** Sorghum = 580 kg/ha and Millet = 490 kg/ha[17] **RESIDUE:** Sorghum = 2 030 kg/ha and Millet = 2 695 kg/ha[18]
Storage	**GRAIN:** Stored mostly in mud silos on household compound. **RESIDUE:** Stored by leaning against household walls.
BIOMASS PROCESSING	
Drying	**GRAIN:** Sun dried, mostly when on the grains are on the panicle. **RESIDUE:** Sun dried. Left on the field to dry.
Threshing	**GRAIN:** Beating the panicle with a baton.
Cleaning	**GRAIN:** Through winnowing, vigorous shaking and hand picking of contaminants **RESIDUE:** Through removal of all dried husks from the stalk till woody part is left.
Packaging	**FOOD:** Packaged in jute or other forms of sacks **FUEL:** A number of stalks are bundled together with a rope
Transport	**FOOD:** Carried to the market in carts, tricycles etc. **FUEL:** Donkey carts. Sometimes responsibility of the buyer.

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[17] *Quaye, W. (2008). Food security situation in northern Ghana, coping strategies and related constraints. African journal of agricultural research, 3(5), 334-342*

[18] *In local terms, this will amount to about 12 donkey carts per hectare.*

Table 11 (cont'd): Comparison of the value chains of the BAU scenario and the IFES

	BAU	IFES
Sale	**FOOD:** Average millet/sorghum price = GHS 2 (USD 0.50) per kg **FUEL:** Bundle of stalks = GHS 2 (USD 0.50). A donkey cart of stalks = GHS 10 (USD 2.50). A donkey cart of firewood = GHS 40 (USD 10)	
FOOD AND FUEL END USE		
Food end-use	Eaten as is, or milled into flour. For human, animal and industrial consumption	
Fuel end-use	Stalks are sold	(1) Stalks are used alone (2) Stalks are used to complement Firewood
Cooking system	**Stove:** Traditional 3-stone stoves. **Fuel**: Firewood	**Stove:** Traditional 3-stone stoves. **Fuel**: Firewood, sorghum/millet stalks

SUSTAINABILITY OF THE SORGHUM-MILLET BASED IFES

In this section, we discuss the advantages the IFES has over the BAU scenarios, which make it a more sustainable system.

SOCIAL PILLAR

Social pillar of sustainability was assessed by the criteria of food security, energy access, health and adaptive capacity to climate change. We found that the IFES performed better than the BAU scenario in the area of food security and energy access. Whereas the IFES did not differ much from the BAU in terms of adaptive capacity to address climate change, we found a number of relevant practices in the study community which can be used for upscaling (Table 12).

Food security

We found that using the IFES improved the food security of households through savings on cooking expenditures, hence reducing the cost of food. To demonstrate this, we recall that there were no differences in the production practise of the IFES and BAU users. The main difference is with regards to fuel end use.

We identified three kinds of fuel end-use based on the availability of sorghum and millet stalks within the calendar year:

- Fully dependent on firewood (BAU Scenario): Households depend on firewood all year round and do not use stalks for cooking.
- Partially dependent on sorghum and millet stalks (IFES case): In months of no stalks (June to October), households depend on firewood. In the months when firewood and stalks are both available (November to May), households mix the fuels for cooking. We assume that on average two thirds of their cooking fuel is firewood and one third stalks.
- Predominantly dependent on sorghum and millet stalks (IFES case): In the best case scenario we observed that a number of communities cook entirely on stalks and use firewood only for certain processing activities, but these were few cases where enough land and labour were available to farm

larger fields and harvest sufficient amounts of stalks. A larger number of households cook entirely on stalks for seven months (November to May) and use firewood for the remaining five months (June to October). For ease of calculation we assume as an average for this case that firewood is one third of their annual cooking fuel, and stalks contribute two thirds.

Data from the focus group discussions revealed that in the BAU scenario households not using stalks on average spent GHS 50 (USD 12.5) per month on firewood, or GHS 600 (USD 150) per year on cooking energy per household. When households are partially dependent on sorghum and millet stalks and substitute only one third of firewood with their own stalks they have a total cooking energy expenditure of GHS 400 (USD 100) per year, amounting to a saving of GHS 200 (USD 50). In the IFES case where households substitute two thirds of the cooking fuel with stalks, they spend can save 100 USD per year in cooking fuel expenditure.

Energy access

Throughout the fieldwork, it was observed a number of alternative fuel sources are available with varying degrees of access. Yet the most preferred was firewood. It came out during focus group discussions that firewood from indigenous trees was preferred because it provides more intense heat and lasts longer than the less dense stalks. Firewood is also available all year round. This notwithstanding, the general consensus was that firewood access is becoming more and more difficult due to changes in the climate and pressure on forest resources. Firewood collectors must travel sometimes over 10 miles three times in a week to get a household's supply of cooking fuel without payment. For the seven month that stalks are available, they present households with a freely available, easy to access and affordable alternative cooking fuel.

Adaptive capacity to climate variability

Even though we did not observe a clear advantage of the IFES over the BAU scenarios with regards to adaptive capacity to manage climate variability, a number of practices associated with both systems in some communities are worth discussing.

We think of adaptive capacity as the ability to adjust to constant changes brought about by climate variability. Asante et al (2012) argue that adaptive capacity reflects in the actions of people when they are faced with climate vulnerability. Focus group discussions revealed that farmers have developed the capacity to adapt to climate variability in three ways:

(a) We observed a number of improved soil fertility management practices. In one case, some communities have banned the burning of harvested fields. Animals are strictly to graze the farms in order that their droppings could be captured on the fields. The remaining biomass after harvest is ploughed into the soil. In another example of the adaptive capacity to manage, the soil is the strategy to double up on legumes during crop rotation.

(b) Farmers have developed the capacity to improve on the management of forest resources. In some communities, shared rules have emerged naturally regarding the cutting of trees to minimise consequences of forest cover loss.

(c) To cope with water and rain shortages, farmers have adapted by cultivating also early maturing crops to complement the long-maturing varieties.

Table 12: Comparison of social indicators of sustainability between the BAU and IFES systems

Criterion	INDICATORS		BAU	IFES
	Impact	Performance		
Food security	Land size (ha)		< 4 ha	
	Estimated crop yields (kg/ha)		Sorghum = 580 kg/ha and Millet = 490 kg/ha	
	Estimated stalk yield			
	Household expenditure for woodfuels for cooking purposes (USD per year)		USD 150	Partially dependent on stalks = USD 100 Predominantly dependent on stalks = USD 50
Energy Access	Availability of fuel	'Modern' fuels i.e. electricity or LPG	Most communities are not connected to the grid, some have solar installations but no electricity for cooking, and LPG is only available in the major trading centres.	
		Solid biomass fuel sources	• Firewood: Collected; available all year, but supply is reducing. • Charcoal: Purchased; available all year. • Crop stalks (sorghum/Millet/Pigeon pea): Harvested from fields for free; available for 7-8 months.	
		'Modern' fuels i.e. electricity or LPG	Electricity not accessible in quality needed for cooking, LPG considered too expensive	
		Solid biomass fuel sources	Firewood: Becoming difficult to access.	Stalks: Easy to access when available.
Health		Generation of smoke (Low/ Medium/High)	Firewood: High	Stalk: High
Adaptive capacity to climate change and variability		Awareness of climate change impacts [Yes/No}	Yes	Yes
		Climate change mitigation mechanisms	1. Planting of early maturing crops 2. Doubling up on legumes during crop rotation 3. Strict rules on burning of farms 4. Strict rules on allowing animals to graze harvested sorghum and millet farms	

ENVIRONMENTAL PILLAR

The three criteria used to assess the environmental sustainability of the IFES were soil health, pollution from pesticides and climate change mitigation. The main difference between the BAU scenario and the IFES were found in the area of climate change mitigation (Table 13).

Soil health

There are no major differences between the BAU and IFES concerning soil health as both systems utilise similar soil management practices. While in the BAU, in addition to the leaves, the stalks are more likely to rot on the field and serve as mulch. In the IFES, the stalks are removed from the fields and taken to the houses, which results in removing nutrients from the field. In the IFES soil fertility could be improved if the ashes from the stalks would be brought back to the fields and recycle the mineral nutrients.

Pollution

We did not find differences in the pollution regarding pesticides but we could detect a difference regarding air pollution. In the BAU, the stalks and residues are often burnt on the field in an uncontrolled manner leading to incomplete combustion. This leads to increased air pollution as more smoke especially particulate matter is emitted than if the stalks are burnt in slightly better controlled cooking fires in the IFES case.

Table 13: Comparison of environmental indicators of sustainability between the BAU and IFES

Criterion	INDICATORS		BAU	IFES
	Impact	Performance		
Soil health		Organic fertilizer applied to crop (Yes/No)	Yes	
		Inorganic fertilizer applied to crop (Yes/No)	No	
		Management practices to improve soil fertility (Yes/No)	Yes	
Pollution (pesticides)		Organic pesticides applied (Yes/No)	No	
		Inorganic pesticides applied (Yes/No)	No	
		Management practices to manage pests (Yes/No)	No	
Pollution of air (smoke)		Air pollution through uncontrolled burning of residues in the field (Yes/No)	Yes	No
Climate change mitigation		Clean-burning cooking fuel (Yes/No)	No	
		IFES depends on fossil fuel (Yes/No)	No	
		IFES depends on renewable natural resources (Yes/No)	No	Yes
		Energy component is forest-friendly (Yes/No)	No	Yes
Reduction of GHG *emissions*	Estimated tons of CO_2 emitted/ year		2.02 t CO2/year	Potentially 0 if all firewood is substituted by stalks, more realistically between 0.67 and 1.33 t CO2/year

Climate change mitigation

The main differences between the IFES and BAU in terms of climate change is that the energy component of the IFES. Even though firewood is in principle a renewable biomass, and hence carbon neutral, the reality in northern Ghana is that firewood is mostly sourced from unsustainably managed indigenous forests and not from farmers-owned or communally managed woodlots or energy plantations. Unsustainable management of resources in the region makes firewood, to a large extent, a non-renewable biomass, which in the IFES case is substituted with sustainably managed renewable agricultural residues. Thus, the IFES contributes to reduce GHG emissions and ease the pressure on natural forest resources from the need for cooking energy. As farmers only collect fuelwood when needed and they do not have to pay for the quantities collected. Data regarding the quantities of fuel used was not available. This would need to be measured over a larger period than what was available during the fieldwork. However, the following proxies were used to understand the fuel consumption pattern in the regions. An average household uses 1 157 kg of firewood per year, sourced from unsustainably managed indigenous forests that are not replanted, so that we assume that all CO_2 emitted into the atmosphere is additional. Using the standard conversion factor of 1.7472 tonnes CO_2/tonne of wood, is was estimated that 2.02 tonnes CO_2/year of GHG gasses were emitted in BAU. This could potentially be avoided entirely if in the best case of the IFES all firewood would be substituted by annually regrown stalks of millets and sorghum. We found it more realistic to assume in the current scenario that the firewood substitution by stalks ranges between 33 percent (which would translate into 1.33 tonnes CO_2/year) and 66 percent (0.67 tonnes CO_2/year).If more households would adopt this IFES, a big reduction on GHG emissions could be achieved.

ECONOMIC PILLAR

We assessed economic sustainability of the IFES based on the profitability criteria. We found that the IFES has considerable advantages over the BAU scenario (Table 14).

Profitability

Analyses of the data revealed that even if BAU households are to sell all their stalks, their net cost of fuel after deducting stalk revenue, will still be higher than the IFES households. To illustrate this advantage of the IFES over the BAU scenario, a number of points must be made. First, in Section 4.1.1, expenditures on different fuel end-use scenarios are presented. The BAU households spend USD 150 per year on fuel while IFES households spend between USD 50 and USD 100 per annum depending on intensity of stalk use. Second, the stalks have alternative use and thus attract a market value. The average market price of a donkey cart of stalks in the study communities is GHS 10 (USD 2.5), while the same measure of firewood is sold at GHS 50 (USD 12.5). Third, the average stalk output is 12 donkey carts per hectare. Based on this, we estimate that in a year, an average household, regardless the food-energy system they subscribe to, could earn up to GHS 190 (USD 47.5) from sale of all their stalks. Hence, for the BAU households, the net expenditure on fuel per year is USD 102.5, which is still higher than what would be spent by IFES households whose stalks are enough to substitute a third (USD 100) and two thirds (USD 50) of firewood.

Resource use efficiency

Resource use efficiency is discussed here because we observed that uniquely, for both the IFES and BAU scenario, the biomass use efficiency is very high as no part of the crop is wasted. The panicle produces the food component. The stalk first serves as fodder before they are harvested for fuel. The remaining residue – husks, stalk stumps, empty panicles – are ploughed into the soil. When the fuel component is burnt during cooking, the resulting ash, high in potassium nitrate, is converted into saltpetre for cooking purposes (used for faster softening when cooking dry peas and beans).

Table 14: Comparison of economic indicators of sustainability between the BAU and IFES systems

Criterion	INDICATORS		BAU	IFES
	Impact	Performance		
Profitability (retailer)	Fuel - retail [USD]		1 donkey cart of firewood = 12.5	1 donkey cart of stalk = 2.5
	Net cost of fuel – purchased firewood less sold stalks [USD per year]		102	Partially dependent on stalks = USD 100 Predominantly dependent on stalks = USD 50

REPLICABILITY OF THE SORGHUM-MILLET BASED IFES

This section covers the specific conditions under which the IFES may be scaled up. The analyses explores how the internal features of the IFES, stakeholders surrounding it, the policy environment and existing human and technical capacities open space for expanding the usage of the IFES.

WHERE AND HOW THE IFES CAN BE REPLICATED?

The use of sorghum and millet stalks as cooking fuel is predominant in northern Ghana to varying degrees. This is the same geographic area where the crops thrive, hence best placed to scale up the IFES. Replication efforts ought to focus first on upgrading households from BAU to IFES; and then among the IFES users, from partial to predominant dependence on stalks. With adequate capacity building and extension services to farmers the uptake of the IFES can be increased in such communities with no or difficult access to wood fuels.

The main idea of this IFES to substitute fuelwood from mostly (non-renewable) indigenous forests with (renewable) woody agricultural residues from annual plantation is not limited to stalks from millets and sorghum. We found areas where also the woody stalk from pigeon peas (Cajanus Cajan) is used as firewood substitute. So the basic idea of this IFES can be replicated wherever any of the crops can be grown. This basically applies to the entire country as there are numerous pigeon varieties suitable for different climatic conditions.

ENABLING OR CONSTRAINING FEATURES OF THE IFES

There are a number of characteristics that make IFES easier to expand in northern Ghana. The chances for the IFES to be adopted increase with the degree of scarcity of fuelwood resources. Thus, the chances for replication are highest in northern Ghana, where the IFES has evolved by itself as a response to fuelwood scarcity.

Natural resource potential:

The uniqueness of this IFES is that is combines firewood and sorghum and millet stalks. With regards to sorghum and millet, production will continue in northern Ghana because first, the crops are adapted to the savannah climate and secondly, there is high demand for these staple cereals. Atoklpe et al (2011) mention that the crops constitute 60 % of all cereal production in northing Ghana.[19] In addition to the adaptability and high demand, Angelucci (2013) mention that despite the bottlenecks faced by farmers, the crops continue to be important in northern Ghana from a social and religious point of view. This means that the supply of biomass feedstock for fuel use will continue. Despite these facts, survival of the crops is threatened by inadequate land, and low access to production inputs (especially labour) and a skewness of policy efforts towards maize production, albeit maize is less suitable for areas with lower rainfall and high rainfall variability.

The continuous supply of firewood in northern Ghana is however severely threatened. Households reported that they are spending more time in walking longer distances to collect firewood. Meanwhile, due to the slower growth and the open canopy nature of trees in northern Ghana, they have higher calorific values than those from southern Ghana, hence their demand for usage as charcoal or firewood is very high throughout Ghana (Energy Commission, 2009). This pressure on forests resources presents an opportunity to promote the IFES as a national mechanism to rescue the dwindling forest resources.

Renewable energy technology potential:

The cereals' place as a staple crop in northern Ghana and among southern Ghanaians of northern decent lends itself for national research support. The Savannah Agricultural Research Institute (SARI) of the Council for Scientific and Industrial Research has provided support for the cereals in terms of varieties and production technologies. The SARI breeding programs target farmers need for high yielding and early maturing cereals which mitigates the effects of shorter rainfall days resulting from climate change. Whereas the capacity to support the cereals exist, one of the weaknesses of SARI is that they have not yet been able to strike a balance between breeding for yield, drought tolerance, early maturity and more or higher calorific value biomass stalk. For this reason, SARI breeders revealed that whereas land races could yield up to 9 tonnes per hectare of dry biomass, improved varieties produced only 5 tonnes per hectare. A systematic upscale of the IFES will therefore require a collaborative effort between policy makers, farmers and breeders to develop varieties that yield more food and biomass. A weakness of the IFES is that the stalks do not necessarily burn cleanly in the open fires, yet also not much worse than firewood. The length of the stalks also pose a physical challenge, even though they are easier to cut than larger logs of firewood. The stalks are thinner and less energy dense than firewood so the cooks, mainly women, must always be present to keep pushing the stalks into the fire. There is however an opportunity for introducing a technological solution to these problems. As mentioned earlier, this IFES has evolved naturally and is not pushed by any project or organisation. Thus there are currently no efforts to replace the traditional three-stone stoves with more advanced stove technologies. A unique solution to these problems, which can facilitate the diffusion of the IFES among households in northern Ghana, is therefore to substitute the three-stone cook stoves with a modern fuel efficient one that utilizes the stalks as fuel. A Fuel-efficient cook stove can further leverage the savings of fuel and forest resources and the reduction of greenhouse gas emissions. As an example, a top-lit up-draft (TLUD) gasifier where the fuel is filled in one batch and then lit at the top will not only fulfil farmers' cooking needs but also provide biochar as a by-product of cooking. This biochar residue can applied in the soil to further improve on the fertility of farmers' fields.

Clarity and credibility:

One of the features of the IFES that creates opportunity for successful upscale is that it is naturally-emergent and clear to use. Households do not need expensive high external technology or additional inputs (except a traditional stove and stalks) to cook. IFES households were certain about the results that their specific IFES practices would achieve, making it a credible and replicable system.

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[19] http://www.csir.org.gh/images/CSIR-SARI_Reports/CSIR-SARI %20Annual %20Report %202011.pdf

Legitimacy:

This IFES has the potential of being accepted on a wider scale because it addresses a pressing need in northern Ghana – demand for cooking energy by rural poor households, with no access to 'modern clean energy', faced with dwindling forest resources and rising cost of firewood. This legitimacy of the IFES is further strengthened by the fact the processes of the IFES are owned by households. No aspect of the IFES, whether food production or fuel use, is externally owned and transferred to these IFES households. Ownership of the IFES is further demonstrated by certain communities who have developed strictly enforced rules, through the traditional leadership system, to protect the environment through implementation of the IFES.

Ease in assessing IFES results:

Within the first production year of utilization of the IFES, households are able to clearly measure the benefits and challenges associated with its usage. We observed this during the field visits when farmers were able to, without any help, list their preference for stalks (early millet, late miller or sorghum), compare the energy content of different fuels and calculate the financial costs associated with the IFES and BAU systems. This relative ease in assessing IFES results is an advantage for any extension activity to introduce the IFES to BAU households.

Business model (funding):

One advantage the IFES has is that it has limited tradable components, except for firewood purchase from June to October every year when stalks run out. This means that the promotion of the IFES, as it is now, does not require external funding for developing components. However, there is opportunity to upgrade the IFES through the introduction of energy-efficient improved stoves. For this to happen, an organization needs to take up the business of producing and trading the stoves. Such an organization would require funding to set up the stove development activities.

Alignment and linkage:

Whereas the IFES demonstrates legitimacy, in the sense that it meets some of the basic energy needs of households in northern Ghana, it sometimes fails to align with their interests. An example of misalignment can be seen in the competing demands on the stalks. Households are usually interested in uninterrupted all-year-round fuel supply, yet they continually face the trade-off between using the stalks for fuel or one of its other uses (forage, weaving or construction). The deliberate addition of nitrogen-fixing pigeon peas and their integration into the farming systems for both firewood and soil improvement could be a solution to provide more stalks between the seasons of availability of stalks from sorghum and millet. Another interest of households is to have fuels that are convenient to use. The need for constant adjustment of the stalks during cooking threaten this interest. While they are relevant, these misalignments are not enough to dampen the additional benefits derived from use of the IFES such as improvement of the farming system and useful by-products (salt peter).

Complexity, coordination and behaviour changes:

The IFES does not come with any complexities. Farmers do not have to rely on external contracts or organizations to grow their cereals in this IFES system. As such, there is no need for major behavioural changes when one is switching from BAU to the IFES. This presents an advantage for future replication of the IFES. This lack of complexity, notwithstanding, in order to replicate this IFES to BAU households as well as increase the intensity of its use, they will need to be assured of the possibility to increase their grain and residue yields. This will require behavioural changes in terms of adoption of high yielding varieties and some technologies in soil improvement. As mentioned above, the addition of pigeon peas intercropped with the sorghum and millets could be a potential solution to assist with the soil improvement.

Acceptability in local knowledge systems and culture:

As mentioned earlier, the IFES is widely accepted and used to varying degrees in northern Ghana. But acceptability is linked to the degree of firewood shortage. The IFES is more frequently used in communities with depleting forests and higher shortage of firewood.

ROLE OF STAKEHOLDERS AND INSTITUTIONS IN THE REPLICATION OF THE IFES

This section outlines the key stakeholders within the IFES and their current roles. Direct stakeholders produce, process and trade the IFES. They include

- **Sorghum and millet farmers:** These are the first and most important stakeholders. They produce the crop and the residue (stalk) which form the IFES.
- **Grain and stalk buyers** are the stakeholders who signal the demand for grains and stalk to farmers.
- After the crop is produced and harvested. **Women and children** within the households have the responsibility of gathering and processing the stalks. The same stakeholders are responsible for collecting firewood when stalks are in short supply.
- **Transporters** are the owners of tricycles or donkey carts which are used to move stalks or firewood to homes.

Stakeholders who are not directly involved in the IFES are those who provide critical services or activities that facilitate the action of those directly involved. These include:

- The **Savannah Agricultural Research Institute (SARI)** are breeders and suppliers of planting materials to seed multipliers who supply to farmers.
- The **Ministry of Food and Agriculture** are responsible for dissemination of important cropping information, though its army of agricultural extension agents.
- The **Ghana Grains and Legumes Development Board (GGLDB)** was established to produce and distribute good quality foundation seeds of cereals and to make available processing and storage facilities to registered seed growers and other farmers.
- **Non-governmental organizations** provide different services such as markets, inputs, credit etc to cereal farmers. Angelucci (2013) reveals however that the contribution of the private sector organizations like NGOS are sporadic and represent an exception to the norm.

THE EFFECT OF GHANA'S POLICY ENVIRONMENT ON POTENTIAL REPLICABILITY OF THE IFES

Presently, there is a conducive policy environment for the promotion of the IFES.

Cereal production policies

Ghana's food and Agriculture policy document "Food and Agricultural Sector Development Policy" (FASDEP II) provides the policy framework for crop development. The Medium Term Agriculture Sector Investment Plan (METASIP) outlines the actual investment plan to implement the programmes of the policy of FASDEP II by end of year 2015. The policy framework provide strategies for increasing sorghum and millet yields by 50 % and reducing postharvest losses by 20 % through: (a) support for development of certified seeds of high-yielding, disease and pest-resistant varieties and (b) intensification of dissemination of improved technological packages.

This policy environment creates room for the IFES' replication because the food component is likely to improve with output increases. Additionally, output increases could also mean more stalks harvested. This linkage may however be weak because the cereal policy framework does not specifically make room for residue (stalk) production. Future effort to replicate the IFES should ensure that the trade-off between residue and grain is addressed by the policy framework and the plant breeding research institutions like SARI.

Regardless of the general policy direction, sorghum and millet have a relatively low ranking among policy makers. Their development in Ghana has been overshadowed by the overemphasis of maize by policy makers (Atokple et al, 2014; Angelucci, 2013). To replicate the IFES sustainably, it is important for more government focus on these cereals that are more suitable for the drier climates and less vulnerable as maize with high rainfall variability.

Energy policies

The overarching objective of Ghana's cooking energy policies is to promote the use of cleaner fuels such as LPG, alternative fuels such as agricultural biomass and improved cook stoves. More specifically, the national policy target is to reduce the wood intensity of charcoal production from an existing ratio of wood input to charcoal of 4:1 in the Savannah zone where the study was conducted and to cut the share of wood fuels in the energy mix from 60 % to 40 % by 2020.[20] These policy objectives and targets can be positive for replicating the IFES, yet, there is little or no information available in national policy documents about national strategy of systematically promotion of sorghum and millet stalks for household thermal energy utilization. It needs to be clarified if the national policy differentiates between woodfuels in general and solid biomass fuels which would include also the agricultural residues.

Climate policy

The objectives of Ghana's climate change policy, which concerns the IFES, are to minimise the loss of carbon sinks by reducing activities that lead to the destruction of the forest cover and to enhance carbon stocks through programmes that restore degraded forests and other natural ecosystems. With this focus, the policy environment creates adequate room for the replication of the IFES. Most importantly, the IFES could be a strategic mechanism to improve achieve these policy goals.

Due to its integrated character the replication of the IFES requires concerted efforts and alignment of different government and policy sectors, namely agriculture, energy, forest, environment, climate etc. All need to be made aware of the potential of the IFES.

THE EFFECT OF HUMAN AND TECHNICAL CAPACITY ON REPLICABILITY OF THE IFES

The human and technical capacities needed to replicate the IFES are in the area of crop variety development, farmer training and appropriate modern stove construction. The current capacity at SARI for sorghum/millet breeding adequately supports the food component of the IFES and could be relied on for any replication efforts. The breeders at SARI however need technical and financial support to develop varieties with woodier stalk, higher calorific content and still meet early maturity, drought resistance and high yield needs at the same time.

The Ministry of Food and Agriculture provides institutional support and agricultural extension workers in all districts within northern Ghana. The current successes of the IFES has in part, depended on the

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[20] http://www.ecowrex.org/system/files/repository/2009_re-policy-framework-for-climate-change_reeep-energy-commission_.pdf

utilization of their organizational and capacity building skills to influence sorghum/millet farming activities. Future replication of the IFES will depend on whether or not these capacities are further enhanced and retained at the Ministry of Agriculture.

The energy component of the IFES is upgradable as stalks can serve as fuel in a carefully designed fuel-efficient modern stove. Whereas there is an active cook stove artisan community in Ghana, the stove models produced are targeting charcoal fuels. Much more support in terms of funds for research and training is required for the development of innovative stove that will use stalks as fuel while at the same time providing additional benefits like comfort, reduced health risks etc. Much more effort will be required to push these modern cookstoves to households in northern Ghana, as they will have to compete against free 3-stone-fires that are accessible everywhere at no cost.

CONCLUSIONS

In this report, we have described the utilisation of stalks from sorghum and millet farms to substitute firewood cooking fuels to varying degrees in northern Ghana – Northern and Upper East Regions. This integrated food-energy systems which had naturally emerged over the years, is widely used by households in the study areas.

Users of the IFES can be classified into two – those who partially depend on sorghum-millet residue by substituting about a third of their firewood with stalks and (2) those who predominantly use the IFES and substitute at least two-thirds of their firewood by stalks. We did not find enough cases of 100 percent usage of the IFES because the stalks are not adequate to cover the cooking needs of households all year round. With the intensification and deliberate cultivation of varieties with higher biomass yield and/or intercropping with woody pigeon peas, more useful biomass for cooking energy can be grown.

In comparison with a BAU scenario, where no stalks are utilized, this study described the entire value chain of the IFES. We observed that the production practices and husbandry of sorghum and millet grains are not different for the IFES and BAU scenario. We further observed that the main difference between the two systems lie in the end-use of the residue (stalk). Whereas in the BAU scenario, the residue is either sold or used as fodder, they are used for fuel in the IFES.

With the aid of some pre-selected indicators, we identified certain advantages the IFES has over the BAU scenario which makes it a more sustainable system of food production and cooking energy use for northern Ghana.

- The IFES can improve the savings on cooking fuel by households in northern Ghana by up to 66 %. This enhances the food security position of these households, which are known to be among the poorest in Ghana.
- The net fuel cost of the IFES per year, when revenue from sale of the stalks is factored into the costing of cooking energy use, could be anywhere between 49 % and 98 % lower than the BAU scenario.
- The utilization of the IFES eases the pressure on the already dwindling forest resources in northern Ghana and contributes to the climate change mitigation efforts.

The findings from this study further point to the fact that the IFES is replicable. To properly understand the need for replicability we conceptualized the two food and energy systems studied in northern Ghana as a continuum, with the BAU scenario on one extreme pole and the full dependence on stalks on the other. The goal of any replication effort is to move households from BAU into the IFES and then nudge them further down towards complete dependence of the IFES.

We conclude that the IFES is best replicated in northern Ghana where there is generally pressure on the forests for wood fuels and the climate is best suited for the production of sorghum and millet.

Several positive characteristics of the IFES strengthen it as a system and make its replicability feasible. Among others, these include the cereals' adaptability to the savannah climate of northern Ghana; the ease-to-use nature the IFES and the fact that there is no need for external funding to use the IFES. The replicability of the IFES is also boosted by an overall positive enabling food production, energy and climate policy environment as well as a network of stakeholders who have the capacity to support its development.

One other reason why replication of the IFES is feasible is that, it has the potential to be upgraded so as to address some of the challenges of the IFES and expand its scope of benefits. The first challenge that provides an opportunity to upgrade the IFES is the complex problem of scarcity of land and soil degradation. This challenge provides an opportunity to develop sorghum/millet varieties which can improve the quantity of harvested grains and stalks at the same time. There is also the potential to develop varieties with stalks that have higher calorific values without compromising yield needs.

Another challenge of the IFES is that the stalks do not burn cleanly in the 3-stone-fires and often require cumbersome adjustments when in use. This challenge creates the opportunity to upgrade the IFES with the development and promotion of efficient cook stoves that can use less stalk to generate more heat energy, thereby prolonging the availability of the stalks. With the appropriate stove, households can harvest adequate biochar to improve the fertility of their soils.

In summary, we conclude that replication of the IFES will best be achieved with the implementation of a comprehensive programme of concerted multi-sectoral effort involving researchers (breeders and social scientists), policy makers, extension workers, stove makers, community leaders, farmers etc. . This would involve working together to ensure that the IFES is used as a deliberate mechanism to ease mitigate the effects of climate change, while meeting the demand for cheap and convenient to use energy.

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INTEGRATED FOOD-ENERGY SYSTEMS IN MOZAMBIQUE

PRODUCTION OF HEAT ENERGY BY USING RICE HUSKS TO PROCESS RICE

SYNOPTIC SUMMARY

Case study : Bioenergy use for commercial food processing:

Rice husk furnace at commercial rice mill at EOZ

Location : Nicoadala, 35 km from Quelimane, Zambézia Province

Actors : Modern commercial rice mill built with donor support in 2009,

Operated by Empresa Orizicola Zambezia, managed by GAPI and co-owned by association of over 2 000 rice-growing small holder farmers

Key element of IFES : Rice husk residues substituting diesel as a fuel source to generate heat for mechanical rice drying in a commercial rice mill.

Manually-operated rice-husk powered furnace to provide hot air for re-circulating batch dryer. The inclined grate furnace is easy to operate by a semi-skilled experienced worker and burns the rice husk without smoke.

IFES – BAU comparison : The IFES was compared to two ‚Business-as-usual' scenarios commonly found in the rice-processing sector in Mozambique:

BAU 1: Rice mills relying only on sun-drying of rice (no drier, no furnace).

BAU 2: Rice mills with a mechanical drier and a fossil fuel (diesel) furnace

What are major benefits that make this IFES likely to be sustainable : Benefits from usage of rice husk residue from rice milling as bioenergy fuel in the rice-drying process:

Social criteria:

- **Access to clean, reliable and affordable energy increased** through self-sufficiency in access to thermal energy: by using rice husk as a reliable fuel source already at the factory, there is no dependency from outside sources of fuel
- no negative impact on human health through clean burning furnace

Environmental criteria:

- at least **50 % less GHG emissions** through controlled burning of husk and replacement of fossil fuel. The same would apply to unsustainably harvested firewood.

Economic benefits: High profitability!

- no cost for purchase and transport of fuel for furnace
- improved resource use efficiency through use of husk and reduced cost for waste management through avoided transport
- better rice quality through mechanical drying, thus higher sales prices

		➢ reduction of post-harvest losses through improved drying, thus more quantity to sell and **more food availability in the country**
Where and how can this IFES be replicated	:	The rice husk furnace is only replicable at commercial size rice mills that already have a drier and want to switch to a bioenergy furnace or where the investment of a drier and a furnace make economic sense. The furnace can probably be built at less than 1 000 USD from local bricks and a cast iron grate. Costs for a drier vary with size and the degree of sophistication from a couple of hundred USD to more than 10 000 USD for a recirculating batch drier with a capacity of 10 tons of rice per batch.
Challenges	:	No disadvantages of the IFES were reported compared to the two BAU scenario. This IFES does not impact the farming systems and farmers activities on their fields, it only concerns the operations at factory level.
Outlook	:	The remaining rice husk could be utilised as cooking fuel in households with the introduction of appropriate rice husk stoves. The utilisation of the created rice-husk char as biochar in the fields could increase food production and sequester carbon, making cooking carbon-negative.

SYSTEM AND CONTEXT

BACKGROUND: RICE PRODUCTION IN MOZAMBIQUE

In Mozambique, rice is the third main cereal consumed after maize and wheat (INE, 2010). Mozambique's hot to warm moist climate is suitable for rice production as it fulfils all the requirements of the crop. Rice is considered a strategic crop relevant for food security in the country. Mozambique has a 500-year old tradition of rice cultivation. Today, rice is seen more as a cash crop. Many of the farmers produce rice, but do not eat it. They tend to sell 50 % of the rice they produce to the urban areas where working women prefer rice to maize because it is easier to prepare and store (IRRI n.d. 1). However, the rice sector in Mozambique is characterized by low productivity, mostly attributed to traditional farming techniques with low input utilization, which also applies to the rest of the agricultural sector. Smallholder farmers produce nearly 90 % of the total rice, often predominantly as a subsistence crop under rain-fed conditions with only one harvest per year. Plot sizes are typically less than 0.5 hectares (ha) and irrigation is scarce (INE, 2010). Rice irrigation schemes are emerging, but are not yet very widespread. The area dedicated to rice production has expanded in the last decade (see blue line in Figure 2 below), but is far from reaching the potential 900 000 ha estimated suitable for rice production in the country.

Figure 2: Rice Production in Mozambique (1961-2012)

(Legend: Production in 1 000 t grain/year, area in 1 000 ha, yield in t/ha), Source: Ricepedia (n.d. 1)

As shown in Figure 2, the total area for rice production was rising constantly since 1961 but hit a low point of 67 000 ha in 2005 when it decreased to similar levels as pre-independence. In 2007, the Government of Mozambique adopted the Green Revolution Strategy to increase rice productivity in the country. With this, the Strategic Plan for the Development of the Agricultural Sector (PLANO ESTRATÉGICO PARA O DESENVOLVIMENTO DO. SECTOR AGRÁRIO, PEDSA) and the Action Plan for Food Production (PAPA) were developed to ensure food security.

Both agricultural development instruments (PAPA and PEDSA) put rice on top of their agenda to uplift national production and close the gap between internal supplies. Both aim to eliminate the burden of imports and to alleviate poverty for more than 3.1 million people directly dependent on rice production and for the 23 million Mozambican citizens indirectly dependent on rice production (IRRI n.d. 1). In less than 10 years following these political efforts, the area under rice cultivation grew by a fivefold factor over five times from 67 000 ha in 2005 to 376 000 ha in 2014, with paddy[21] production peaking at 271 400 t in 2011.

In 2012, a crisis struck the rice sector: mostly due to extreme rainfall variability including long dry spells interrupted by tropical storms with flooding from January to March, yields fell sharply and the paddy production decreased to 102 000 t.

Total rice consumption has more than tripled from 182 980 t in 2 000 to reach 651 000 t in 2013, with over 500 000 t of rice imported to bridge the gap from low local production. As droughts have prevailed in recent years, rice yields have not fully recovered. Mozambique currently produces 260 000 tonnes (t) of rice per season, out of which 140 400 t (54 %) comes from over 300 000 mainly small

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[21] When we refer to 'paddy' in this document we don't mean the rice variety, but rather the threshed de-husked grain that is taken to the mill.

farmers in the Zambézia province (IRRI n.d. 1). With an area of 103 478 km^2, the province has more than eight million hectares of arable land. The main agricultural products are coconut, tea, cashew, rice, maize, cassava, peanut, sweet potato, cotton and sugar cane.

STUDY OBJECTIVE: BIOENERGY USE FOR COMMERCIAL RICE DRYING

The main objective of this Integrated Food and Energy System (IFES) study was to document and assess a case of an efficient and sustainable bioenergy use for modern commercial food processing, where bioenergy is used to generate thermal energy for process heat required within the food processing value chain. Within the entire rice value chain, thermal energy is mostly needed during the post-production stage for drying, so a good example is the application of sustainable bioenergy to create heat for drying in a typical modern commercial rice milling process as described in Figure 3 below (Source: IRRI, n.d. 3):

Figure 3: Post-Production steps of rice processing

In commercial scale rice milling, the drying process is the most crucial step in the rice processing chain to bring the moisture levels of the grain down to 12 - 13.5 % which is safe for storage of the commodity for less than one year. Moisture contents above 14 % can result in moulds, discoloration, bad odours and insect infestation of the rice after only a few weeks of storage (IRRI, n.d. 3).

It is therefore important to pay utmost attention to the drying of the rice as a way to avoid losses during milling and storage, and increase the commercial value of the rice through higher quantity and quality to sell. The use of mechanical drying systems offers so many advantages over sun drying (such as maintenance of paddy quality, safe drying during rain and at night, increased capacity, easy control of drying parameters, and the potential for saving on labour cost), that it is surprising that so few mechanical dryers are being used.

Box: Importance of heated air drying for commercial scale rice mills

- allows for safely handling large quantities of rice in the peak season, regardless of weather
- better quality grain: less discolouring and odours of grains, less breakages of rice in mill
- increased quantity to sell: less losses of rice due to rotting, mould or insect infestation

All of these benefits lead to higher market value, more income, increased economic viability, and in the long run, better sustainability of the operations. Source: IRRI (n.d 4)

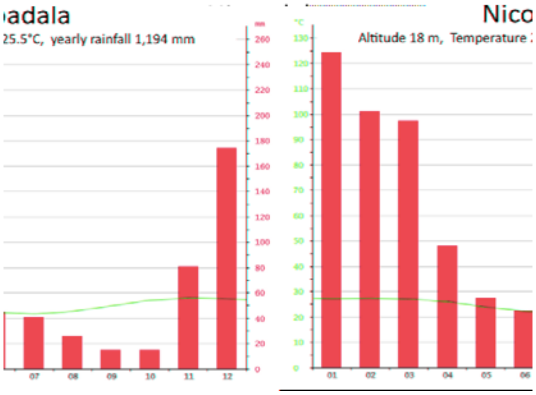
Site and case selection: Empresa Orizicola da Zambézia (EOZ)

The rice factory of the Empresa Orizicola da Zambézia (EOZ) was selected for this case study, as it uses rice husks for the generation of thermal energy to dry the rice. Following the increased focus on the development of the rice sector, a consortium of donors and investors built a new rice-milling factory in Nicoadala with a capacity to process 2 500 t/year.

Figure 4: Location of EOZ

Source: Google earth. The coordinates of the factory are: 17°34'51.97"S, 36°48'0.78"E

Figure 5: Climate Graph Nicoadala



Source: Climatedata (n.d.)

EOZ is located in Nicoadala in the Zambézia Province in central Mozambique, ca. 1 600 km North of Maputo and 35 km North-West of the provincial capital Quelimane.

The climate is tropical, with two distinct seasons, dry (May-October) and rainy (November-April). The average annual rainfall is 1 194 mm, peaking in January. The annual average temperature is 25.5° C.

With normal rainfall patterns this is an ideal climate for rice growing. Rice is currently grown once per year in the rainy season without irrigation and fully dependant on the increasingly variable rainfall.

EOZ was established in 2009 by a union of four cooperatives in the region (Nicoadala, Mopeia, Namacurra and Maganja da Costa) to process rice from 2 000 smallholder farms with a total area of 1 500 ha. Before the existence of EOZ, rice production of the cooperatives was below 100 t/year and the farmers mainly produced rice for self-consumption. Since the company is buying rice from the farmers, smallholder production has increased. In 2013/2014 with favourable weather conditions, rice production peaked at 580 t/year. In 2014/2015, heavy flooding destroyed crops and only 250 t could be harvested. In the 2015/2016 season there was a severe drought and EOZ only received 100 t to process. This means that due to extreme weather conditions there was not enough rice to process and the factory operated only at 4 % of it designed capacity of 2 500 t/year.

Unlike other rice factories in the country, EOZ has mechanized its rice drying process using rice husks as its source of thermal energy. Using heated-air drying usually ensures better quality rice compared to the prevalent traditional open-air sun-drying techniques.

According to the Provincial Directorate of Industry and Trade of Zambézia, the EOZ factory was built in 2009 with an investment of over 1 million USD supported by the Netherlands, the European Union and an Indian investor, who sourced state-of-the-art machinery from India. It is one of the largest rice factories in the Zambézia province, where most of the rice of Mozambique is grown. The compound is spacious and has ample room for expansion should it be needed, although the factory has never gone over 15 % of its total capacity to date, due to the lack of rice to process.

The elements of this IFES concern the end stage of the post-harvest phase as they are based on the end-use of rice husk from the milling process. This has to be kept in mind when discussing the replicability of the IFES.

The processing steps undertaken at EOZ largely follow the steps described in the diagram in Chapter 3.2, where the process is explained in more detail. The major difference is that between pre-cleaning and de-husking the paddy is dried to safe levels for extended storage with a modern **heated-air dryer.**

Any heated-air drying system has two main functional parts:

Box: Explanation of thefurnace and dryer systems

The furnace	**They are connected by an air distribution system with a blower to take the hot air from the furnace to the dryer**	The dryer **including the bin to hold the grain**
EOZ: Inclined grate rice husk furnace		EOZ: re-circulating batch dryer

At the EOZ factory, the core IFES element is the integration of bioenergy into the food processing cycle through thermal energy created from own rice husks for heated-air drying of rice.

The key feature of this IFES documented at EOZ is the end-use of rice husk as fuel for the inclined grate rice husk furnace; which heats the air blown into the mechanised hot-air dryer.

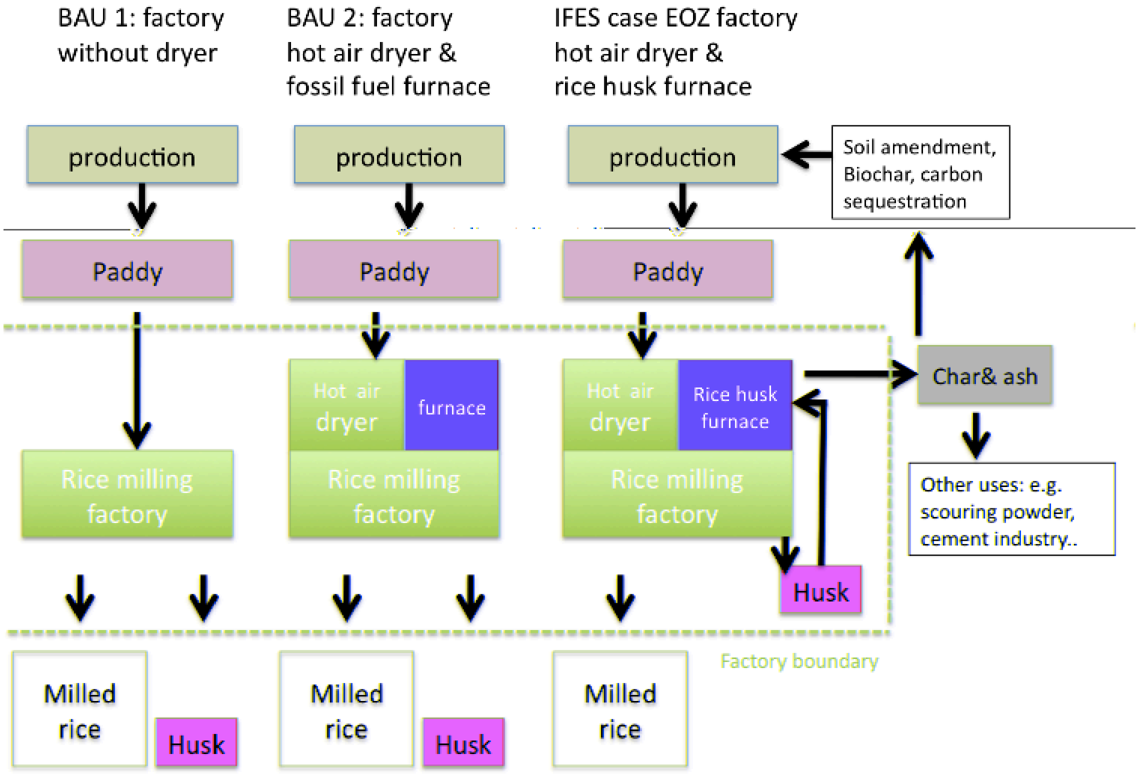
SETTING THE BOUNDARIES OF THE BASELINE AND THE IFES BIOMASS CHAIN

For this particular IFES case, it was not possible to find a concrete baseline business-as-usual case (BAU). The rice husk burner was part of the original design of the EOZ factory built in 2009, so there are no 'before-after' scenarios to compare. Moreover, there is no factory of similar scale in Zambézia since the only other rice-processing factory in Namacurra stopped working two years ago due to lack of sufficient rice to process. Therefore, in the absence of a prevailing baseline system we had to make assumptions for two baseline scenarios for 'Business as usual' (BAU). Figure 6 below gives a visual overview of the assumed cases. In later chapters the three scenarios are compared in detail.

The IFES was compared to two ‚Business-as-usual' scenarios commonly found in the rice-processing sector in Mozambique:

- BAU 1: Rice mills relying only on sun-drying of rice (no drier, no furnace).
- BAU 2: Rice mills with a mechanical drier and a fossil fuel (diesel) furnace
- IFES case at EOZ: like BAU 2, but with a rice-husk-powered furnace.

Figure *6*: Visual comparison of BAU 1 and 2 with IFES scenario



You can see that [parts of] the rice husk in the IFES scenario are recycled within the factory boundary. Char and ash are created from the rice husks, which could be utilised as biochar, soil amendment, or for other uses like scouring powder for the households. Larger quantities could be supplied to nearby cement factories.

MAIN STAKEHOLDERS

The main stakeholders involved in the IFES at EOZ are:

- Smallholder rice farmers, who are organized as members of cooperatives, and form part of the company's administration board. They represent 2 000 farmers from 4 associations. Their main task is to ensure the supply of rice to the processing plant. They benefit as they now have a secure market for their rice without having to worry about finding buyers and negotiating good prices for their products.
- The staff of the EOZ factory. There are 23 employees of the EOZ at the factory site. According to current management, original donors and investors were the Netherlands, the European Commission and an Indian investor. They provided initial funding for the construction of the state-of-the art factory in 2009, exceeding a combined one million Euro for the buildings and the rice-processing machinery imported from India.
- The investment company, Gabinete de Consultoria e Apoio a Pequena Industria (GAPI); which supported EOZ in 2013 to revitalize and restructure the company after it had crashed in 2012. The reasons for the failure of the first company running EOZ were manifold, but management challenges seemed to have started a vicious cycle of low payment, low morale, leading to low

availability of rice to process and increasing lack of revenue finally resulting in bankruptcy. GAPI invested 16 Million MZN (about 200 000 USD at the time) in rebuilding the farmer organization with the members and re-started the operations of the factory. The members of the cooperatives are now shareholders of EOZ in partnership with GAPI. So far at EOZ, GAPI supports the management structure and has not yet given out loans to farmers, although this is planned to start in 2017 with input packages for the farmers.

BOX: Background information on GAPI

GAPI was originally created as a financial institution in 1990 by the German Friedrich Ebert Foundation and the Banco Popular de Desenvolvimento aiming to contribute to social and economic development of rural areas in Mozambique.

GAPI was transformed in 1999 into an investment company (GAPI, Sociedade de Investimentos) and registered in 2007 as credit institution. In 2013, the shareholder structure was as an alliance between public and private investors: State (30 %); private investors (40 %); and civil society, namely the Community Development Foundation (15 %) and the Mozambican Red Cross (15 %).

The mission of GAPI is to design and implement programs and projects in an integrated way, encouraging the expansion, diversification and consolidation of (i) national businesses and (ii) the Mozambican financial system. GAPI gives financial and management support, undertakes capacity building and provides technical advice to the EOZ, including the farmer's cooperatives.

METHODOLOGY

FAO developed an Analytical Framework (FAO, 2014) as a guidance document to assess which factors make IFES truly sustainable and which factors need to be considered when replicating such systems. The underlying assumption is that good decision-making on bioenergy needs to be based on a critical mass of evidence to inform decision-makers, at local, but also at national and global scales.

The Analytical Framework (AF) includes a set of criteria, indicators and measures to help screen IFES projects. The first part of the AF screens IFES projects based on their environmental, social and economic sustainability. The second part of the AF contains a set of leading questions and related features that will help to analyse which factors need to be built into new IFES cases to make them replicable and bring them to scale.

The sustainability assessment is based on both quantitative and qualitative criteria. On the one hand, quantitative criteria allow for better cross comparison between scenarios and between case studies. On the other hand, they tend to simplify – and sometimes – oversimplify a criterion to a degree that the analysis becomes less accurate.

SUSTAINABILITY ASSESSMENT

We developed a list of indicators for each of the three pillars i.e. social, environmental and economic as suggested by the IFES Analytical Framework (AF). Indicators were either on the levels of impact (quantitative) or performance (process or qualitative). Within the framework of the case study no elaborate own measurements could be carried out for cost-efficiency and time reasons. Yields and other quantitative data were often taken from farmers' oral reports. Sustainability was assessed by comparing the assessment of relevant indicators for a business-as usual scenario (BAU) and the IFES case.

REPLICABILITY ASSESSMENT

Replicability was assessed through a descriptive analysis of the extent to which the EOZ-IFES meets four replicability criteria described in the IFES AF – (1) presence of promoting or inhibiting project features of the IFES, (2) stakeholders that may promote upscale of the IFES, (3) alignment of the IFES with national food and energy objectives and (4) availability of capacity for up scaling.

As mentioned in the introduction to the methodologies, the methodology was an outward looking one. Instead of assessing what has happened in the past, we make recommendations under which conditions the IFES case can be replicated and up-scaled in the future. We define replicability as the potential of a project, innovation or pilot test to be replicated, scaled up, expanded, or adapted. The question of interest is: Can an IFES project that has been proven to be sustainable in one location or community, be taken up in other locations, by other communities, be it in the same region, country or even abroad?

This requires the definition of the target group where this IFES can be replicated. In the case of EOZ the core element of the IFES is the **end-use of rice husk in a large rice-husk furnace to provide heat for a mechanised dryer.** This can only be replicated at existing commercial large size rice mills. Thus, the BAU scenario is not the absence of a commercial rice mill compared to an existing rice mill.

The two BAU scenarios were defined assuming existing commercial rice mills, one without any mechanized drying, the other with mechanized drying but with a furnace that is not powered by rice husks.

However, there are alternative end-uses of rice husk that can be replicated at any size rice mill. This could be the introduction of household size rice husk gasifier stoves as well as the use of the rice-husk char whether they originated from a furnace or a household stove. These options are discussed as recommendations in the final chapter.

DATA COLLECTION AND SAMPLING METHOD

The data were primarily collected by Helio Neves and Christa Roth on a joint visit to EOZ on 5th October, 2016, through a guided tour to the factory premises and pre-structured interviews with the manager, Mr. Gervasio Mendonza, the boiler operator and other factory staff. On the same day some rice farmers were interviewed. The information was later complemented by a literature review and follow-up phone calls.

DESCRIPTION OF THE INTEGRATED FOOD-ENERGY-SYSTEM

DESCRIPTION OF THE BUSINESS-AS-USUAL (BAU) SCENARIO

As visually presented in Chapter 1.4, we differentiate between two baseline scenarios:

- BAU 1, mostly applicable to small-scale operations without mechanized rice-drying technology where only sun-drying is used to reduce the moisture level of the rice. Rice is dried traditionally on the factory grounds in the sun, and rice husks are dumped and left to decay.

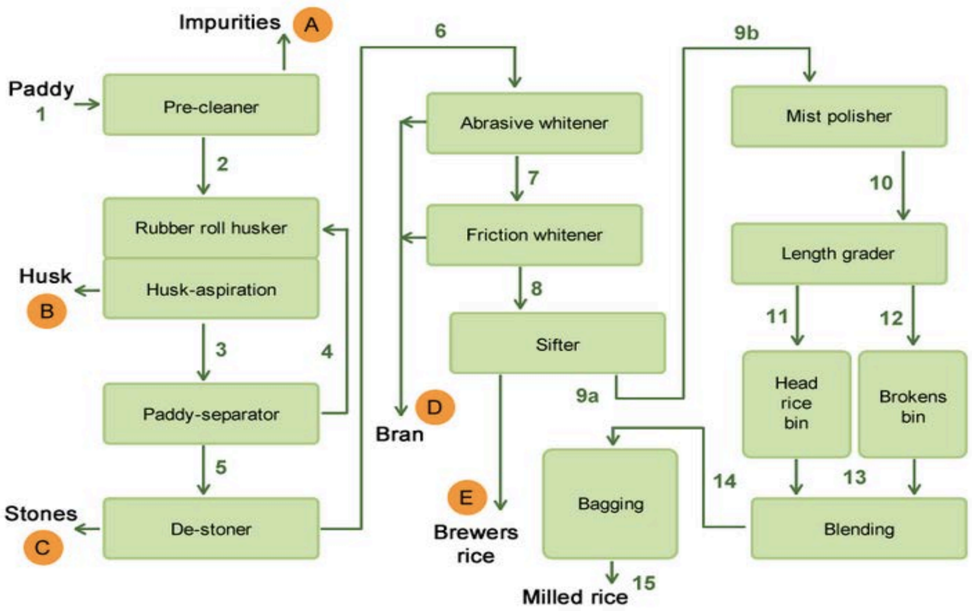
On an industrial scale, an alternative scenario should be considered, where a drying silo is in place but the thermal energy is derived from a different energy source. Electricity is not normally used to generate thermal energy. Biomass or fossil fuels are more appropriate and usually more cost effective energy carriers. The type of furnace is coupled to the type of fuel, which could be diesel or kerosene, LPG or natural gas, fossil coal, or solid biomass. Other types of liquid or gaseous biomass are unlikely to be used, as the investment into the processing of the fuel would be on the higher side (e.g. ethanol distillation, biogas digester etc.). In any other case than rice husk which is available for free at the factory, the fuel would need to be purchased, and the cost of the fuel plus the investment cost for the appropriate burner and heat transfer section to create the hot air as input into the blower would come as an added cost.

- BAU 2 is based on the assumption of a mechanized hot air drying, with a conventional furnace. For the sake of simplicity, we assume that the furnace is fuelled by diesel.

DESCRIPTION OF THE IFES SCENARIO AT EOZ

The processing steps undertaken at EOZ follow largely the steps described by the International Rice Research Institute (IRRI) in Figure 7 below as a typical modern commercial rice milling process:

Figure7: Rice processing steps at a commercial rice mill - Source: IRRI (n.d 5)



What makes the system at EOZ unique is that the thermal energy required to heat the air that is blown in the batch dryer is derived from the rice husk available on site as a residue of the milling process. This is the integration of sustainably sourced climate-neutral bioenergy in the commercial food processing chain and the reason why this example was chosen to apply the IFES analytical framework.

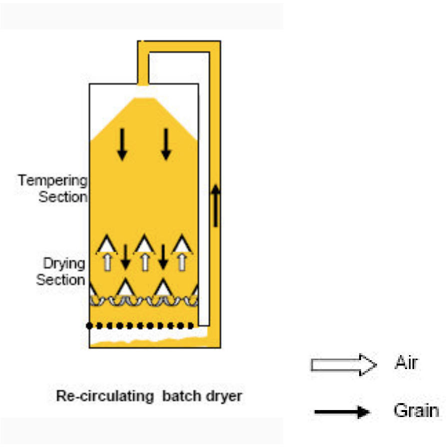
The rice husk, also called rice hull, is the coating on a seed or grain of rice. It is formed from hard materials, including silica and lignin, to protect the seed during the growing season. At EOZ, for each kg of milled white rice there is roughly 0.25 kg of rice husk as a by-product of rice production during milling. 1 t of husk can be converted to clean energy in a medium-sized gasifier equivalent to about 150 litres of diesel. Each ton of gasified husk can save about 1 ton of greenhouse gas emissions (CO_2) compared to current uses (IRRI, n.d. 6).

EOZ uses the largest available size of modern mechanical recirculating batch dryers designed for commercial mills. It can take a batch of 20 t of rice at a time. This type of dryer is common in commercial processing in Asia, but not yet very common in Africa. We were told it is the first and so far only unit in Mozambique of this size, which is the largest type of such dryers designed for co-operative drying stations or large private sector mills. Before loading the re-circulating batch dryer, fines and dust are removed from the paddy as they would restrict the airflow in the dryer, causing uneven drying and increased energy consumption for the drying process.

The rice is transported into the batch dryer with a bucket elevator. The system is dimensioned to achieve an ideal drying rate of 1-1.5 % moisture reduction per hour. Too high heat will damage the grain and result in losses and breakages during milling, as well as lower commercial grades of rice.

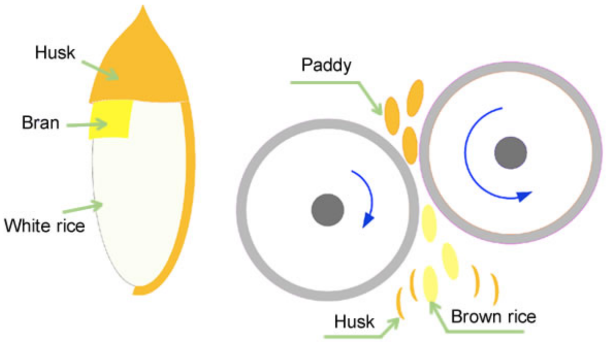
The hot air of ca. 43°C is blown upwards to the dryer by a large blower. The rice is moved mechanically inside the dryer during the drying process, which takes 8-12 hours depending on the moisture levels. It is normally done overnight so that the batch can be milled during the day.

Figure 8: Re-circulating batch dryer



Source of diagram: IRRI (n.d. 7)

Figure 9: Rice grain components

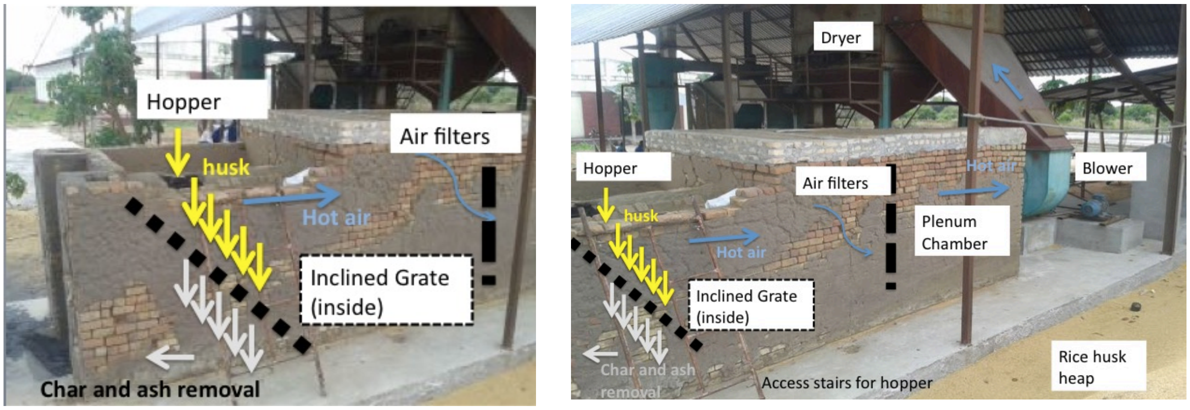


Source of diagram: IRRI (n.d. 8)

Rice husk has a low bulk volume of only 100 kg per cubic meter, so it is not cost effective to transport for longer distances. It is best used to create energy on site in a simple gasifying furnace, where the combustion can be controlled.

The rice-husk furnace at EOZ is very simple, consisting in an inclined grate rice husk furnace; and can be operated manually in a continuous mode. The core element is an inclined cast iron grate onto which rice husks are fed manually by bucket through a hopper above. The husk falls by gravity onto the inclined grate where it is gasified. The husk is ignited from the front end. While the fire is still cold, there is a bit of smoke, which disappears when the rice husk is lit. Once the fire is established it burns virtually smokeless with very little emissions. The husk continues to burn until the fuel is consumed. The fire can be maintained by adding more fuel through the hopper. One burn to dry one batch of rice normally takes one night, 8-12 hours. Thus, the rice is dried in the morning, ready to be processed in the factory.

Figure 10: Sketch of the inclined grate furnace at EOZ



The fire in the furnace needs constant attention to monitor the flame and control the heat. With some skill and experience it is easy to operate and not very physically strenuous other than pouring the rice husk into the top feeder of the burner. If the flame is not properly controlled, the fire might get out of control and risk burning the rice in the silo. This happened once in the early days, but the lesson was learnt and it has not happened since.

The ash and char fall through the grate and are removed after each burn at the front end of the furnace. The hot air enters the plenum chamber through two holes in the separating wall. On the other side there is an access door to clean the filters. There is no metal ducting between the grate and the fan; the plenum chamber is filled with some hanging sacks to filter the dust out and to calm the hot air before entering the blower and the air distribution system.

Figure 11: Photos of the furnace at EOZ

Entrance of the hopper on top: very little visible soot

Front view of the inclined grate between two brick walls.

Dismantling the grate gives access to the furnace chamber

The two air holes in the wall between the furnace and the plenum chamber become visible once the grate is dismantled. The residual ash has black, grey and white components. It still contains some black char, i.e. carbonised rice husk that has not been completely combusted to ash. This is due to the restricted airflow in the fuel bed.

The ash and char removed from the furnace are estimated to amount to about 15 % of the mass of the raw rice husk. They are dumped on the waste area next to the furnace where workers grow some maize. After they observed that the maize grows much better where the char is dumped, they started taking the ash/char onto their maize fields and gardens around their homes. There is no formal system in place currently on how people can access the char, but the manager showed interest in exploring this.

The amount of carbon remaining in the ash depends on the combustion performance (i.e. complete or incomplete combustion). Rice husk ash has multiple uses e.g. as a soil amendment, as an additive in cement and steel, or as a substitute for activated carbon e.g. in water filtration.

Flow of rice at the EOZ factory

The rice is bought from the farmers as paddy (threshed de-husked grain) normally packed in bags. The farmers have sun-dried the rice to a moisture level of 20-24 %, which is still too high for commercial scale milling. Upon reception at the EOZ factory, the rice can be sundried again on a concreted platform, if moisture levels are too high. Otherwise, the rice is taken to the cleaning unit, where impurities are removed on a shaking bed and dust is collected. In the peak season, the rice can be taken for temporary storage to the warehouse, which is directly connected to the cleaning unit with a carriage system on rails for easy transport.

Figure 12: Flow of rice at EOZ

Concrete sun-drying platform outside the warehouse

Warehouse with storage space for 2 500 t of rice

Rails from the warehouse to the dryer next to the factory

Delivery of paddy in bags from the farmer at the factory. The transport is mostly provided by EOZ. The bags are emptied onto the inclined shaker to remove dust and impurities.

The rice falls from the shaker into bucket elevators, which transport it up into the dryer.

The construction seen underneath the dryer contains the rice-husk furnace.

For its electricity supply, EOZ runs a 250 kW transformer on behalf of the government-owned EDM (Electricidade de Moçambique) on their factory premises. It also serves the community around. EOZ pays the electricity to EDM at an agreed tariff. When the factory is running, costs amount to about 35 000 MZN per month for the machinery and the office.

Figure13: Dryer hot air inlet and rice outlet

The hot air from the furnace as described above enters the blower through a square duct

...and is blown upwards into the dryer. The dryer has holes to let the moisture escape.

After drying rice falls by gravity to the hopper in the ground feeding the dehusker.

The husk is then blown through a small pipe from the de-husker inside the factory to the heap of rice husk at the back of the factory building, just next to the furnace where it is needed. No further transport of the lightweight husk is needed.

Comparing the two BAU scenarios with the IFES scenario

Table 15 below shows a comparison of three rice systems – from biomass production to marketing and end use of fuel and food: The BAU scenarios where either no rice drying technology is in place or where there is mechanized drying but no husk furnace is in place to generate thermal energy, compared to an IFES where thermal energy is produced from rice husks to fuel the rice-drying process of the factory. Where the BAU and the IFES scenarios are the same, the information is only listed once.

Table 15: Comparison of BAU 1 and 2, and IFES

	Business as usual 1: **Sun-drying only**	**Business as usual 2:** **Mechanised dryer, fossil fuel furnace**	**Integrated food-energy systems:** **Mechanised dryer,** **bioenergy furnace**
1. BIOMASS PRODUCTION			
Crops	The main cash crop is rice. Some farmers also plant maize and vegetables for self-consumption in small fields or 'gardens' closer to the settlement.		

Table 15 (cont'd): Comparison of BAU 1 and 2, and IFES

Average farm size	The average size of the rice fields in the flood plains varies from 1 to 1.5 hectares per family.
Land preparation	The agricultural season starts in October with land preparation, which is done by hand in 3 cooperatives (Mopeia, Nicoadala and Namacurra). EOZ plans to introduce mechanization in Maganja da Costa in 2017 due to the huge potential of the area. Seeds are provided to the farmers by EOZ on loan as part of the input package.
Planting	The planting of rice is done by hand and occurs in November. Sowing is done directly on moist soil. The seed is usually pre-germinated before it is released into newly prepared and drained soil, or in soils with a water blade in the field. It is done within 2-5 days after the last land preparation. At this point the soil has already stabilized to be solid enough to receive the seed at or near the surface and the weeds are not yet established. In drained soils, small ridges can be made to help drain water to prevent snail attack and emergency problems with stagnant water.
Water management	The rice in the area is rain-fed; there is no irrigation. Currently, the main challenge is the erratic rainfall in the last years, which is negatively impacting the rice harvests in the area.
Soil fertility management	The farmers involved in the EOZ project don't use fertilizer on their land. Some farmers living next to the factory use the ash from the rice husk furnace as soil amendment. This is mostly applied on the smaller maize fields that are closer to the settlement and not to the rice fields in the flood plain further away. Anecdotal evidence suggests that the ash also increases yields on the rice crops. This could be an area of extension for the future.
Weed management	Weed management is done by hand and without using herbicides.
Pest and disease management	Pesticide use is not common. The members of the cooperative normally don't apply any pesticides as EOZ sells the rice as organic product. In the case of pest and disease outbreaks in the farmers' fields that are recognised as a threat endangering the national food security, the provincial directorate of agriculture (government institution) helps the farmers from the community to address the problem. Treatment and pesticides are provided for free through their extension services for communities. The treatment depends on the type of the outbreak. For the private sector, they have to take care of their own pest management.
2. BIOMASS LOGISTICS	
Yield	Farmers have an average yield of 1-2 t/ha. Low yields are low due to the use of basic technologies and rainfed planting.
Harvesting	There is only one harvest per year, normally in May - June. The rice straw is left on the field and the grain is pre-cleaned and winnowed on the field.
Collection & transport from the field	The farmers bring the rice from the field to their houses using their own means of transport. There the rice is pre-dried on the ground, then packed into bags for transport to the factory.
Purchase	EOZ buys the rice as the entire grain with the husk. They normally buy at the farm gate price of 10 MZN/kg, but this year they had to pay 17.5 MZN/kg due to the scarcity of the rice. Their sales prices increased accordingly.
Transport from the farmer to the factory	The collection and transport of the rice is done directly by EOZ using its own lorries. The distance between the fields and the factory ranges from 30 to 100km. The costs for transport have increased since a vital bridge was washed away in 2015 and the distances to cover have increased.

Table 15 (cont'd): Comparison of BAU 1 and 2, and IFES

<table>
<tr><td>Storage of unprocessed rice</td><td colspan="3">Depending on the moisture content, upon reception at the factory compound the rice is again pre-dried on the ground. The pre-dried rice grain can be stored in the warehouse inside the factory. EOZ's warehouse capacity goes up to 2 500 t of rice. These days, due to the low volumes of rice, any delivery at the factory is processed straight away without prior storage.</td></tr>
<tr><td colspan="4">3. BIOMASS PROCESSING</td></tr>
<tr><td>Processing – potential capacity and actual processing</td><td colspan="3">The factory can theoretically process 40-60 t of rice per day, if they work in shifts. However, the normal output per day when working in one shift only is about 20 t/day. This is mostly due to the lack of rice to process.
The factory starts processing in June while rice lasts. So far they have never gone beyond November as there was not more rice to process. In the 2013-2014 season, they processed 580 t of rice. In 2014-2015, they only had 250 t because of flooding in the area. In the 2015-2016 season, there was a severe drought and EOZ expected to receive only 100 t to process. The rice is received, weighed, pre-dried and then cleaned from foreign matter and dirt in a rattling sieve.</td></tr>
<tr><td rowspan="3">Rice drying</td><td rowspan="3">Rice is sundried in the open air spreading grains under the sun, on mats and pavement. Advantages: no cost for energy or technology.
Disadvantages can outweigh the cost-efficiency: the solar energy it not always available, there is risk of contamination from dust, animals, etc. Labour is required to move the rice and protect it from rain.
With sun-drying, only the low levels of moisture needed for safe storage cannot be achieved. This reduces shelf life of the rice and commercial value.
Yet, at commercial scale, rice drying is a crucial element to achieve clean rice at competitive quality.</td><td colspan="2">The thermal energy to dry the rice is a major part of the total energy needs of the rice factory. The total demand depends on the humidity of the rice and the outside humidity. In any case it would be very costly if they had to generate the thermal energy from electricity.
From the rattling sieve the rice is transported by a conveyor into the dryer with a capacity of 20 t. The rice stays there overnight and gets dried by hot air blown into the silo while the rice is being stirred inside the dryer.</td></tr>
<tr><td>Thermal energy is created from diesel in a burner. Thus, the air is heated with fossil fuels. The diesel has to be purchased and CO_2 is emitted from the fossil fuel.
The amount of diesel needed in a typical scenario could not be quantified.</td><td>EOZ uses the biomass residue that they already have on the factory compound. It is a free residue to them and it would cost them more to store or dispose of it. Thus, this is an ideal case of integrating biomass energy in the processing of the food commodities.
The husk is used in the simple manually operated inclined-grate rice husk furnace. They could not quantify how much rice husk is needed for one dryer load (or burnt in one night), as they take it directly from the heap without weighing or putting it into bags. The fact is that the furnace never uses up all the rice husk produced as there are heaps left over.</td></tr>
<tr><td colspan="2">The hot air is then blown with a large blower into the dryer.
Clean and high quality dried rice is produced. It has a long shelf life for extended storage periods without moisture induced losses. All this increases the commercial value of the rice.</td></tr>
<tr><td>De-husking of the grain</td><td colspan="3">From there the rice flows through a pipe to the ground level of the factory building. It is then transported by small elevators to the de-husking unit. The rice husk is extracted and transported outside the building to the side of the furnace house.</td></tr>
</table>

Table 15 (cont'd): Comparison of BAU 1 and 2, and IFES

Sorting of the grain	The rice is then either polished or going directly as brown rice (integral, organic) to the sorting machine where four commercial grades are sorted mechanically: Unbroken rice in extra or first class quality, broken rice in second or third class quality. A fifth grade is the powdery 'trinca' which is used to make Mahewu, a popular local drink.	
4. LOGISTICS		
Storage	The processed rice is stored in their warehouse in Quelimane city until it is sold.	
Transport	Trucks take the processed rice to the sale point in Quelimane city. Rice husks are not cost-effective to transport as they are very light weight / large volume (ca. 100 kg/cubic meter (m^3)). Thus, it accumulates on the factory premises. For a load of 20 tons of dry rice grain from the dryer, about 4-5 tons of rice husk are generated, equivalent to 20-25 % of the mass of the grain. Based on a conservative estimate of 20 %, the 250 t of rice processed in 2015 would leave 50 t of husk. Based on an estimated bulk density of 100 kg/m^3, this would translate into 500 m^3 of rice husk.[22] This would correspond to the volume of nearly 15 standard 20' shipping containers.	
Sale of the rice	The rice is sold to the local and regional markets. EOZ has two commercial outlets serving the local and regional market: one in Nicoadala and one in Quelimane; however, EOZ will close the one at Nicoadala as there is not enough rice to sell this year. The EOZ sells the processed rice in the Quelimane market for 65 MZN/kg. They have a lot of demand for the organic product. Their rice is sold locally as an organic product under the brand name Okalelamo.	
5. END-USE		
End-use - Rice	Rice is used as food for human consumption.	
End –use – Husk	The rice husk is dumped and left to decay, as observed for leftover husk in the IFES scenario. Experiences from other provinces have shown, however, that husks are sometimes used as heating material in kilns to burn bricks. In Maputo and Gaza provinces, husks are also used as animal feed when mixed with molasses, and as bedding in chicken husbandry, but only in small quantities.	Neither the residual rice husk nor the rice husk ash from the furnace is removed from the factory premises by EOZ. Only recently EOZ found a customer who took four 20 t trucks full of rice husk to Maputo to use as feed in the poultry industry. They gave him the husk for free, but think of charging at least a nominal fee for it next time.
End-use – Char and Ashes from the furnace	N/A	The EOZ guards take advantage of sowing some maize for their consumption in a small piece of land inside the factory premises, where the ash is deposited involuntarily by the wind. They observe that the maize is growing very well with the added ashes. Yet, EOZ has not yet formalised the access to the ashes for outsiders due to negligible quantities and lacking awareness.

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[22] In the literature, the values for the bulk volume of rice husk range from 80 to 115 kg/m^3, thus an average of 100 kg/m^3 is assumed.

SUSTAINABILITY ASSESSMENT

To assess the sustainability of the IFES, a table has been developed to compare different aspects of the IFES with the BAU scenario based on the assumptions described above:

BAU 1 is the scenario with solar drying only, BAU2 is the scenario where the rice processing factory has a dryer and a furnace, but the furnace is powered by other fuels than rice husk, e.g. fuelwood or fossil fuels. The IFES scenario describes the situation at the EOZ factory with the dryer and the rice-husk furnace. The fields of the table are merged if the information is valid for more than one case. Where possible, quantitative indicators were selected, showing a numeric result. Chosen measurement units are shown in brackets after each indicator. For some criteria, qualitative indicators were found to be more relevant, showing more accurate results by describing the status of a criterion rather than expressing it in numerical terms.

Wherever there is no change between the different scenarios, the fields were merged. The most significant changes are highlighted through darker shading of the cells.

SOCIAL PILLAR

Food security

This IFES does not impact the farming systems and farmers activities on their fields, it only concerns the operations at factory level. We could not find any change or negative impact on food security from the farming side. Potentially there are positive impacts on food security as the farmers now have a secure market to sell their rice to and they are more likely to be paid fair prices by EOZ as they are shareholders (Table 16).

Table 16: Food security indicators

Indicator	BAU 1: no dryer, no furnace	BAU 2: dryer & furnace (fossil fuels)	IFES: dryer & rice husk furnace
Average farm size	1-1.5 ha , no change		
Rice yield (t/ha)	1-2 t/ha, no change		
Income for rice at the farm gate (MZN/kg)	17.5 MZN/kg, no change		

Energy access

The energy access indicators have been summarized on Table 17.

Table 17: Energy access indicators

Indicator	BAU 1	BAU 2	IFES
Energy access at farmer level: Electricity	Grid-connection is scarce and supply unreliable.		The generator of EOZ is run on behalf of the electricity utility and provides access to electricity for the surrounding communities.
Energy access at farmer level: Cooking energy	Reliance on solid biomass fuels, mainly firewood and charcoal.		Option to introduce rice husk stoves for households in vicinity of EOZ to utilize surplus rice husk from the mill as cooking fuel. Currently no change.

Table 17 (cont'd): Energy access indicators

Energy access at company level: Electricity	Electricity from the grid or generator (assumed).		The generator of EOZ run on behalf of the electricity utility provides reliable access to electricity.
Energy access at company level: Thermal energy cost	No cost for fuel.	Fuel has to be purchased, high cost depending on fuel type.	No cost for fuel.
Energy access at company level: Thermal energy reliability / availability of fuel	Varies with the seasons, solar energy not available in sufficient quantity all year.	Depending on storage capacity and procurement of fuel for furnace.	Reliable availability while the factory is processing. The husk accounts for 20-25 % of the total weight of the rice. So, out of 20 t of rice 4-5 t of husk become available for use in the furnace.

Electricity at farmers' level: Access to electricity is particularly restricted in the area, and is unreliable. If there is no grid, people use lanterns with batteries for lighting purposes. Beneficiaries of the electricity from EOZ are less impacted by power cuts, especially while the factory is operating, as it is in the interest of EOZ to keep the factory downtime as short as possible. Electricity is mostly used for lighting, entertainment, communication and some productive uses.

Cooking energy at farmers' level: There is no change between the BAU and IFES, so no detailed quantified assessment was done. The cooking energy system is just described: People rely on solid biomass fuels such as firewood and charcoal or agricultural residues (excluding rice husk) to fulfil the most basic cooking and heating needs. Neither LPG nor electricity is used for cooking. Three meals per day are normal. Cooking happens mostly outdoors or in well-ventilated kitchens, so exposure to cookstove smoke is not a perceived problem.

Cooking with firewood is done on three stone stove, charcoal is used in rudimentary charcoal stoves. Charcoal is still rather cheap (300 MZN/bag) which makes the need for change to fuel-efficient stoves and practices less urgent. Yet, there is a potential to introduce rice husk stoves for households in vicinity of EOZ to complement their cooking energy options and utilize surplus rice husk from the mill. This requires specialised rice husk stoves with forced draft to be initially imported and made available in the area. The EOZ management already expressed interest in importing such stoves for a pilot trial. In principle this option can be introduced anywhere with available rice husks (this is expanded under recommendations in later chapters).

Thermal energy access at company level:

In the BAU 1 scenario there is a complete dependency on sunshine to dry the rice. Avoided costs for thermal energy are potentially outweighed by lower commercial value of the rice. In BAU 2 for fuel there are high costs as well as dependency on supply.

In the BAU 2 there is complete dependency on the availability of fuel sourced from outside, whether it is fossil fuel or firewood.

For the IFES case at EOZ the access to reliable and clean thermal energy is granted: thermal energy for rice drying is to 100 % satisfied by renewable rice husk. The husks are reliably available at no cost as part of the milling process. Thus, there is no dependency on outside suppliers. Factory downtime due to shortages in thermal energy can hence be avoided and overall profitability of the factory operations increased. The downstream use of the by-products of the rice husk furnace has positive impacts on soil health and food security through better yields on farmers' fields.

Electricity at company level: This feature is not intrinsic to the IFES. It is in principle the same for both BAU and IFES scenario. In the case of EOZ, the electricity supply is rather reliable as the generator operation is within the mandate of EOZ and does not rely on the supplier EDM (Electricidade de Mozambique).

Adaptive capacity to climate change and variability

The adaptive capacity to climate change and variability indicators have been summarized in Table 18.

Table 18: Adaptive capacity to climate change and variability

Indicator	BAU 1, BAU 2 and IFES
Percentage of years without crop failure due to floods and droughts (since start of the project in 2009)	50 % No change at farmers' level as dependent on regional climatic conditions, where variability has increased since 2012.

here was no change between the different scenarios. Resilience to droughts could be increased if more biochar would be systematically incorporated into fields to increase water retention capacity of soils.

Health impacts

The health impacts indicators have been summarized in Table 19.

Table 19: Health impacts

Indicator	BAU 1	BAU 2	IFES
Smoke from furnace	N/A	Possible, but not known	No smoke exposure for operator under normal circumstances. No visible traces of soot were found beyond the inlet of the hopper, which leads to estimate that no smoke reaches the communities.
Burns	N/A	Possible, but not known	No reports of any burns or other furnace related injuries.
Risk of inhalation of harmful substances	N/A	Possible, but not known	Handling of the rice husk ash can be potentially harmful if dust is inhaled, but the operator has a protective mask that he can wear.

In BAU 1 there is no combustion involved, thus, there is no source of high heat or emissions, while in BAU 2 there might be exposure to heat and emissions from a fossil fuel furnace.

In the IFES case at EOZ the furnace seems to work rather smokeless, as no traces of soot or wood vinegar were found that would indicate an incomplete combustion. The development of its activity therefore does not show negative impacts on the health of farmers, workers and the surrounding communities. No burns or other injuries related to the operation of the furnace were reported. Care has to be taken though in the handling of the ashes due to their high content of fine silica particles (sometimes in the form of cristobalite). Protective masks should be worn to avoid inhalation of the fine particles that can potentially cause lung damage and respiratory diseases.

Employment

The employment created for the drying operation have been compared in Table 20.

Table 20: Employment

Indicator	BAU 1	BAU 2	IFES
Employment created for the drying operation (yes/no)	Yes, sun-drying labour intensive	Possible, but not known	No extra employment is generated as the furnace operator also doubles as security guard, however, he receives a higher remuneration.

The BAU 1 scenario foresees that the rice is dried under the sun. According to IRRI (n.d. 9), sun-drying is very labour intensive unless mechanized. Hence, employment might decrease when rice is dried in a dryer instead as in BAU 2 or the IFES case. This decrease could not be quantified.

In the IFES case at EOZ the rice furnace is only operated at night by one designated night guard who receives a premium for the operation of the furnace, as it needs constant attention to monitor the flame and control the heat. With some skill and experience it is easy to operate and not very physically strenuous other than pouring the rice husk into the top feeder of the burner.

ENVIRONMENTAL PILLAR

Soil health

Soil health has been assessed via farmer perception of crop yields (Table 21)

Table 21: Soil health

Indicator	BAU 1	BAU 2	IFES
Farmer perception of crop yields	N/A		Not quantified, but farmers observed increased yields when ash and biochar from the rice husk furnace are used on the maize fields

For rice production there is no difference between the BAU and the IFES scenarios in terms of soil management. There is a difference for those community members who produce maize, however.

In the IFES case at EOZ, the field assessment showed that the residues from the rice husk furnace are used as soil amendment by some factory workers who apply the ashes on their maize fields. Residues from rice husk gasification contain the minerals that the plant took up from the soil, i.e. silica with significant amounts of Potassium (K) and Phosphorus (P). Rice husk ashes furthermore contain traces of Sulphur (S), Iron (Fe), Calcium (Ca), Magnesium (Mg), and Sodium (Na).

The exact effects of ash application on maize fields could not be quantified in this study, however, farmers' perceptions were positive. They reported higher yields on the maize fields. The ashes are not yet used as soil amendment on the rice fields, as the fields are further away and higher quantities of ash would be needed for the larger fields.

Due to the low amounts of rice processed in the last years, not much ash was available. So far, EOZ has not formalized the disposal of the char and ash as a commodity. This might be an option as operations grow and more char and ash become available. In fact, a study from India showed that direct application of rice husk ashes to rice and wheat crops additional to the application of recommended Nitrogen, Phosphorus and Potassium significantly increased the grain yield of wheat and rice over un-amended control in all the seasons (Thind et al., 2012). The increase in wheat yield over control ranged from 16.2 to 38.3 % (mean 25 %). Also, the rice yield increased significantly (10.7–18.3 %). The authors assume that the increase in grain and straw yields of rice and wheat with rice husk ashes can be attributed to the increased availability of nutrients and favourable effects of ashes on soil physical conditions and microbial processes.

Pollution (air)

Air pollution has been assessed via presence of Smoke from furnace (Table 22)

Table 22: Pollution (air)

Indicator	BAU 1	BAU 2	IFES
Smoke from furnace (yes/no)	No furnace, but often heaps of rice husk self-ignite, creating smoke due to uncontrolled and incomplete combustion of the smouldering husk	Depending on type of furnace, not known	No smoke from rice husk furnace, more complete combustion through controlled air and temperature in the furnace, less polluting through avoided smouldering rice husk fires

As for air pollution, there have been no observed changes in air quality since the use of the rice husk furnace. The system seems to work well without creating smoke, as no traces of soot or wood vinegar were found that would indicate an incomplete combustion.

Regarding other types of environmental pollution, we observed no impact on water, soil or air quality in relation to the farming activities or the rice processing.

- Rice farmers usually do not use fertilizers or pesticides in the area; hence, the water quality of nearby waterways is not affected. As observed in the study area, industrial fertilizers and pesticides are hardly used in rice production in Mozambique. According to FAO (MAFAP_ FAO, 2014), the proportion of households with access to agricultural inputs in the rice production in Mozambique is 0.4 % using fertilizer and 0.1 % using pesticides in their fields.
- Regardless if it is BAU or IFES, no water is used in the rice processing at the factory, thus, there are no effluents from the factory premises.
- However, there may be issues with water quality regarding the ashes from rice husk stemming from the furnace. When dumped on the factory grounds, they carry the risk of escaping into the atmosphere or entering the local waterways via surface runoff. However, the risk in this particular IFES case is small as the quantity of ash produced is relatively small.
- There is also the risk of long-term application of ashes to the agricultural fields, particularly to soils that are already high in available Phosphorus, as too much ash might lead to over-fertilization. This may lead to Phosphorus losses through surface runoff and leaching into ground waters in sandy soils (Thind et al., 2012). It seems unlikely in this case, however, as only a couple of people were using the ashes from the factory to amend their maize fields. Moreover, the soils in the area are much depleted. Hence, over-fertilization is not an issue in this case.

GHG emissions

Table 23: GHG emissions

Indicator	BAU 1	BAU 2	IFES
GHG emission from decaying rice husks (t CO_2eq) in 2015	1.26 t CO_2eq.		0.63 t CO_2eq. (estimation calculation based on the 62.5 t of rice husk = 25 % of the mass of 250 t of rice grain processed in 2015)
GHG emissions from energy used for rice drying (t CO_2eq) in 2015 estimation	0, only solar energy	Depending on furnace and fuel consumption, no comparable data available	0, even in the worst case scenario; carbon neutral as rice husk is available on site already and no extra transport costs have to be factored in. If remaining char is used as biochar on fields as soil amendment, the balance is negative, as the carbon will be actively removed from the carbon cycle and sequestered for some decades. The amount depends on the percentage of char contained in the ash.

GHG emissions could not be directly measured during the field study, and a full life cycle assessment was out of scope for this assessment. However, we can infer emission reductions in relation to rice husk use from the data that was obtained during the stakeholder surveys. Rice husk is often considered a waste and either both dumped and left to rot, or openly burnt at the rice processing factories. For both BAU scenarios we therefore assume that the rice husk was left to decay on the factory grounds under aerobic conditions, producing significant Methane (CH_4) emissions. Methane has a GWP (Global Warming Potential) of 21, in other words 1 t of Methane would be equivalent to 21 t of CO_2, expressed in t CO_2eq.

In the IFES scenario, about 50 % of the rice husks were utilised in the furnace on site. The other 50 % of the rice husk were left to decay releasing CH_4 emissions. Only recently some rice husks were sold, but that just means that they would merely decay at a different location instead of on the EOZ compound.

The emissions released from the furnace are mainly CO_2 emissions, which according to Intergovernmental Panel on Climate Change (IPCC) guidelines are considered carbon neutral. Thus, the energy from rice husks is carbon neutral, if not carbon negative, if biochar is used as soil amendment.

Decaying rice husk, on the other hand, is a very potent source of CH_4. In the IFES scenario, these are reduced by half compared to both BAU scenarios.

A study calculated GHG emissions from decaying rice husk (Mitsubishi Securities Clean Energy Finance Committee, 2003). Using the formulae provided in the IPCC guidelines, the emissions were calculated for 1 000 t of biomass. When 1 000 t of biomass were dumped in year 1, 2.4 t of CH_4 were released in the same year. With a GWP of 21, this translates 21 x 2.4 t of CH_4 which is 51 t CO_2eq per 1 000 t of rice husk.

In the IFES case, 250 t of rice were processed in 2015 from the 2014/15 crop, and approximately 50 t of rice husk were generated. Half of these, 25 t, were left to decay. In 2015, the factory therefore produced 0.06 t CH_4 or 1.26 t CO_2eq. In the BAU scenario, on the other hand, 0.12 t CH_4 or 2.52 t CO_2eq were produced in the season of 2015. For 2016, the figures would be less than half as only 100 t of rice were processed, due to the severe drought. At full capacity the rice husk furnace could save 10 times the values of the year 2015, which would be 25.2 t CO_2eq per year.

Agro-bio-diversity

Table 24: Agro-bio-diversity

Indicator	BAU 1	BAU 2	IFES
Number of crop species on the same field	1 (rice monocrop), no change at farmers level		
Number of crop species planted by the farmers in total, but in different locations	>5: rice monocrop, intercropped: maize, cassava, sweet potato, pigeon pea, beans, vegetables etc. no change at farmers level		

No change could be detected between the systems at farmers' level.

ECONOMIC PILLAR

Profitability

Profitability has been assessed through output – input costs of rice processed.

Table 25: Profitability

Indicator	BAU 1	BAU 2	IFES
Output – input costs/t of rice processed	No data, but profitability tends to be lower due to lower rice quality and higher expenditure in workforce.	No data, but costs for fuel higher than in other scenarios.	No data, but profitability tends to increase as with better drying rice quality improves (better prices) as well as the quantities of rice that can be sold due to avoided losses due to high humidity in the grain (fungus, rotting, etc.). EOZ started to provide input packages for farmers so that the benefit from better prices for inputs.

It was difficult to determine the overall profitability of the three different rice scenarios as no comparable cases for BAU 1 or 2 were available in the area to study. Hence, our analysis is based on assumptions for the cost of labour versus the cost for thermal energy creation counterbalanced by higher sales prices achievable with mechanised rice drying. Yet, this is mainly a question of scale and envisaged markets: sun drying is suitable for small and medium scale operations, and if the rice is meant for self-consumption or local markets where shelf-life of the commodity is rather short. At the level of a factory targeting national and export markets, mechanical drying of the rice is essential to ensure safe storage and extended shelf life of the rice at the same quality level.

BAU 1: for sun-drying, there is no cost for thermal energy, but there are higher costs for labour and a higher risk for incomplete drying resulting in lower quality rice and generally lower sales prices. Proper and uniform drying of the rice is the precondition for increased rice quality and quantities. High moisture levels can have a couple of consequences that would affect the profitability of the entire operation: moisture can enhance grain discoloration, which would result in lower commercial grades – hence lower selling price. In addition, moisture induces mould development and pest attacks. Thus, it can destroy the processed rice and in the worst case render it partially or completely unfit for human consumption. It can thus reduce the quantity that can be marketed and negatively impact the quality, meaning the commercial grade, as which it can be sold.

BAU 2 and IFES both have a mechanical dryer that is a necessity for a state-of-the-art factory in any case, regardless of the source of thermal energy. Both cases require the same amount of electricity input for the moving of rice and hot air. The difference between BAU2 and IFES is the source of the thermal energy and the corresponding furnace. The economic advantage of the IFES would depend on the initial investment cost for the furnace and the running costs for fuel consumption and maintenance of the furnace. Investment costs for the furnace depend on model and scale. Running costs depend on the price of fuel, e.g. diesel delivered on site. These costs highly depend on the scale and location of the operation.

In BAU 2 the purchase of fuel is required, so this is the comparative advantage of the IFES case, where the fuel is on site at no additional cost.

According to EOZ, the use of rice husk for the drying process reduces the total cost of energy required for normal operation of the plant by about 25 %, if one were to use electricity instead of rice husk.

If the furnace were powered by diesel, the costs would depend on the efficiency of the system, but definitely all fuel would need to be purchased. No data could be collected, as there was no comparable factory in the area.

The current EOZ management estimated the cost for the rice husk furnace and dryer to be less than 10 000 USD, as everything was made from local materials with local labour.

Avoided disposal costs of the rice husks could also be considered as an economic benefit.

Conclusion: IFES has the best rating for profitability and economic viability. It can obtain the highest sales prices with the lowest investment and running costs. Both BAU scenarios have a risk on economic viability and long-term ability to operate.

Resource use efficiency (Energy)

Table 26: Resource use efficiency (Energy)

Indicator	BAU 1	BAU 2	IFES
Processing equipment with energy efficient technologies in place (yes/no)	No	Depending on dryer	Yes. Manually operated inclined bed gasifying rice husk furnace is the most energy efficient furnace, as no other fuel or mechanical energy is needed in addition to the rice husk. Only the human power of one person to load the rice husk into the hopper.

There are two types of energy requirements at the EOZ rice factory:

- ➢ Electricity to power the machinery used mainly for cleaning, de-husking, polishing, sorting of the rice, and the conveyor belts transporting the rice between the machines, as well as operating the blower for the hot air connected to the dryer. This electrical power comes from the generator run on behalf of the public electrical power network and is paid for at the full public tariff. Wherever possible, energy efficiency has been applied in the factory set-up by using energy efficient conveyors such as bucket elevators to transport the rice into the vertical drying silo, while the transport from the silo to the de-husking unit operates by gravity. The modern machinery is state of the art from 2009 and the factory layout is optimized for short and direct connections between processing stations to optimize resource use for both space and transport energy.
- ➢ Thermal energy to dry the rice in the drying silo. 100 % of the thermal energy is created based on the existing biomass residues on the factory compound, the rice husk, which is used in the furnace for the production of heat at no extra cost.

Hence, processing equipment with energy efficient technologies is in place, albeit only for parts of their operations. In the BAU 1 scenario, there is no processing equipment for rice drying. Rice is dried in the open sun, hence “solar” energy is used in this case. From an energy use efficiency point of view, there is therefore no difference between the BAU 1 and the IFES scenarios. Compared with BAU 2 there is a positive impact of the IFES as no additional resources are needed to be purchased from outside.

CONCLUSION ON SUSTAINABILITY

We conclude that the following benefits from the usage of rice husk residue from rice milling as bioenergy fuel in the rice-drying process make this IFES highly sustainable.

Social criteria:

- **Access to clean, reliable and affordable energy increased** through self-sufficiency in access to thermal energy: by using rice husk as a reliable fuel source already at the factory, there is no dependency from outside sources of fuel
- no negative impact on human health through clean burning furnace.

Environmental criteria:

- at least **50 % reduction in GHG emissions** through controlled burning of husk and replacement of fossil fuel. The same would apply to unsustainably harvested firewood.

Economic benefits: High profitability!

- no cost for purchase and transport of fuel for furnace
- improved resource use efficiency through own use of husk and reduced cost for waste management through avoided transport
- better rice quality through mechanical drying, thus higher sales prices
- reduction of post-harvest losses through improved drying, thus more quantity to sell and **more food availability in the country.**

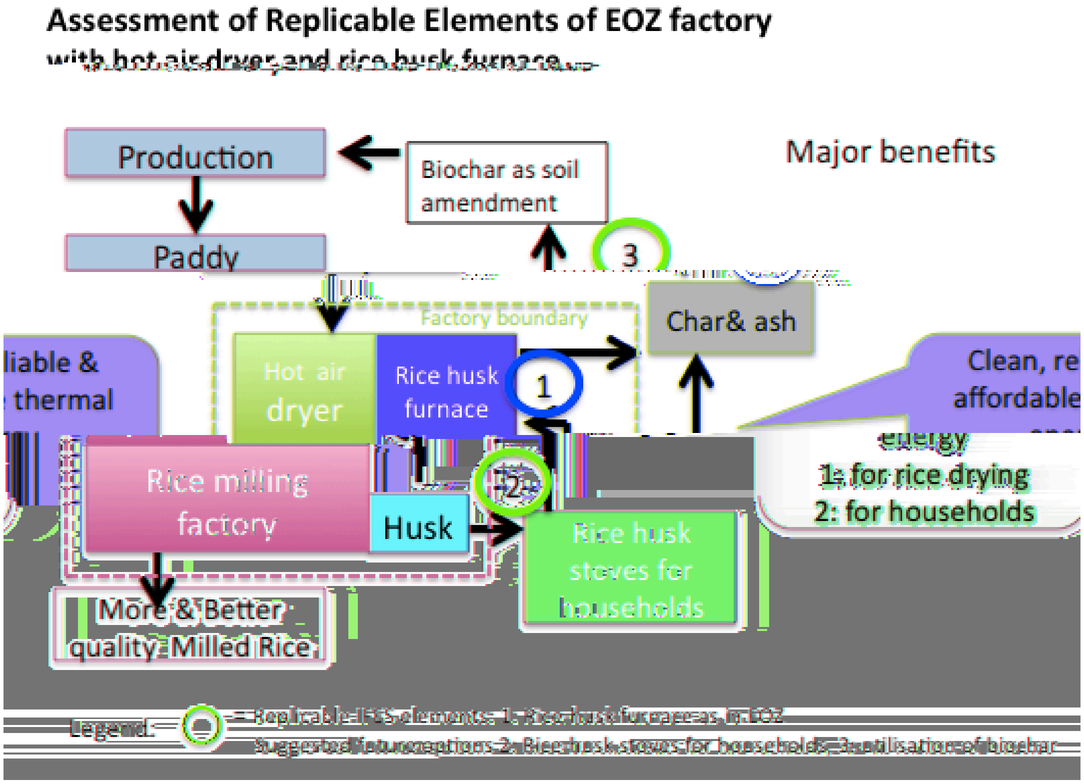
REPLICABILITY ASSESSMENT

The assessment of the replicability requires the definition of the target group where certain elements of this IFES can be replicated. Within the entire rice value chain, the elements of this IFES are purely at the end of the postproduction as they are based on the end-use of rice husk from the milling process.

WHERE AND HOW CAN THE IFES (RICE-HUSK FURNACE) BE REPLICATED?

In the case of EOZ the core element of the IFES is the **end-use of rice husk in a large rice-husk furnace to provide heat for a mechanised dryer.** This element is marked as Number 1 in Figure 14 hereafter. It can only be replicated at existing commercial medium-to-large size rice mills, where the rice that is processed is also marketed through the entity that operates the infrastructure. For smaller rice mills e.g. at village level, where people bring their own rice to de-husk against a fee, it does not make any economic sense to invest into the construction of a drying system with a dedicated furnace.

Figure14: Assessment of replicable elements of EOZ factory



There are alternative end-uses of rice husk that can be replicated at any size rice mill. This could be the introduction of household size rice husk gasifier stoves (marked as Number 2 in Figure 14) as well as the uses of the rice-husk char (marked as Number 3 in Figure 14) whether they originated from a furnace or a household stove. Both options are discussed in the recommendations in Chapter 7, but have not been assessed in the field as these options are not available yet in the study region.

To get a better understanding of the economic context of the furnace we show some cost factors before going into the guiding questions to assess replicability as proposed by the Analytical Framework.

The cost for the furnace at EOZ are not exactly known but it is estimated to be around 1 000 USD as the most expensive part is the cast iron grate and the costs for that depend on where the next available foundry is. The rest of the furnace structure is made from local bricks, so the cost depends on the bricks, cement and labour. In the Philippines they also make the step-grate furnace-designs with brick grates, which would lower the cost. Estimates from similar size buildings for tobacco drying are well below 1 000 USD for the structure including ducting.

According to information from IRRI (n.d. 10) the costs for a recirculating batch dryer of 10 t capacity amount to 10 000 USD. This is only half the size of the dryer at EOZ, but considering that EOZ never operated at that capacity we assume that a 10 t dryer would be sufficient in other places. A flat-bed dryer can be built starting from 1 000 USD.

So the cost to convert an existing factory to a rice husk furnace will depend on what is there: a simple dryer seems to be feasible starting from 1 000 USD; a more sophisticated for a 10 t batch 10 000 USD; and the step-grate furnace as found at EOZ from 1 000 USD. Please note the cost of the dryer will also depend on the size of the entire mill and the throughput per year. We estimate that a batch of 10 t is more than appropriate considering the current yearly throughputs at EOZ, where there is not enough rice to process and the capacity of a 20 t batch dryer is never really needed.

It is worth noting that a rice husk furnace as we found it at EOZ is only replicable at commercial size rice mills. The total number of such rice mills in Mozambique is estimated to be around 20.

EOZ is the only mill with a modern rice husk furnace in Mozambique. Hence no lessons can learnt regarding the replication of existing rice husk furnaces. The following four chapters will describe the potential for replication of the **the core element at EOZ, the rice husk furnace,** based on the limited experience from this sole case.

1. What are the enabling/constraining project features that simplify/complicate the replication of IFES?

2. What is the role of stakeholders and institutions in the replication of IFES?

3. How does the policy environment enable or disable the replication of IFES?

4. How does human and technical capacity shape the replication of IFES?

ENABLING OR CONSTRAINING FEATURES OF THE IFES

This section focuses on potential enabling or constraining project features that simplify or complicate the replication of IFES.

Clarity and credibility

In Mozambique, the EOZ is the first and only case with this kind of technology for drying rice. Despite the fact that experience with such rice drying technologies is very limited in Mozambique, GAPI, an implementing and well-recognized entity in the promotion of rural development, has systematized the information that shows that the use of rice husk as an energy source has reduced operational costs. Therefore, they are in good position to encourage other players to come in on this approach.

Legitimacy

The farmers, the investor and the government share the ownership of the project. All partners cooperate with common goals and the smallholder rice farmers belong to the company's administration board and are shareholders of the EOZ. The project idea was originated by outside partners but in consultation with government and the local community.

Ease in assessing results

Tangible results can be measured in the first year of use of the furnace. EOZ has only been operating since 2013 and only seen positive impacts of the rice drying technology. It has not spent any money on fuel to dry the rice, which increases their competitiveness compared to other factories that don't use IFES approaches.

Business model including financial viability

The project is commercially motivated, however it needed substantial initial funding to take off. The EOZ factory was fully funded with external support from the Netherlands, the European Commission and an Indian investor. Additional funding had to be provided at a later stage. Determining whether the initially high investment in the drying technology and the furnace pays off in comparison with traditional drying in the sun would require a detailed economic feasibility study for each particular case. In the EOZ case it was difficult to quantify all benefits to the necessary extent, as no data were available for the first years of operation before GAPI took over the management and the savings on fuel were lower than predicted, as the factory was not operating at full capacity.

Opportunities for replicating the business model, including the rice husk furnace and the drying technology, certainly exists elsewhere in the country as benefits of rice drying with rice husks lay at hand and have been shown in the EOZ case.

Alignment and linkages

The overall policy environment is favourable, as the support for the rice sector is a declared national policy of Mozambique.

The project is perfectly aligned with national and local policies such as the Strategy for Conservation and Sustainable Use of Biomass Energy, which is one of the instruments for the implementation of the New and Renewable Energy Development Policy approved by Resolution No. 62/2009 of 14 October by the Council of Ministers of Mozambique. We could not identify any contradicting policies.

Complexity, coordination and behaviour change

Neither the operation nor the maintenance of the rice husk furnace requires any special expertise, because it is simple and basic. It does not clash with the local culture and is in the best interest of the main stakeholders (farmers, management).

ROLE OF STAKEHOLDERS AND INSTITUTIONS IN THE REPLICATION OF THE IFES

The EOZ factory was conceived from the start to include a step-grate rice husk furnace that is very common in Asian countries but not yet in Africa. So the role of the **original funding entities and support organisations** was to get designers from Asia for the knowledge transfer from proven experiences in Asia to be applied in Mozambique. The EOZ has become a **champion** by successfully operating the furnace since the start. This can be the showcase and the encouragement for other entities to replicate this in their operations. The role of EOZ to replicate the furnace elsewhere would be to allow visitors to see the furnace in operation as a convincing example and share their experiences, good and bad ones, to provide other stakeholders an honest basis for decision making.

Now that the concept of the rice husk furnace is proven in Mozambique by the successful operated in Mozambique good quality interaction should be the key to ensure the successful replication of this IFES.

We could not find out if there is a rice processors association or another platform that can be used to sensitize other rice processors about this cost-saving furnace. When it comes to funding a new rice husk furnace, it depends if the rice processor needs external funding or can do the conversion or new construction of a rice husk furnace with own capital.

GAPI could be a strong resource partner, as a credit institution with a shareholder structure between public and private investors composed of the State (30 %), private investors (40 %) and civil society (30 %). They can play important role on promotion of EOZ as champion and on facilitation of the quality interaction improvement among relevant stakeholders.

GAPI invested in the restructuring of the EOZ after its crash in 2012. If this investment proves to be profitable on the long run, one can assume that that GAPI will recommend and potentially invest in similar projects.

THE EFFECT OF THE POLICY ENVIRONMENT ON THE REPLICATION OF THE IFES

The country has several policy instruments that promote the involvement of the private sector and the communities in use of renewable energies (Strategy for Conservation and Sustainable Use of Biomass Energy-Ministry of Energy, 2013) and in the production of food (Strategic plan for the Development of the Agrarian Sector-Ministry of Agriculture, 2010). Both are in favour of this IFES, meaning the use of rice-husk to generate bioenergy and improve food production.

The Strategy for Conservation and Sustainable Use of Biomass Energy foresees roles for different actors including the government as well as other relevant sectors like the private sector, household sector and academy, requiring joint action for a transition from traditional energy to modern and more climate friendly energy. It also envisages making the market of biomass energy more structured, attractive and sustainable.

Therefore, this practice of using rice husk as fuel for the rice drying process (use of agricultural residues for production of renewable energy) is a clear demonstration of the implementation of these policy frameworks above mentioned.

On the other hand, the fact that this initiative is participatory, involving private sector, public and communities is a great advantage for issues like credibility, legitimacy, support and champion organization of IFES due that these characteristics are one of the basic conditions for facilitating the implementation and replicability of it.

There is a policy for the development of small and medium enterprises which can serve as a platform to boost the development of technologies and capabilities needed in bioenergy programs (Industrial Policy and Strategy of Mozambique, 2007). Mozambique is in its incipient phase of industrialization and as a way of boosting this process approved in 2007 its industrial policy and strategy, which advocates that the development of the technological base, institutional, information and management should enable the broad transformation of industry and boost the rapid, diversified and sustainable growth of the sector.

Therefore, this legal instrument can serve as a good way of facilitating IFES initiatives with regard to processing technologies that involve bioenergy.

Currently in Mozambique there are no concrete Research and Development (R&D) strategies of using bioenergy crops for energy production and development of relevant technologies and also there is a need to building of human capacity in the field of technologies of using biomass like rice husks as energy resource.

THE EFFECT OF HUMAN AND TECHNICAL CAPACITY ON THE REPLICATION OF THE IFES

Although the technology of the rice husk furnace was transferred from Asia, it was built using local clay brick and local labour. The assembly of the factory complex was made by Indian technicians, who then trained Mozambicans staff on maintenance of it.

The technique is simple and its maintenance is now made by the company employees, without the need to hire specialized personnel. So, the existing technical schools in the country could play an important role in the improvement and dissemination of this technology in their school curricula.

We do not see any constraint regarding human or technical capacity to replicate the IFES.

Conclusion on replicability

The rice husk furnace is only replicable at commercial size rice mills that already have a drier and want to switch to a bioenergy furnace or where the investment of a drier and a furnace make economic sense.

The furnace can probably be built at less than 1 000 USD from local bricks and a cast iron grate. Costs for a drier vary with size and the degree of sophistication from a couple of hundred USD to more than 10 000 USD for a recirculating batch drier with a capacity of 10 tons of rice per batch.

We found that core-element of this processing plant, the rice-husk furnace has only positive impacts, no constraining frame conditions and sufficient technical and human capacity to be replicated without negative side effects.

The main constraint is the economic viability and the context where it fits which will be discussed in the next paragraph. Earlier on we differentiated two scenarios for the BAU cases, which strongly influence the economic viability of replicating the rice husk furnace, depending on what to build upon. In the BAU 2 the mill already has an existing dryer& furnace, so it would only require a modification of the existing furnace to be powered with rice husk instead of the fuel used before. In the BAU 1, only sun-drying is applied which would require a larger investment into both a new dryer and a new furnace.

The following table compares the prospects of adoption of the rice husk furnace for BAU 1 and 2:

Table27: Comparison of prospects of the adoption of a rice husk furnace for BAU 1 and 2

Aspect	BAU 1: Existing mills with sun-drying: Need to add a heated air dryer and a furnace	BAU 2: mills with an existing dryer& furnace: Need to modify existing furnace to be powered with rice husk
Enabling/ constraining features	- Investment cost for both heated air dryer and furnace depending on size of operation - Heated air dryer in competition with low temperature drying - Dryer costs: can vary from an estimated 500 USD for a 2x3 m flat-bed dryer built on site to over 10 000 USD for a large recirculating batch dryer -/+ Economic viability only feasible if there is enough rice to process and the gain in commercial value through better quality rice justifies investment	➢ Space needed to integrate a rice husk furnace into the processing chain ➢ Payback period for cost for construction of furnace depends on cost of current fuel and size of operation.
	Once paid back, initial investment fuel costs will continue reducing the operational costs and increase profitability	

Table26 (cont'd): Comparison of prospects of the adoption of a rice husk furnace for BAU 1 and 2

Role of stakeholders	➢ Infrastructure to be owned by factory management ➢ Factory management as well as owners (e.g. cooperative members) open to the changes and ready to invest ➢ Investment capital or Investor needed	
Policy environment	➢ Favourable, as support for the rice sector is a declared national policy of the country	
Human/ technical capacity	➢ Simple flat-bed dryers and the furnace are easy to construct but it needs plans (e.g. from IRRI) and/or samples ➢ Skilled labour for construction needed ➢ Management needs ability to handle more complex rice processing chain	Manually operated inclined grate rice husk furnace is easiest model to build and operate, but it needs plans (e.g. from IRRI) and/or samples

The introduction of a dryer and/or furnace hinges on the economic viability, which is context specific and depending mostly on these factors:

- How quickly can the investment be paid back?
- How much rice is there to process?
- Is there a market and enough economic incentive for better quality rice to justify the investment?
- What are alternative fuel costs?

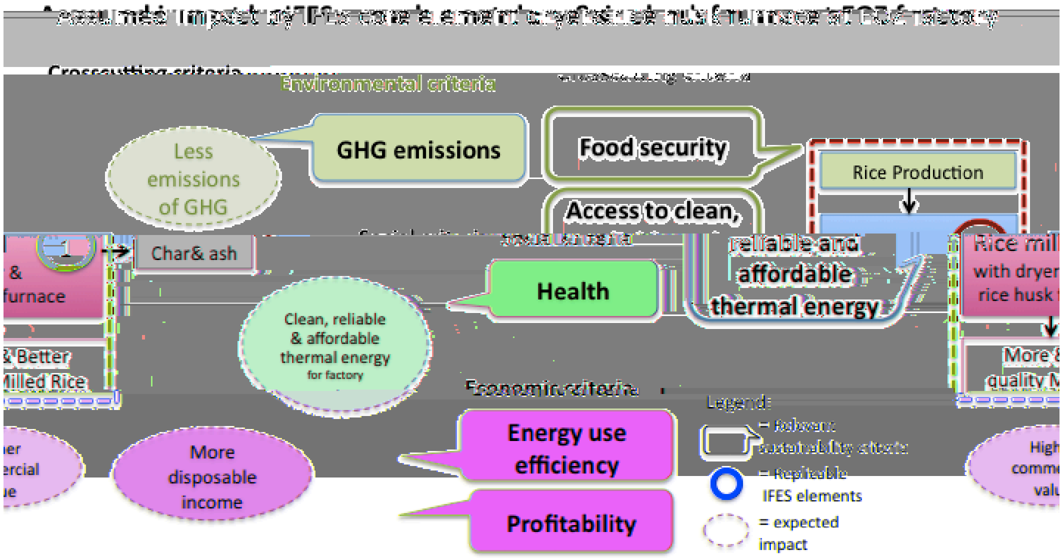
Once the economic feasibility is answered favourably, there should not be a major constraint apart from the technical capacity to build and run such a rice husk furnace to adopt this IFES at factory level.

CONCLUSIONS

The IFES example of EOZ maximises the utilization of all by-products of the milling process and shows a perfect synergy between energy and food production at the same time. It proves that thermal bio-energy produced from rice husk can enhance availability of higher quality and quantity of food and thus contribute directly to better food security of both producers and buyers of the rice.

No disadvantages of the IFES were reported or observed compared to the two BAU scenario. This IFES does not impact the farming systems and farmers' activities on their fields, it only concerns the operations at factory level. Not every indicator could be measured on site but from the observations in the field and experiences documented in the literature, some assumptions are made on the expected impacts and their contributions to the sustainability criteria described above. The Figure 15 below visualises the directly deducted impacts:

Figure15: Assumed impacts of the IFES ‘dryer and rice husk furnace’ at the EOZ factory



At factory level, the rice husk furnace provides clean, reliable and affordable thermal energy, which contributes to reduced GHG emissions and better health for the workers and surrounding communities. The reduced fuel costs of the furnace lead to better profitability and long-term economic sustainability.

For farmers and factory owners, the higher commercial value of rice leads to more disposable income, which enhances the economic viability of the factory. This is also in the interest of the farmers as it enhances their chances for long-term access to high quality processing facilities promising economic benefits. It is in the national interest that post-harvest losses are minimised while the rice produced is of higher quality and fetches higher prices on the market. This is likely to enhance local and regional economy as well as food security.

The IFES is aligned with the relevant policies such as the Strategy for Conservation and Sustainable Use of Biomass Energy which is one of the instruments for the implementation of the New and Renewable Energy Development Policy approved by Resolution No. 62/2009 of 14 October by the Council of Ministers. As visualised in Figure 15, positive impacts can also be assumed regarding improved Access to energy which coincides with the UN Sustainable Development Goal 7.

No competition for resources or negative impacts could be observed. Therefore, we conclude that this IFES has replication potential among the larger-scale factories not only in Mozambique but anywhere!

RECOMMENDATIONS

As mentioned earlier, the utilisation of rice husk in a furnace for rice drying has limited replication potential, as there are currently only few commercial rice mills in the country. Where no commercial rice mills exist, where the introduction of a furnace is not profitable, or where rice husks remain unused for other reasons, the husk could be utilised as cooking fuel in households with the introduction of appropriate rice husk stoves. The utilisation of the created rice-husk char as biochar in the fields could increase food production and sequester carbon, making cooking carbon-negative.

EOZ will only remain profitable and operational on the long run, if there is more rice to process for the factory. Thus, new ways to increase and intensify smallholder rice production are needed that also make production more drought resilient e.g. with better availability of water through irrigation or better soil water and nutrient management (green manure, mulching, application of biochar and ash, complemented if needed by inorganic fertilizer, etc.). The example of the interviewed farmers who grow normally 20 to 30 bags of rice in a good year and harvested only one bag in the last season makes the drastic need for more resilient systems very obvious, in order to mitigate the devastating effects of recurrent droughts. Otherwise, farmers will give up rice production and switch to other crops.

GENERAL RECOMMENDATIONS TO SPECIFIC STAKEHOLDERS

As any integrated system, IFES needs multi-stakeholder support to advance the potential benefits of a cross-sectoral integrated approach. We thus suggest some general recommendations for different stakeholders and later lay out some visions what could be done with the remaining rice husks as mentioned above.

Recommendations for the public sector:

- The role of the public sector is to create favourable conditions for producers to be able to carry out their activities in a competitive environment by providing basic goods and services for this purpose. Thus, the Ministry of Agriculture and Food Security, Ministry of Mineral Resources and Energy and The Ministry of Industry and Commerce should disseminate rice husk residue technologies as a source of energy in rice processing factories, since these systems contribute significantly in reducing not only the operational costs but also the GHG emissions.
- Conduct research for the development of tax incentives and technological packages for drying kilns with a view to achieving energy efficiency in the field of bioenergy and its use in agro-industry and also reduce the cost and risk of investing in such IFES bioenergy initiatives.
- To form human capital, including producers, researchers, specialists in the area of bioenergy, having as main focus their multiple uses as energy and food.
- Improve the image of bioenergy by creating more awareness on national level of positive examples of usage of available residues that are otherwise wasted.
- Compile and spread information on available technologies, their suppliers and estimated cost in order to facilitating the stakeholders in this bioenergy field.
- Develop a system of fiscal advantages for companies using rice husks as source of energy.

Recommendations for civil society:

- Civil society organizations, particularly non-governmental organizations, researchers, universities and academia in general play a key role in the development of human and social capital. It is therefore recommended that they participate in the organization and structuring of producers in profitable cooperatives and with market-focused.
- On the other hand, civil society is encouraged to promote studies, technical advice and training on bioenergy and its developments, as well as to support the mobilization of financial resources for technical assistance and the dissemination of the advantages of integrated food and energy systems.
- Encourage research institutions to increase efforts to find appropriate rice varieties that are shorter maturing and less vulnerable to droughts and other climatic variability. Involve farmers in participatory research and the multiplication of varieties (which can also be more traditional

varieties). There are good successes reported from West-African upland rice growers utilising NERICA (New rice for Africa) varieties.

- Start a pilot to research the effect of biochar in rice fields e.g. on water retention, fertilizer savings, resilience of plants and soils.

Recommendations to the private sector:

The private sector is the largest category in the development of the economy, including producers, traders, processors and service providers. Therefore, we recommended:

- Share their experience in the use of IFES and participate in research in partnership with other sectors, which can significantly contribute to the removal of constraints in the rice value chain and the use of this as bioenergy for the various purposes.
- Contribute to the development of cooperatives and in the creation of credit lines for agriculture transformation and the development of the agro-industrial sector, capitalizing all opportunities that may arise from the use of bioenergy in order to become more productive, competitive and efficient.

SPECIFIC RECOMMENDATIONS REGARDING THE USE OF RICE HUSK FOR COOKING AT HOUSEHOLD LEVEL

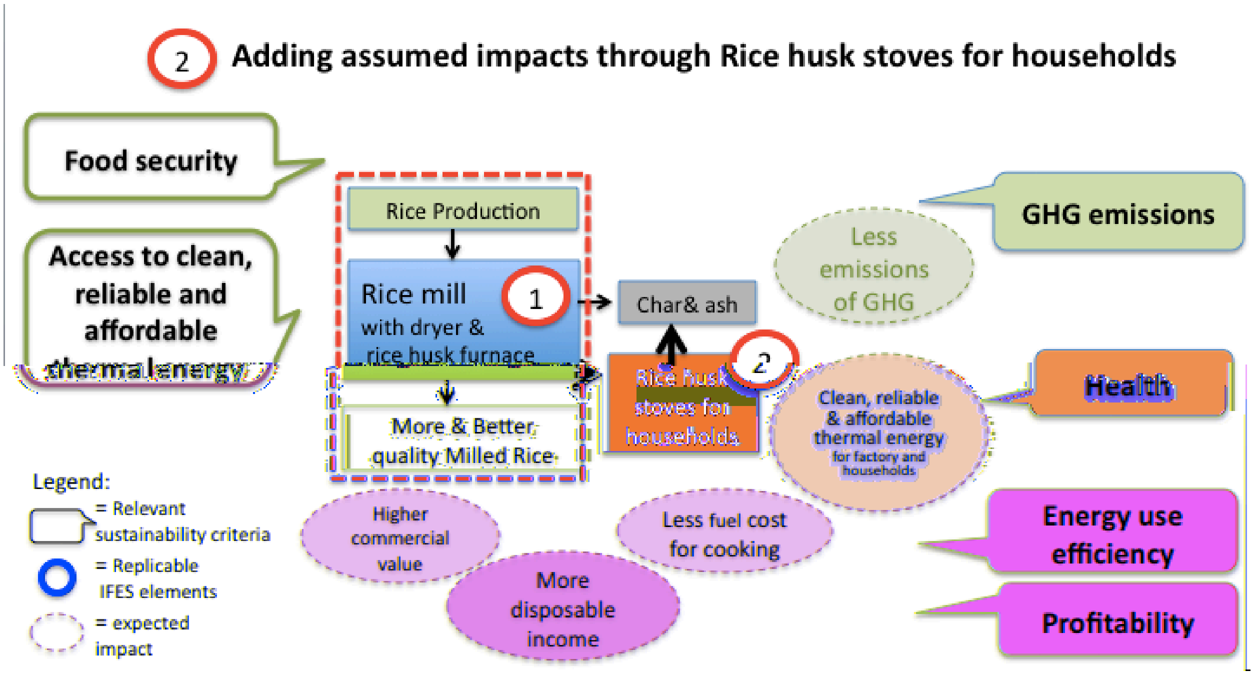
As mentioned above there are alternative end-uses of rice husk that can be replicated at any size rice mill. This could be the introduction of household size rice husk gasifier stoves as well as the uses of the rice husk char whether it originated from a rice husk furnace or a household stove.

Only 25 % of the Mozambican population have access to electricity, mostly concentrated in the urban areas. Neither electricity nor LGP are widely used for cooking, less so in rural areas where rice husk is generated. Cooking energy is still mostly provided by solid biomass. Thus, we have to explore alternative renewable energies as cooking fuel.

Rice husk can be such a renewable source of cooking energy, but it needs to be coupled with the introduction of specialised cookstoves that are designed to burn rice husk cleanly.

At any rice mill rice husk is created as a residue often without further uses. Even if there is a rice husk furnace at the factory, it will never use up more than half of the rice husk created. So there is a residue to be turned into thermal energy as well on household levels. The target group would be the communities in reasonable distance around the rice mill, so that it makes economic sense to transport them (best without motorised transport due to the bulkiness of the husk).

Figure16: Assumed impacts of the utilisation of rice husk in cookstoves for households



The stove element has not yet been introduced at EOZ, but it has been identified as a recommendation for EOZ and there is interest by the EOZ management to do so.

Why was this not done before? So far, no modern and convenient rice-husk stoves are available in Africa: Rice husk stoves need an electrical blower to function conveniently, so a small amount of electricity is needed. This used to be a major constraint for the introduction of rice-husk stoves in African rural areas, where grid-power is scarce and unreliable. Since 2016, there are battery-operated rechargeable fans available from Vietnam at an affordable factory price of 5 USD. With a solar panel to recharge the battery, the costs may increase by 3 USD.

Rice husk stoves for households have been also been further developed in recent years especially in Vietnam, so that technical solutions including off-grid blowers are available in the price range of 10-30 USD (in Vietnam). This development is a game-changer and now paves the way for the introduction of this type of household stoves.

There are also rice -husk stoves available in India, which can be researched and tried out.

What is needed is an initial investor (preferably a commercial enterprise) with capital and willingness to invest into up-front purchase of stoves before they can be sold to the households at a commercial price.

The investing enterprise also needs the capacity and experience to import stoves and blowers from Vietnam, handle customs procedure and logistical challenges including safe warehousing of the stoves.

In a next step the stoves need to be tested with a small target group for acceptance and suitability in the communities. The challenge is to weigh the risk between importing a small number of stoves at high cost for acceptance testing versus taking the risk to import a larger quantity with better prices.

Following the testing of acceptance and willingness to pay for the stoves, commercial distribution channels have to be created around the rice mill, where people can have access to the rice husk.

Once the technology is tested and accepted, trials can be done to replicate the stoves locally and then assess the cost-benefit of local production versus the landed costs of the imported stoves. Import tariffs will play a major role there and need to be assessed.

The management of EOZ has shown interest to become an importer and distributor for rice husk stoves from Vietnam or India.

Human capacity is needed to enable field acceptance, which might not be available at EOZ level. Cooperation with extension workers or NGO field agents could be sought. Care has to be taken that stove distribution is set up commercially to cover all related costs and generate profit, otherwise it will not be sustainable.

Access to the rice husk for needs of stove users to be regulated by EOZ. A small fee could be charged. The price needs to be worked out as cooking with rice husk stoves should still be cheaper than with purchased firewood or charcoal.

The rice husk stove will not be able to address all the cooking energy needs of a household as they are batch-fed, with each batch running for about 25-30 minutes. This is not suitable to cook dry beans, but should suffice for most other cooking needs.

The stoves are best lit using maybe a bottle-top full of kerosene or other liquid fuels. If rice husk is accessed for free the starter fuel is the only the cost for fuel.

The convenience factor of using the stoves should be higher than firewood or charcoal stoves, as they burn with a clear flame that is comparable to LPG, the power can easily be regulated with the speed of the blower. The speed and ease of lighting the fire is high if liquid fire starter is used: the pot can be put on the stove one minute after ignition.

The rice husk stoves are gasifiers that don't burn the entire husk but leave up to 30 % (by weight) of the initial husk in the form of char and ash. The char and ash contain many minerals and can be used as soil amendment to increase yields and create other co- benefits.

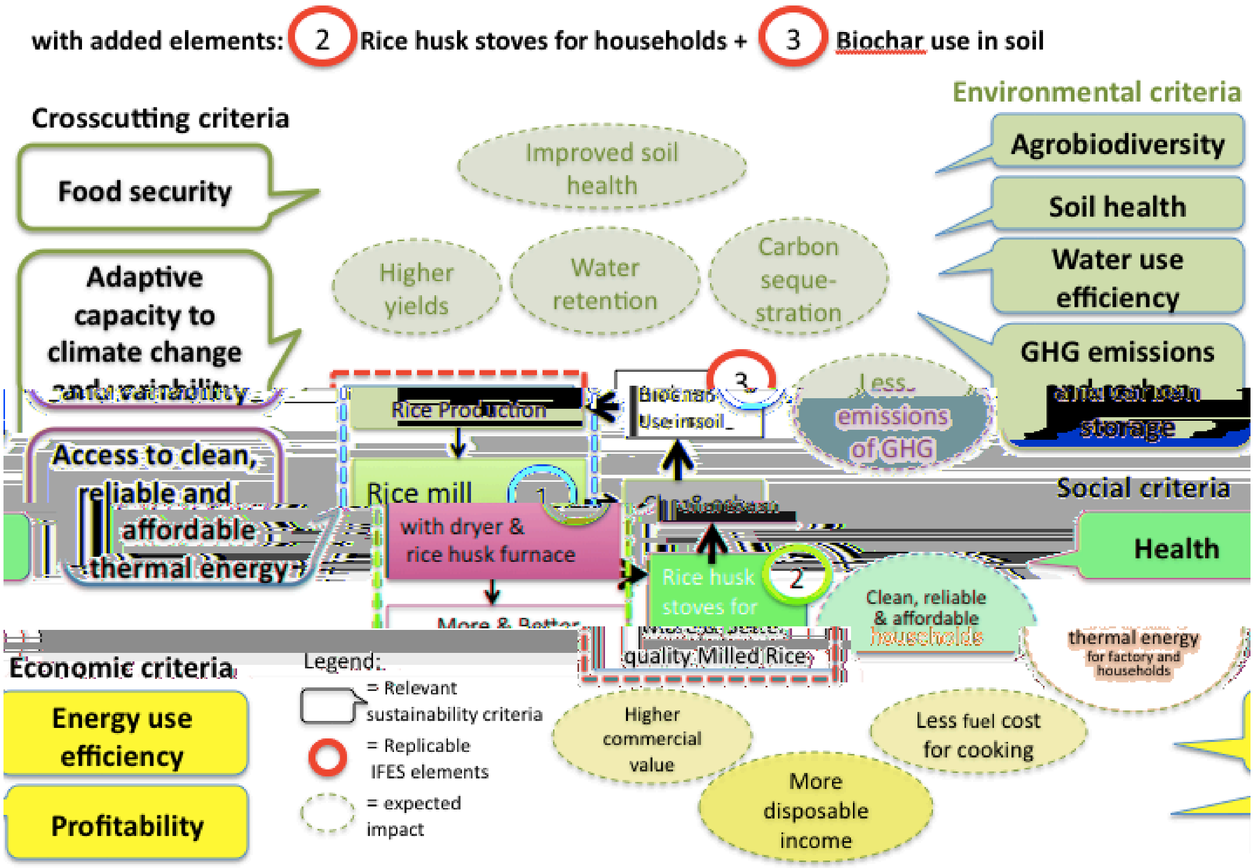
SPECIFIC RECOMMENDATIONS REGARDING THE UTILISATION OF RICE HUSK CHAR AS SOIL AMENDMENT

This element can be introduced anywhere that rice husk is gasified in a furnace or a gasifier stove. There is normally a restricted airflow that prevents the husk to burn completely to ash.

There is scientific evidence as well as experience from farmers at EOZ that the application of the residue of the burnt husk increases yields of maize.

Scientific evidence exists also for a number of environmental, social, and economic co-benefits such as carbon sequestration, increased water retention capacity and cation-exchange-capacity of acidic tropical soils. This IFES element adds a lot of complexity for implementation but it also enhances achievable positive impacts, as visualised in Figure 17.

Figure 17: Maximising impacts of the IFES utilisation of rice husk for energy



These results are evident to the users once they have been demonstrated to them, but they are harder to quantify scientifically. The biochar-element of the IFES contributes most favourably to increased food security and reduction of GHG emission.

The following are needed for the replication of this IFES element:

- availability of rice husk char and ash
- accessibility to farming communities in the vicinity (factory furnace or household stoves)
- demonstration of the benefits on fields
- training of farmers on utilization and good agricultural practices (e.g. mixing char with compost and/or manure, application of small amounts in planting holes, etc.)

This is more complex and takes more than one agricultural season to demonstrate. It will need support through an entity with extension services (GO or NGO) and/or local leaders.

Biochar should never be applied in the soil without having been mixed with manure and/or compost, so the behavioural change is more complex.

There is a lot of literature available on biochar and its benefits. One of the most comprehensive sites is the site of the International Biochar Initiative, for details see http://www.biochar-international.org/

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JATROPHA FENCES AROUND SMALLHOLDER FOOD CROP FIELDS

SYSTEM AND CONTEXT

BACKGROUND

Interest in Biofuels in Mozambique

Around 2006, the biofuels agro-business emerged as an important area of interest for investors in Mozambique. Land is the property of the state in Mozambique, where formal requests must be made to lease land for feedstock production, including evidence that an adequate community consultation process has taken place. By the end of 2008 the Mozambique government had officially received proposals from 17 biofuel projects, five of which were for bioethanol feed- stock production and 12 for biodiesel crops (Thornhill et al 2016).

Consequently, in 2009, the Government approved both a national strategy and policy to promote and regulate the biofuels sector while guaranteeing that future investments generate meaningful social and economic benefits. Confirming this growing interest, between 2008 and 2014, the Agriculture Promotion Centre (CEPAGRI) received 195 proposals for agricultural projects from which 36, or around 18 percent, were biofuels project proposals. These biofuel projects required an area of 409 452 ha, representing around 16 percent of the total area requested by agricultural projects in the same period. On the economical side, biofuel projects had planned a total investment of USD 3 695 776 843 or one-third (33-30 percent) of all expected investment in agricultural projects. (CEPAGRI, Final Biofuel Report, 2016)

Despite this initial enthusiasm, the interest in the biofuel sector has decreased sharply. As early as 2013, a report by the Overseas Development Institute (ODI) noted that only 18 of the initial 36 projects were operational. Out of the total area 209 000 ha of planned area, only 6 000 ha had actually been planted (Atanassov 2013). Currently there are only 11 companies in operation that exploit the raw materials included in the list approved by the Government for the production of biofuels, namely Jatropha, coconut, sugarcane and sweet sorghum.

Currently sugarcane has become the most interesting and dynamic crop in the biofuel sector. Mozambique has a long experience in the production of sugarcane for sugar production and thus has the advantage of using the crop and its by products for ethanol production. Investments in sugarcane are large-scale and have increased significantly in recent years. Moreover, the production of sugar cane in Mozambique continues to be an important source of employment and contributes to socio-economic development of rural areas. As a result, sugarcane production has increased from 13 224 tonnes in 1992 (soon after the civil war) to 423 063 tonnes in 2014. (CEPAGRI, Final Biofuel Report, 2016)

Overview on the Jatropha sector in Mozambique

As mentioned above, one of the biofuel crops that were promoted by the Mozambican government was Jatropha Curcas. It was generally assumed that Jatropha could foster national and local energy production, enhance agricultural productivity through private sector investment and the transfer of technology in the agricultural sector and facilitate rural development.

Jatropha was promoted as an opportunity for smallholder farmers and as a crop that was easy to cultivate. Although the promotion of Jatropha by the Mozambican government had mainly focused on smallholders and communities, it also attracted investors with interest in planting this biofuel crop on large-scale agro-industrial plantations.

According to the Mozambique Biofuels Policy and Strategy (2009), an important reason for promoting biofuel and Jatropha production was to reduce its expenditure on fuel imports by creating a domestic market for Mozambican biofuels and to increase exports to generate tax revenues and access to foreign currency. Several concrete targets were set by Government with the aim to reduce oil imports and create of 150 000 jobs. An addition target was to dedicate 450 000 ha of land to grow biomass for biofuel production and the compulsory blending of liquid fuels for transport. This included a bioethanol blending target of 10 percent and 5 percent biodiesel blending.

Biodiesel was primarily expected to be sourced from Jatropha. This was due to the fact that it is a non-food crop and hence would would not conflict with edible oil for human consumption and avoid potentially negative impacts on food security. From 2008 to 2016, the country received expressions of interest to grow Jatropha from 22 companies. The interest peaked in 2008 and quickly died down by 2013 as shown in Figure 18 below (based on data from CEPAGRI 2016).

Figure 18. Number of Jatropha intention projects per year (2008 – 2016).

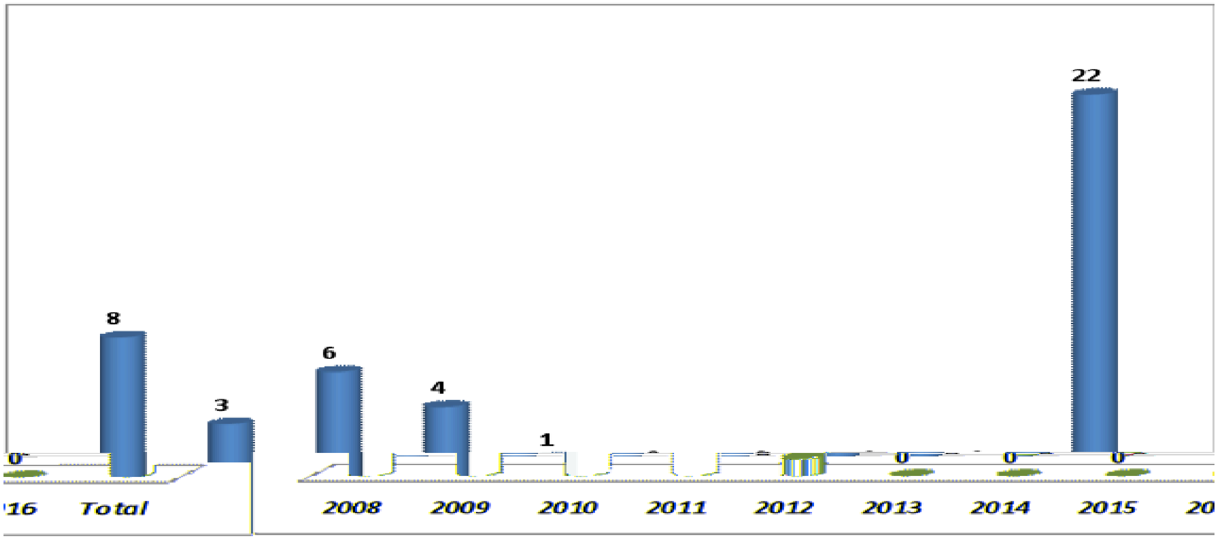
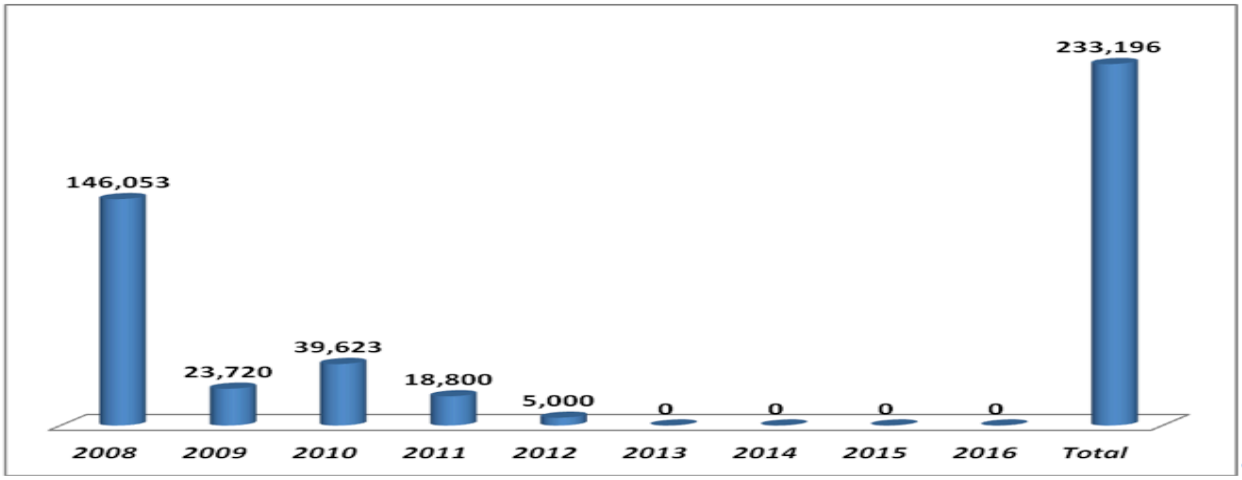


Figure 19 shows the submitted requests for the allocation of land amounting to a total of 233 196 ha, distributed throughout the country. The initial requests in 2008 were the most ambitious with 146,053 ha requested by only eight companies, equalling on average 18 250 ha per proposal (CEPAGRI 2016).

Figure 19. Requested land (in ha) for Jatropha production per year (2008 – 2016)



Despite the enormous interest being expressed, not all investments were successful. As a result, only two Jatropha projects are still known to be operating in Mozambique. One is the Dutch company Niquel aiming at large-scale production, yet so far they only planted Jatropha on 3 000 ha out of the planned 6 500 ha in Sofala province. They are hopeful to harvest 3-4.5 t of Jatropha seed per hectare. Currently, the company is in the implementation phase of its processing unit for oil extraction and in 2014, the first harvest of 120 tonnes was exported to the Netherlands for laboratory tests.

The second project is in Cabo Delgado province, where there was a strong community involvement in the production of Jatropha oil for various purposes such as the production soap and fuel for mills. The oil production was not meant for export but targeting the local market to substitute diesel in the remote areas. Many of the rural farmers who planted Jatropha in 2007 abandoned it in the following years due to the difficulties with farming Jatropha and the lack of economically interesting markets for Jatropha seed. The number of subsistence farmers and hectares covered is currently unknown but it seems to be below the 2 000 ha in total.

STUDY OBJECTIVES AND JUSTIFICATION OF IFES CASE

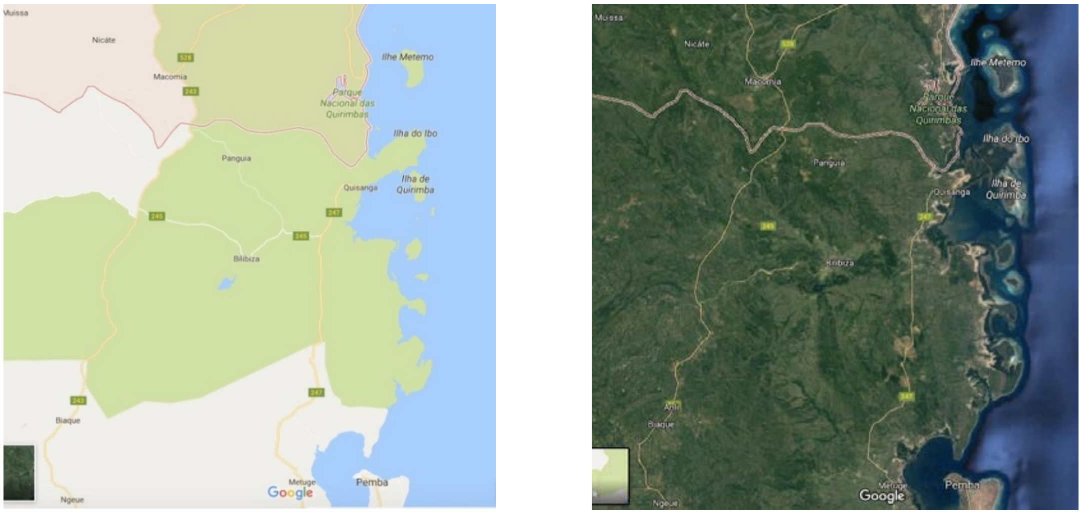
Bioenergy production is a multidimensional undertaking. Its success depends on various local socio-economic factors as well as national energy and agriculture policy. Therefore, bioenergy projects should be built on sound local evidence that supports its success. Nevertheless, concerns over diverting farmland or crops for biofuel production have been expressed in the past years and as such these concerns also hold over the large scale mono cropping of Jatropha. This study however, aims to study and document a case where Jatropha was integrated into smallholder farming systems as opposed to large-scale mono cropping of Jatropha. We wanted to assess the sustainability and replicability and analyse the impact of Jatropha planting on food production and other socio-economic factors.

SITE AND CASE SELECTION

The case study was selected as the only known case in the country where there is still a certain level of continued production of Jatropha by small-holder farmers for energy purposes. This case is specifically interesting since the introduction of the Jatropha was originally not intended for energy production, but instead as a hedge to protect food crops within the newly declared National Park of the Quirimbas in Cabo Delgado province (for location on the map see Figure 20).

Cabo Delgado Province is located in the north of Mozambique with approximately 77 867 km² and a population exceeding 1.9 Mio. The Rovuma river is a natural border with the United Republic of Tanzania in the north, in the south, the river Lúrio separates it from the province of Nampula; the western limits to Niassa Province are defined by the rivers Lugenda, Luambeze, Street and Mewo (successively from north to south) separated with Niassa Province, the eastern limit is the Indian Ocean.

Figure 20. Location of case study site Bilibiza in the National Park of the Quirimbas



Map and Satellite view of Bilibiza in the National Park of the Quirimbas (Source Google Maps)

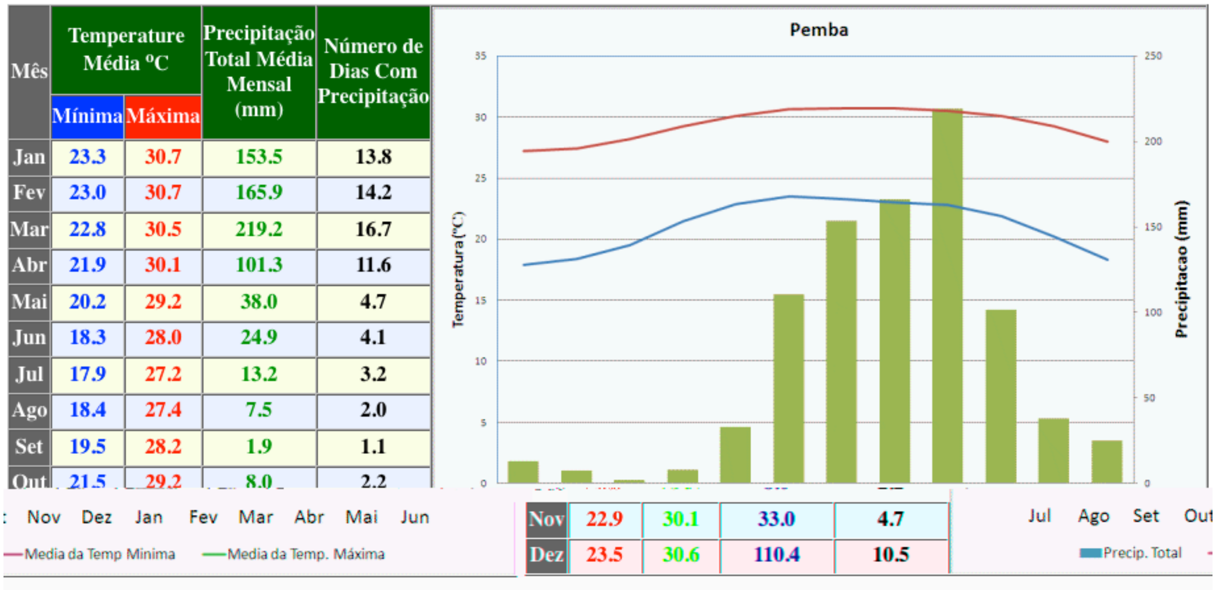
The case study was carried out in three districts of the province of Cabo Delgado, namely:

Quissanga District in the Central Zone of Cabo Delgado Province is about 120 km from the city of Pemba. In North is separated with Macomia district, south by the districts of Pemba-Metuge Ancuabe and to the east by the Indian Ocean that separates the district from Ibo and West with the district of Meluco. This has an area of 2 060 km² and a population estimated at 34 328 inhabitants, this district has a population density of 20.4 inhabitants/km ².

Macomia district: It has a limit, to the North with the districts of Mocímboa da Praia and Muidumbe (this also to the Northwest), to the West and Southwest with the district of Meluco, the South with the district of Quissanga and the East with the Indian Ocean. In 2007, the Census indicated a population of 79 825. With an area of 4 049 km ², the population density reached 17.3 inhabitants/km².

Ancuabe district is located in the southern province of Cabo Delgado, about 100 km from Pemba, the capital city, is bordering in the North with Meluco district, south by the district of Chiúre, and east the districts of Pemba-Metuge and Quissanga and west with the district of Montepuez. It has an area of 4 836 km2 and an estimated population of 108 924 inhabitants, this district has a population density of 21.9 inhabitants/km². Figure 21 summarises the climate in the study area.

Figure21: Climate graph for the City of Pemba (1971-2 000)



Mês	Temperature Média ºC		Precipitação Total Média Mensal (mm)	Número de Dias Com Precipitação
	Mínima	Máxima		
Jan	23.3	30.7	153.5	13.8
Fev	23.0	30.7	165.9	14.2
Mar	22.8	30.5	219.2	16.7
Abr	21.9	30.1	101.3	11.6
Mai	20.2	29.2	38.0	4.7
Jun	18.3	28.0	24.9	4.1
Jul	17.9	27.2	13.2	3.2
Ago	18.4	27.4	7.5	2.0
Set	19.5	28.2	1.9	1.1
Out	21.5	29.2	8.0	2.2
Nov	22.9	30.1	33.0	4.7
Dez	23.5	30.6	110.4	10.5

Source: http://www.inam.gov.mz/

The climate in Cabo Delgado is humid equatorial, with a dry winter. The mean temperatures have a small thermal amplitude 24 -26 °C, due to the tropical location and the considerable proximity to the Equator line. The precipitation varies from 800 – 1 000 mm and there are two well-defined seasons throughout the year: the dry season (May to October) and the wet season (November to April). Yearly rainfall ranged around 886 mm, but variability has increased in the last years, less overall rain is received and the start tends to be later, e.g. in 2017 it only started raining in mid- January instead of November.

Agriculture is the most predominant activity and involves almost all households, having as main subsistence crops cassava, maize, beans and groundnuts. Cash crops are cashew, rice and coconut.

SETTING THE BOUNDARIES OF THE BAU AND IFES

Jatropha is a naturally occurring tree in the area, but it was never cultivated. Therefore, we define the business-as-usual scenario by the absence of purposely-cultivated Jatropha. The IFES scenario is when farmers cultivate Jatropha in consortium with food crops. Furthermore, we differentiate two IFES scenarios according to the implementing organisation. These are detailed in turn.

Specific background on the National Park of the Quirimbas

Here we provide some context of this specific case in the Quirimbas National park, where Jatropha was initially introduced under a food security programme out of which the exploitation for oil and energy emerged later on.

In 2002, the Government of Mozambique started the preparations to declare a new national park in order to conserve the unique biodiversity of the pristine Quirimbas islands with valuable coral reefs and to protect the coastal mangrove forests with an inland buffer zone. In 2005 the National Park, Parque das Quirimbas' was officially declared comprising about 7 000 km² both land and maritime areas, divided in five districts. The national park did not expel the farmers living in the area, nor was it limiting farming activities, so it did not directly affect the farming activities of 140 000 inhabitants living in small communities in the park. However, due to the ban on hunting wild animals, they started to raid the fields and destroy crops. Thus, the national park negatively affected the farmers' food security and livelihoods, which also reduced school attendance, as farmers increasingly failed to raise the money for school fees.

Introduction of Jatropha fencing to improve food security

Recognising the challenges faced by farmers near the national park, the Danish NGO called Associação de Desenvolvimento do Povo para Povo (ADPP), which runs a teacher training centre in Bilibiza (seeFigure 20) considered developing a social programme to mitigate the adverse effects of the National Park on the farming communities. One of the ideas was to group farmers' fields in farming blocks that could be protected more easily against the wild animals as the risk is reduced for the crop to get raided by a group of monkeys if it is not a single plot exposed to them. This was tried and showed effect but in order to further improve food security and prevent crops for human alimentation to be destroyed by animals so they were looking for a boundary planting of a plant that would not be eaten by animals to physically prevent the animals to enter the fields. Consequently, the Jatropha project emerged as protective fencing grown by smallholder farmers around their fields to protect their livelihoods.

Figure22: Business-as-usual Situation before Jatropha fences

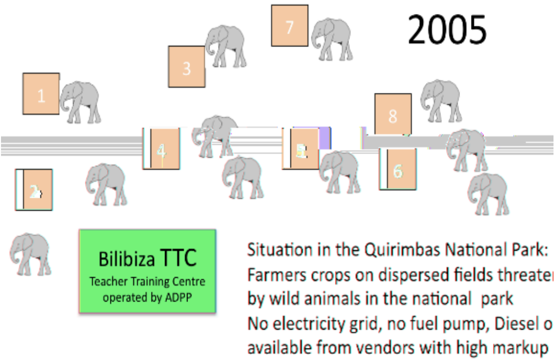
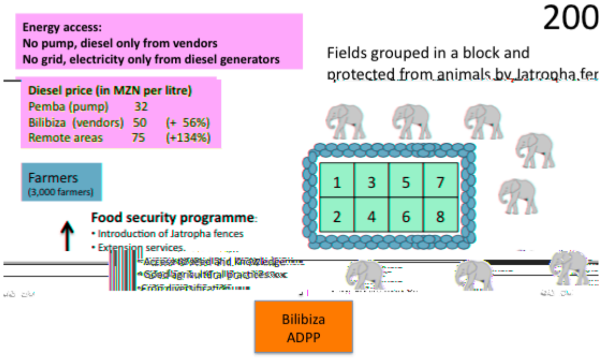


Figure23: Situation after the fencing of fields with Jatropha



Jatropha was introduced to protect the food crops on the fields, such as maize, cassava and groundnuts. The idea was introduced by ADPP as part of a food security programme to increase income and food security for smallholder farmers in the Quirimbas national park by decreasing risk of crop being destroyed by stray animals. The original project idea also included the promotion of other crops like sesame, vegetables etc. Farmers received extension services through ADPP which also helped to increase yields, crop diversification and overall food security. The energy aspect of the Jatropha only came in once the plants started fruiting. At the time ADPP partnered with the Dutch FACT foundation which supported biofuel projects worldwide.

Jatropha was seen as a suitable feedstock to produce liquid fuels intended to substitute diesel. The grid had not yet reached Bilibiza and there was no diesel pump in the park, as a result, diesel was only available from vendors at high prices. Subsequently FACT supported ADPP to build an oil processing facility in Bilibiza on the compound of the Teacher Training Centre (TTC). The so-called 'BBC' (Bilibiza Biofuels Centre' operated by ADPP ran a generator on pure plant oil (PPO) from Jatropha to provide electricity for the compound. The oil was also used as fuel for the vehicle of the TTC. The PPO was sold at competitive prices and this gave an enormous benefit to the TTC. BBC sold surplus PPO to maize mills in the area to substitute the expensive diesel from vendors. The farmers were happy as they got paid 5 MZN per kg of Jatropha by the BBC and could also buy PPO for lucrative soap making. By the end of the project phase in 2010 over 3 000 farmers' cultivated Jatropha fences to protect their food crops and sold seed to the BBC (see Figure 24).

Figure 24: Situation at the end of the ADPP phase (IFES1)

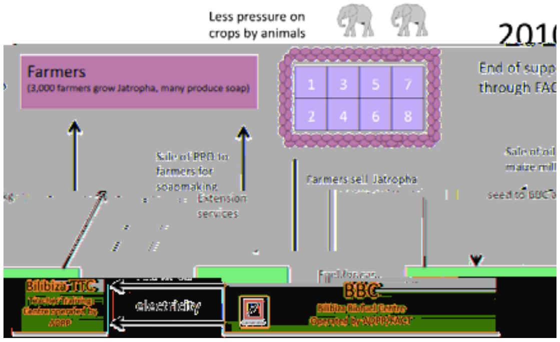
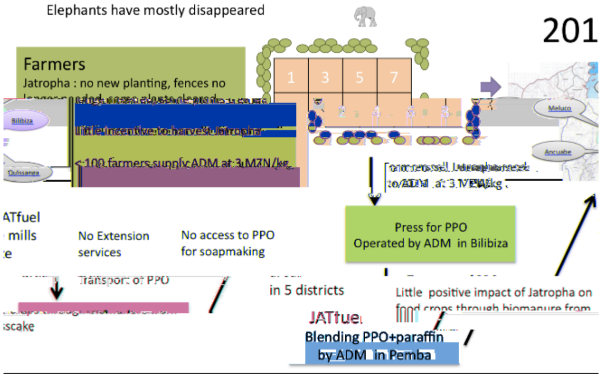


Figure 25: Current situation with ADM making JatFuel (IFES2)



After the ADPP project stopped, Mr Bachir Afonso who had previously operated the BBC, continued to work with the farmers through his NGO 'Grupo de Saneamento de Bilibza' (GSB). They got financial support through CEPAGRI to keep mobilising farmers to grow Jatropha. In 2011, the new player *Agro-Negócio para o Desenvolvimento de Moçambique, Limitada (ADM)* came with the intent to process PPO into a fuel blend marketed under the brand of JATfuel. With the assistance of GSB in 2013, the numbers peaked at over 6 200 farmers growing Jatropha. However, after 2013 the price for Jatropha seed was reduced to 3 MZN which due to the rampant inflation meant a severe reduction in purchasing power. Farmers no longer had neither access to extension services nor were they granted access to buy PPO for soap making. With the pressure by animals mostly gone, farmers stopped maintaining or even cleared the Jatropha fences for crop protection. The energy aspect of Jatropha as biofuel was never important to them, as they never used PPO for energy, only for soap making. For the biofuel prices two major external circumstances combined to lower the prices: two official fuel pumps opened in the National Park, and the world oil prices hit record low, bringing the retail diesel prices down and thus the profit margins along the entire Jatropha biofuel value chain.

With the low prices for Jatropha farmers lost interest in the crop so that currently less than 100 farmers supply seed to ADM as they have no incentive to harvest Jatropha. Thus ADM had to create some own fields of 13 ha each in two locations in order to ensure supply of seed for their JATfuel. ADM is the only buyer of Jatropha seed and maintains a certain profit margin by blending only a small portion of Jatropha PPO with subsidised paraffin to JATfuel at the major port in Pemba. They now sell the JATfuel in five districts to remote maize mills, for whom it makes economic sense as the price of JATfuel is just below the diesel pump price and ADM offers a delivery service. The current situation is visualised in Figure 25. None of the farmers we spoke to were happy with the relationship with ADM. They were all frustrated that due to the lack of a press outside ADM and the fact that ADM would not sell a single drop of oil to the farmers, they could no longer find access to Jatropha oil to make soap, which was the most interesting use of the oil with the highest profits.

Another important factor that was instrumental in the decline in Jatropha production was that development of a central grid in Bilibiza. It is no longer necessary to produce electricity from biofuels as the national grid got extended in 2013. Figure 26 details the timeline of the development of energy access in Bilibiza described above while Figure 27 shows the development of use and processing of Jatropha over the same timeline.

Figure 26: Development of Energy Access in Bilibiza

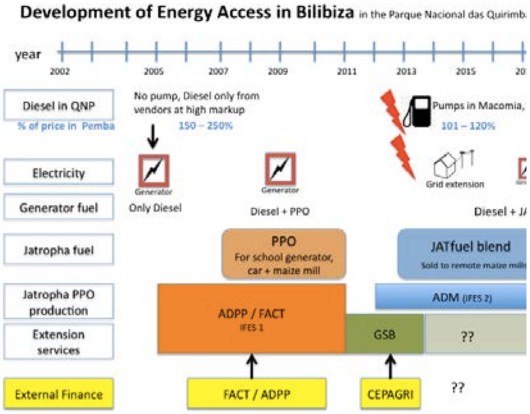
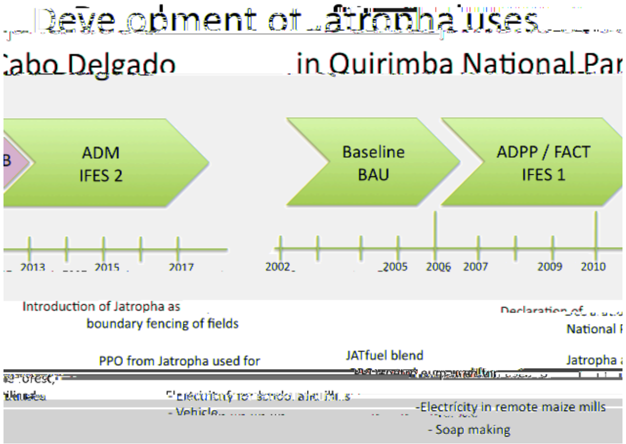


Figure27: Development of Jatropha uses and processing over time



We can see three major distinct phases which we can summarize as follows:

In the Business-As-Usual (BAU) scenario, the smallholder farmers produce food without Jatropha fences. In the IFES scenario, the Jatropha is cultivated as the boundary crop. Given the two distinct ways in which Jatropha plant has been planted, we define two types of IFES, according to the main oil processors, which has implications on the way farmers participated in the IFES:

- IFES 1: ADPP (Associação de Desenvolvimento de Povo para Povo) in the period from 2006-2010 operating the Bilibiza Biofuel Centre (BBC) where Jatropha oil was pressed and sold. The original idea for the introduction of Jatropha Curcas for cultivation by smallholders came as part of a project to ensure food security for farmers living within the Quirimbas National Park (declared in 2002). Jatropha was primarily introduced as a fence to protect smallholder fields from being raided by animals from the park.
- IFES 2: ADM, the Japanese-managed enterprise since 2012 operating the only functioning press for Jatropha oil in Bilibiza. They subsequently move all the oil to Pemba for further blending with petroleum and other substances to make the fuel sold under the brand name JATfuel. In the current phase of IFES 2 also the two minor fields of monocropped Jatropha are included that ADM set up to complement the slumping supply of Jatropha seeds from smallholder farmers.

MAIN STAKEHOLDERS

The others main actors for the development of IFES in the province are:

- Farmers clubs composed by small-scale agricultural producers and their family members who rely on rain fed agriculture to produce food for their own subsistence and income generation.
- FACT Foundation (Fuels from Agriculture in Communal Technology) is a Dutch non-profit organization and in 2006 initiated a project targeted at Jatropha production by the poor farmer population in Bilibiza-Mozambique, with a long-term goal to make a tangible contribution to the development of biofuels in developing countries, enabling local communities to benefit from this renewable energy source also when supplying the world market on the medium term. The objective of this pilot project was to build an infrastructure and capacity to enable the autonomous up-scaling of the activities after termination of the project. The project initiated the local production of Jatropha seeds and the development of local market of end-users of the oil. The creation of capacity among

the local small farmers and technicians was an important component of the project. The budget for this initiative was Euro 432 000.

- Danish association for development assistance from people to people (ADPP). It has been active in Mozambique since 1982 and operates 78 projects in the country within the sectors of education, primary health and HIV/AIDS prevention and care, agriculture, community development and economic development. ADPP recognizes that one of the vital elements in succeeding to create long-term development is the art of truly involving and engaging the beneficiaries in the process of development. So, within the Farmers' Clubs program ADPP reaches 12 000 farmers with skills programs in how to obtain better yields, enable low-cost irrigation, diversify crops, organize around marketing and transport, and how to create surplus income to alleviate poverty. Within the project period from 2006-2010 they provided
  - extension services for the Integration of Family Sector Agriculture in the Production, Processing and Commercialization Processes of Agroenergy Crops in intercropping with Food Crops.
  - They also established a Multifunctional Processing Unit for Jatropha and Food Crops, the Bilibiza Biofuels Centre.

  Therefore, the implementation of these initiatives ensured the promotion and dissemination of Jatropha cultivation in more than five districts of Cabo Delgado (Quissanga, Ancuabe, Macomia, Meluco and Palma), and the processing and utilization of Jatropha oil, involving 3 000 householders.

- The local NGO Grupo de Saneamento de Bilibiza was founded in 2007 by Mr Bachir Afonso as a community-based organization working in the areas of agriculture and food security, water, sanitation and renewable energy. Mr Bachir Afonso was the main actor involved in the development of the IFES 1 under ADPP/FACT from the concept development, proposal writing to implementation. He became the main driving force during IFES 1. After the ADPP/FACT project terminated in 2010, GSB received funding from CEPAGRI to continue the ADPP initiatives to promote the production and use of biofuels. GSB installed a multi-functional platform and kept distributing planting material to farmers clubs. Once that stopped and ADM came on board, Mr Afonso was then recruited by ADM to continue the mobilization of the farmers. He left ADM in 2013 and went on to work full-time with GSB. He is the one person involved in both IFES 1 and 2 who brings in the continuity and the institutional memory on all Jatropha related activities, knowledge and practices. GSB is today the organization with the best contacts to the farmers and implements small projects to contribute to the improvement of the living conditions of the local populations. Mr Afonso Bachir was the person who had arranged the appointments and visits during our field work in January 2017.

- The Government, through the Agriculture Promotion Centre (CEPAGRI) and Provincial Directorate of Agriculture and Food Security. The main role was to promote the involvement of the communities in the production and commercialization and use of biofuel in the country. Due to the challenges to find appropriate land for biofuels agriculture resources, in 2009 CEPAGRI received from the Nederland Government a fund to implement a 5 years programme with the main objective of strengthen and improve CEPAGRI capacity to promote sustainable investments on biofuels while simultaneously promote poverty reduction. Thus, that programme had, as main focus, the promotion of CEPAGRI and other actors in the agricultural sector activities, namely in: (i) formulating policies; (ii) analysing, monitor and evaluate investment projects; (iii) developing biofuels agricultural production processes with widely spread benefits, particularly, with the involvement of local communities; and (iv) establishing national standards for the sustainable production of biofuels considering the main socio-economic and environmental sustainability criteria. The program disbursed for this initiative about USD 66 000 during 2 years.

- Agro-Negócio para o Desenvolvimento de Moçambique, Limitada. (ADM), was registered as a Japanese-Mozambican enterprise in Mozambique in March 2012 and has established nurseries and cultivated Jatropha saplings through 100 farmers' clubs. ADM's business consists of production and sale of biofuel and bio-fertilizer, made from Jatropha seed cake, and produced by and for local entities. The business model is unique because farmers are involved not only as direct beneficiaries, but also as producers. Specifically, club members grow Jatropha saplings provided by ADM as fences for their farmlands and sell seeds to ADM for biofuel and bio-fertilizer production.
- Nippon Biodiesel Fuel Co., Ltd (NBF), a Japanese enterprise having 90 % ownership of ADM, has conducted research on Jatropha varieties and products in many countries including Mozambique. In Mozambique, NBF has been conducting collaborative research with the University of Tokyo (Japan) and Eduardo Mondlane University (Mozambique) on production efficiency and sustainability of Jatropha as an Official Development Assistance (ODA) project financed by the Japan International Cooperation Agency (JICA)/ JST (2010-2015).

METHODOLOGY

FAO developed an Analytical Framework (Bogdanski, 2014) as a guidance document to assess which factors make IFES truly sustainable and which factors need to be considered when replicating such a system - be it a pilot project, a business innovation or a research experiment. The underlying assumption is that good decision-making on bioenergy needs to be based on a critical mass of evidence to inform decision-makers, at local, but also at national and global scales. The Analytical Framework (AF) includes a set of criteria, indicators and measures to help screen IFES projects. The first part of the AF screens IFES projects based on their environmental, social and economic sustainability. The second part of the AF contains a set of leading questions and related features that will help to analyse which factors need to be built into new IFES cases to make them replicable and bring them to scale.

SUSTAINABILITY ASSESSMENT

We developed a list of indicators for each of the three pillars social, environmental and economic as suggested by the IFES Analytical Framework (AF). Indicators were either on the levels of impact (quantitative) or performance (process or qualitative). Within the framework of the case study no elaborate own measurements could be carried out for cost-efficiency and time reasons. Yields and other quantitative data was often taken from the reports of farmers. Sustainability was assessed by comparing the assessment of relevant indicators for a business-as usual scenario (BAU) and the IFES case.

REPLICABILITY ASSESSMENT

Replicability was assessed through a descriptive analyses of the extent to which the IFES meets four replicability criteria described in the IFES – AF:

1. presence of promoting or inhibiting project features of the IFES,
2. stakeholders that may promote upscale of the IFES,
3. alignment of the IFES with national food and energy objectives and
4. availability of capacity for up scaling.

DATA COLLECTION AND SAMPLING METHOD

Data and information were collected through various methods:

Basic information about the main project that initiated the promotion of Jatropha growing by smallholder farmers was obtained from initial project proposals as well as interim and final reports from the

DAPP/FACT foundation project between 2005 and 2011 (see list of reports in the Annex). Not much written information was available from the current intervention by ADM, the Japanese company producing JATfuel.

Information from reports was verified and complemented through interviews and site visits in Cabo Delgado during a joint visit of the consultants Hélio Neves and Christa Roth in January 2017. In the absence of reliable statistics or active Jatropha producer organisations, no quantitative approach was used so no standardised questionnaires or randomised visits were done. The key informants visited were chosen deliberately based on the information needed, their historic and current roles in the Jatropha growing and processing as well as their willingness to disclose information. Neither ADPP nor ADM had been helpful or able to arrange meetings with farmers, so visits were arranged by the current manager of GSB. He had been involved in the Jatropha project since the beginning. He first worked with ADPP/FACT and then with ADM and still maintains relations with a good network of farmers on the ground, so that we were able to speak to farmers that were involved in both IFES 1 and 2.

The information was collected through field visits and interviews from:

- Farmers: individual interviews and Focus Group Discussions with farmers clubs, current and former Jatropha growers, nursery operators and planting material multipliers, soap makers
- NGO staff: ADPP, GSB
- Government staff: District Directors of SDAE (Serviço Distrital de Actividades Economicas) of the Ministry of Agriculture in Macomia and Quissanga districts
- GSB partners,
- ADM employees, maize mill operators and customers of JATfuel in Mueda district. Information was complemented in Maputo.
- Oil processing units in Bilibza: the defunct BBC at ADPP and the current ADM unit
- Petromoc in Pemba and fuel pumps for information on pricing of diesel and kerosene.

DESCRIPTION OF IFES CASE

VALUE CHAIN COMPARISONS OF BAU AND IFES

Jatropha is integrated into the traditional farming systems as a live-fencing boundary around the fields of the food crops. Jatropha did not displace any of the existing food crops. It protects them and provides the opportunity for an additional cash crop if farmers sell the fruit to an oil mill. The seasonal calendar visualizes the integration into the farming system of the major food and cash crops. The synergy of the Jatropha planting with the food production is described in more detail further below.

In this context, the IFES case study is compared to a Business as usual (BAU) scenario where food production (maize and/or cassava) doesn't have Jatropha in their field. The IFES scenario is normally characterized by the production system based on maize or cassava cultivation in larger block fenced with Jatropha. For the timeline of the IFES cases consult Figure 27.

- BAU: traditional farming system on dispersed fields without Jatropha
- IFES 1: farmers' fields concentrated in larger blocks fenced with Jatropha and additional food and cash crops as promoted by ADPP/FACT from 2006-2010 with BBC (Bilibiza Biofuel Centre).
- IFES 2: farmers' fields concentrated in larger block fenced with Jatropha, JATfuel processing in Pemba.

Table28: Comparison of a BAU and two IFES cases

	BAU	IFES 1 (ADPP/FACT)	IFES 2 (ADM JATfuel)
1. Biomass production			
Average family farm land size	Less than 1 ha in dispersed field	1 ha in farm block	1 ha in farm block or dispersed
Land preparation for details see seasonal calendar per crop	Clearing starting in September before the rains		
Planting	Food crops with the first rain (around November-December, latest January) Jatropha first planting in November, then only pruning in September		
Water management	None	Planting holes with compost and ridges for water harvesting, Jatropha fencing and vetiver grass for erosion control	Not actively supported by ADM
Soil fertility management	None	Agroforestry, intercropping, crop rotation, mulching, integration of Jatropha press cake in bio fertilizer	Agroforestry farming practices no longer supported, no Jatropha press cake available
Weed management	Manual weeding		
Pest and disease management	none	Mixture for spraying with local ointment from Tobacco, soap, neem tree, garlic, chilli	Not actively supported by ADM

The following points are only for Jatropha processing as the processing, logistics and endues of food crop is not affected by the by Jatropha plantation in the IFES scenario.

Table 29: Comparison of a BAU and two IFES cases- post-harvest stages

	BAU	IFES 1 (ADPP/FACT)	IFES 2 (ADM JATfuel)
2. Production and initial storage of Jatropha seed			
Harvesting	n.a.	2-3 harvests, harvesting seeds by hand, de-husking in the field. Husk is left in the field for mulching.	
Collection & Transport from field to farmers club collection point	n.a.	By the farmer and his family in small buckets on the heads, Jatropha not stored at house but concentrated at farmers club level to be collected by the BBC upon advise of the farmers	

Table 29 (cont'd): Comparison of a BAU and two IFES cases- post-harvest stages

	BAU	IFES 1 (ADPP/FACT)	IFES 2 (ADM JATfuel)
2. Production and initial storage of Jatropha seed			
Transport from farmers club to processing centre	n.a.	Collection from the farmers club by BBC/ADM with their transport directly to the processing centre in Bilibiza	
Sale of Jatropha	n.a.	Sale of shelled Jatropha to BBC at 5 MZN/kg	Sale of shelled Jatropha to ADM at 3 MZN/kg
Storage at farm house of *food crops*	n.a.	Improved drying, maize stored on the cob in granary either hanging or with ventilation spaces (new method introduced by ADPP).	New methods no longer actively supported by ADM
3. Jatropha seed processing			
Processing	n.a.	Pressing and filtering of oil at BBC on ADPP compound	Pressing, filtering, refining (heating and decantation in several steps) of Jatropha oil at ADM compound in Bilibiza, then transport of oil to Pemba and blending with paraffin and other components to make final product JATfuel
4. Logistics of Jatropha oil			
Storage	n.a.	Storage of oil in 220 l drums	Storage of JAT fuel in 220 l drums
Transport	n.a.	No transport	By ADM pickup to depots in Macomia and Mueda, from there deliver to client
Packaging	n.a.	No packaging, farmers would bring their containers	No packaging, transfer to clients containers on site
Sale	n.a.	Sale of PPO (Pure Plant Oil) directly to farmers	Sale of JAT Fuel to over 100 maize mills in 5 districts, no sale of PPO to individual farmers
5. End-use of Jatropha oil			
End-use	n.a.	Energy use: Use as PPO in generator for electricity at ADPP school, diesel substitute in project vehicles, oil lamps lighting Other use: soap making is the most lucrative use of the oil for farmers for self-consumption and a guaranteed market.	All oil processed into JATfuel, no oil is made available by ADM for sale to the public. JATfuel currently only used in maize mills Farmers have no access to oil from the press as ADM does not allow sale of oil, so they can't make soap.

DESCRIPTION OF BASELINE FARMING SYSTEM – WITHOUT JATROPHA

The Business as usual (BAU) scenario describes the farming system before the introduction of Jatropha. The scenario is characterized by food crop production only. The main crops produced in the region are:

- Staples: The main staples are maize and cassava. They are typically planted annually in November with the first rains intercropped with food crops on the same field in alternate rows. Sweet potato and yam are also frequent, as well as plantains. Sorghum is sometimes grown as perennial crop. Rice is only grown in suitable rain fed areas, through direct seeding with the first rains.
- Legumes and oil crops: The major legumes are bean; which are added on the main field between in January or when the rains start to peak and harvested after two months. Some also plant several crops of beans as emergency crop in times of food shortage. Pigeon peas are grown sometimes intercropped or on the boundary, mostly as perennial crop. Groundnuts are also commonly intercropped on the main field. Sunflower is occasionally found, but not processed in the region. Edible oil has to be brought in from outside the park area and is mostly produced from cotton seed.
- Vegetables: All vegetables are collected or grown on rain fed fields. Nearly all farmers grow Moringa trees (Moringa Oleifera) around their homestead and the leaves are used for vegetables, in some areas this is the most commonly used green vegetable. Pumpkin is intercropped on the main field, the leaves are also eaten as vegetables. Tomato, onion, cucumber, lettuce, cabbages, and other vegetables are sometimes grown on small plots around the house. Indigenous leaves are collected as ingredients for relish.
- Fruits and nuts: Major fruits are commonly banana, papaya, mango, coconut and cashew. Some farmers grow lemons and oranges. These are complemented with wild fruits from the forest.

DESCRIPTION OF IFES VALUE CHAINS

Both IFES cases are characterised **by the addition of Jatropha as a new crop**, either newly introduced as boundary planting around food fields or as intensively grown plant for energy purposes. ADPP/FACT project introduced Jatropha as a boundary crop in between 2006-2010, in addition to other crops **to improve income and food security of farmers in the newly declared national park**.

The following value chains were concerned:

- Sesame: can be either intercropped within the maize/cassava or grown on a small piece of land. This depends on local conditions and farmers preferences.
- Irrigated vegetables: are grown on small plots like 20x40 m in areas that can be irrigated from a stream, dam or shallow well with a rope pump. Watering frequency depends on the location. It is the major money spinner for people who started it.
- Jatropha introduced as a fencing crop to protect the food crops on the main field from wild animals. Jatropha was known in the area as part of the natural forests, but it was not cultivated.

Live fencing is a known concept in the area, but the trees that are normally used around the homesteads (Moringa, Cassia, Papaya etc.) were not deemed suitable to create a dense enough bush to resist an elephant invasion. Various solutions were tried before the Jatropha, e.g. a fencing belt from chill, but the farmers refused that solution because they often got irritated red eyes when they accidently touched their face after handling the plant. Sisal hedges proved to have a good effect as a fence, but again the farmers complained that they had too many thorns that hurt them when they started chasing animals, e.g. monkeys out of the field and they would get injured when they got too close to the hedge. Thus this idea also was also abandoned. Jatropha emerged as the best solution for boundary live fencing as it is neither eaten by animals nor does it have thorns. Three years after planting the seedling, it grew into a large enough bush that can repel even elephants, especially when planted in two rows with offset stands.

Seed material was available from wild species of Jatropha in the community of Shinavane in Macomia district. Seeds were collected and multiplied in nurseries at the ADPP office in Bilibiza. Jatropha was found cost-effective as it is very resistant and perennial and the seed material can be locally multiplied. Together with the extension services provided by ADPP to encourage farmers to aggregate their fields in one large block this worked for about five years, until the farmers moved on from their plots, when the soil fertility went down. Yet, the Jatropha remained in the field and when it started fruiting, farmers asked what to do with the fruits. That is when Mr Afonso working with ADPP started to investigate uses of the fruit and the oil and found the potential uses for renewable energy but also for soap making. With the assistance of FACT, funds were raised to establish the production facilities for PPO at the Bilibiza Biofuels Centre. It had two oil presses and filtering machines. Under the management of Mr Afonso and his team, it produced enough PPO to run the generator to provide electricity to the school and the teacher-training centre as well as the project vehicle. Oil was also sold to the farmers for soap making.

In the IFES 1 the cultivation of Jatropha was started by ADPP/FACT according to the following calendar:

- September-November: Jatropha multiplication of seed in the nursery at BBC or at some farmers clubs who had pumps, little irrigation needed for rooting, planting in normal soil and polyethylene tubes.
- November-January: distribution of ca. 250 seedlings (20-30 cm high) per farmer in rainy season, planting by farmers into the soil at final location, no further attention, and rain fed, weeding was done at the same time as the crop field. No extra work.
- February-March: weeding.
- April-August: no attention, if already fruiting then collection of seeds.
- In the following September-October: pruning by the farmer to develop branches. Fruiting/ harvesting depending on soil fertility: March-April, June-July, and November-December.

In the IFES 2 under ADM, a new technique was introduced in that the first pruning happened already just before transplanting the seedlings in November, to encourage branch development and create stronger and more resilient plants.

In the context of integration on Jatropha in existing farming system, local farmers have received skills and knowledge on growing *Jatropha curcas* alongside their own crops on farm and at the Bilibiza and other localities in Cabo-Delgado, while also receiving capacity building to improve their general farming techniques. Leaders from the farmers clubs were also taught how to make soap.

According to FACT end report (2011), Jatropha was grown as hedges not plantations, but approximately 600 ha equivalent of land has been planted with over 600 000 Jatropha Curcas trees over the four year period, which is more than the original target deliverable which was a maximum of 500 ha.

In 2013, the number of farmers involved on Jatropha plantation increased from 1 800 to 6 000 which consequently tripled the area of planted Jatropha. The farmers indicated that they found the additional support for their food security activities (training, rope pumps, watering cans, extension support) offered by the project and it was very useful and they had enjoyed being a part of this initiative.

JATROPHA VALUE CHAIN IN THE FARMING SYSTEMS

Production and processing steps of Jatropha

According to Heller (1996), Jatropha grows in tropical and sub-tropical regions, with cultivation limits at 30ºN and 35ºS. It grows in lower altitudes up to 500 meters above sea level. Jatropha is not sensitive to day length. Flowering is independent of latitude and the plant may flower at any time of the year. It is a succulent shrub that sheds its leaves during the dry season, with deep roots that make it well suited to semi-arid conditions.

While Jatropha can survive with as little as 250 to 300 mm of annual rainfall, at least 600 mm are needed to flower and set fruit. The optimum rainfall for seed production is considered between 1 000 and 1 500 mm per annum and the optimum temperatures are between 20˚C and 28˚C. Very high temperatures can depress yields (FACT, 2007). The Jatropha genus includes over 100 species and is originating in the Caribbean and in Central America. The genus has also become neutralized to many tropical and subtropical areas, including India and North America, being spread to Africa and Asia through its trade as a valuable hedge plant (Buikema at all, 2009). Constraints in Jatropha cultivation, Jatropha curcas is a potential source of bio-diesel, however, it needs to be explored. The initiatives made to explore the possibility and potential of Jatropha have not yet reach to the final conclusion.

All parts of the plant exude sticky, bitterly pungent and astringent latex, which can be used as making ink. The bark contains tannin, wax, resin, saponnins etc. that makes it useful for industrial purposes. The kernel, which forms 60-68 percent of the weight of seed contains oil equivalent to about 46-58 percent of the kernel weight and 30-40 percent of seed weight. The oil is used for illumination without smoke, substitute diesel, kerosene, lubricants, soaps and candle manufacturing. It can be used as hair oil and has application to livestock against sores. As an excellent source of organic manure, it contains 3.2 percent nitrogen, 1.4 percent phosphorus and 1.2 percent potassium (Punia, 2010).

Jatropha was initially introduced in Cabo-Delgado, Northern of Mozambique through a project implemented by ADPP (Associação de Desenvolvimento do Povo para Povo). The project encouraged small-scale Jatropha cultivation for subsistence farmers, and had the following main features:

- Farmers were motivated to plant Jatropha in hedges around their fields. Low cost inputs and training in conservation farming was provided. The idea was to diversification of crops and increased yields of food crop
- Farmers were united in farmers clubs of 50 members each, engaging both men and women.

Normally, Jatropha is planted at densities ranging from 1 100 to 2 500 plants per ha. Yield per tree is likely to increase with wider spacing but with a decline in yield per ha (Achten, 2008), but in Cabo-Delgado was not planted in ha, but in rows about 500 plants per farmer, all intercropped with food crops, equivalent to 0.5 ha.

Propagation practices

Jatropha can grow easily from seeds. However, commercially it can be propagated by three different ways such as by seeds, nursery and stem cutting.

Direct sowing

Fully matured seeds are selected for sowing and are pre-soaked in water for 24 hrs. Another way is to soak seeds is cow-dung slurry for 12 hrs before sowing. Soaked seeds are generally sown in poly bags of 10 x20 cm size filled with soil, sand and FYM (Farm yard manure) in the ratio of 1:2:1 respectively. The seed generally germinates after 4-5 days and continues up to 15 days. If the seedlings are to be retained for 5-6 months before transplantation, bigger poly bags (15x25 cm) should be taken.

Sowing in nursery beds

Raised beds (10 cm high) are prepared by digging and mixing soil with sand and FYM in 1:1:1 ratio. Each bed is prepared having 1 m x 5 m dimensions. Shallow furrows of 2 cm depth are made by finger or using a stick. Soaked seeds are placed in furrows at an interval of 5 cm. and covered with a thin layer of soil. Care is taken to avoid deep sowing. Light Irrigations are given after seed germination and bare rooted seedlings are transplanted after 3-4 months in the field during the rainy season.

Through stem cutting

Jatropha responds well for vegetative propagation. Propagation through branch cuttings is not new and farmers know these technique. In fact, 80 % Jatropha in Cabo-Delgado was planted via this method, but it is easy to have termite attacks. So, they should plant in rainy season and on good soils to avoid it.

Harvesting

Seeds are ready for harvesting around 90 days after flowering when the fruits have changed from green to yellow-brown. In wetter climates, fruiting continues throughout the year, while the harvest may be confined to two months in semi-arid regions. Even then, the fruits do not ripen together, requiring weekly picking and making the harvest labour intensive and difficult to mechanize. The yellow and brown fruits are harvested by beating the branches with sticks to knock them to the ground, or by hand picking.

In the region, it is estimated that around 1-3 kg of seeds can be harvested after de-husking. During the field trip it was also learned that farmers were able to harvest the Jatropha at the same time as working other crops, and that they did the de-husking around the fire at night.

Oil extraction

Oil can be extracted from seed through hand presses, although they are not efficient and result in sub-optimal oil output. Other more efficient presses require a mechanical engine driven by a fuel. In Cabo-Delgado (Bilibiza), they currently process the seed at ADM plant using engine-driven screw presses, which can extract about 40 percent of the available oil, producing 1 litre of Jatropha oil from every 4-5 kg of dried seed. To enable longer storing period, solids fraction in the oil are removed, by either sedimentation, centrifuge or filtration. Sedimentation is the normal method for small-scale oil production. Table 30 below shows the systematization of the seasonal calendar for different crops.

Table 30: Jatropha fitting in the seasonal calendar of major food crops

		Jatropha	Maize	Cassava	Beans	Sesame	Vegetables
Motivation to grow		Protection of field	1st Staple	2nd Staple	1st legume	Income	
Use		(Cash crop)	Self-consumption, surplus for sale			Cash crop & consumption	
Month	**Rain**	Fence main field	Intercropped on main field (rainfed)				Irrigated Plot
Nov	**(x)**	Year 1 Transplanting Year 3: harvest	Planting seed	Planting cuttings			
Dec	**Xxx**						
Jan	**Xxx**		Weeding & guarding		Planting seed		
Feb	**Xxx**		Guarding			Planting seed	

Table30 (cont'd): Jatropha fitting in the seasonal calendar of major food crops

		Jatropha	Maize	Cassava	Beans	Sesame	Vegetables
Mar	**Xx**	1st harvest	Weeding & guarding		harvest		
Apr	**X**		Harvest	Guarding			Planting
May	**X**		Drying	Guarding			Watering up to 1-2x day weeding, harvesting
Jun		2nd harvest	Consumption (sales)	Guarding			
Jul				harvest		harvest	
Aug							
Sep		1st year Nursery: planting, watering Field: pruning	Field preparation: clearing, planting holes				
Oct							
People in 2010		3 000					
Ha		200					
People in 2013		6 000					
Ha		600					

During the interview, farmers expressed that Jatropha fits very well into the prevailing farming system and was generally considered beneficial for their socio-economic development. Benefits mentioned include:

- It does not require extra land, as it is planted on the boundary of the main field. On other contrary, the Jatropha fencing helps them to reduce the pressure from elephants, monkeys and wild hogs.
- The dense Jatropha also reduces erosion through surface runoff or wind, thus maintaining soil fertility.
- It does not require extra labour other than for the initial planting and the yearly pruning. Weeding is done at the same time as the main field.
- It does not need additional watering or fertilizing once established in the field.
- Harvesting of Jatropha can be done 2-3 times per year in months not coinciding with food harvest.
- No extra time in the field needed for the harvest, as farmers are anyhow in the field to guard the crop against animals. So they can harvest and shell the Jatropha while watching the food crops and securing their food supply.
- At no time are there labour or land conflicts between food crops and Jatropha when grown as boundary fencing.

SUSTAINABILITY ASSESSMENT

The sustainability table hereafter was elaborated based on the assumptions mentioned above. It describes the situation in early 2013 at the peak of the Jatropha production at a time when the original project by ADPP/FACT already had ended and ADM had taken over buying seed from the farmers to blend Jatropha oil to produce JetFuel as a commercial product.

Table 31: Description of BAU and two IFES cases

BAU	IFES 1	IFES 2
No Jatropha grown by farmer, no other extension services apart from government, for energy any generator or mill is fuelled by diesel at usual prices in the park	Farmers organized in clubs to grow Jatropha, and get extensions services and inputs (pumps, seeds for maize, vegetables, sesame etc.) to improve their overall farming and food security levels. As regards energy, the project vehicle and any generator at the school or mill is fuelled by 100 % Jatropha oil from the BBC (diesel only used for starting).	Farmers grow Jatropha, ADM buys shelled Jatropha at 3 MZN/kg. Farmers do not receive any extension services or other inputs. As regards energy, only maize mills are fuelled by JATfuel from ADM. The composition of the elaborated JATfuel is assumed to contain only 1 % Jatropha oil, the rest is fossil petroleum and undisclosed additives.

The following section compares these three scenarios in terms of their social, environmental and economic performance. The fields of the table are merged if the information is valid for more than one case. Where possible, quantitative indicators where selected showing a numeric result. Chosen measures are shown in brackets after each indicator. For some criteria, qualitative indicators were found to be more relevant, showing results that are more accurate by describing the status of a criterion rather than expressing it in numerical terms.

SOCIAL PILLAR

Food security

Table 32: Food security

Indicator	BAU without Jatropha	IFES 1: ADPP/FACT as per Dec 2010	IFES 2: ADM as per Jan 2017
Physical displacement, change in access to resources	N/A	Voluntary farmer's fields were consolidated into larger blocks, which were seen as an advantage. Nobody was forced to move.	No change to IFES 1

Table 32 (cont'd): Food security

Indicator	BAU without Jatropha	IFES 1: ADPP/FACT as per Dec 2010	IFES 2: ADM as per Jan 2017
Average farm size	0.4-1 ha. Fields are dispersed and exposed in the bush. Farmers are farming alone, no competition between farmers.	Farmers' fields were consolidated into larger blocks and fenced with Jatropha. Landholding size increased to average 1 ha, as a larger area was fenced with Jatropha. Land availability is not a constraint.	Field size not known, some farmers said after shifting from the old plots that their new fields are now smaller and no longer fenced. Many lines of Jatropha have been neglected, cut or destroyed by fire. Farmers do not maintain the Jatropha rows as there is no interesting market for them.
Yield of maize (t/ha)	In good years 0.7/ha, only traditional planting methods, no extension services, no good agricultural practices. No intercropping. Yields decreasing because animals raid the fields.	Maize yield gone up to 1.5-2 t/ha, due to extension services by the project, better seeds, better farming practices: row planting, planting holes with compost and manure, agroforestry for soil improvement, intercropping with different types of beans. Competition between farmers as they were no longer farming alone. Incentives by the project for best farmer stirred ambition. Fencing of the plots with Jatropha protected crops from animals. Men were also guarding the grouped fields to repel wild animals.	No figures known, but estimated to be similar or a bit less. Still farming in blocks, but no fencing, so no less physical protection from animals, but the pressure from elephants has decreased as a result of poaching
Income from maize: price in MZN/kg	3 MZN/kg (USD), but no really surplus to sell. So sales negatively impact farmers' food security.	5 MZN/kg (price remained until 2015), as yields increased there was surplus 5-10 bags to sell.	35 MZN/kg due to better marketing power through the farmers clubs and crisis through shortage on the market
Income from Cassava	5-10 bags Cassava of 30 kg, at 2 MZN/kg	10 bags Cassava of 30 kg, at 4 MZN/kg more cassava production	10 bags Cassava of 30 kg, at 15 MZN/kg more cassava production
Income from Sesame	Not grown, 0	New product as a cash crop, good income 25 MZN/kg, 2 bags of 50 kg	50 MZN/kg, 2-3 bags of 50 kg

Table 32 (cont'd): Food security

Indicator	BAU without Jatropha	IFES 1: ADPP/FACT as per Dec 2010	IFES 2: ADM as per Jan 2017
Income from Vegetables	Not grown, 0	Different vegetables grown with irrigation through rope pump, dedicated farmers make 600 USD per season. Biggest income opportunity for farmers which stopped people from selling maize and increase their own maize and food consumption. Current prices in MZN: per kg: Onions 25, tomato 25, per head: lettuce 5, cabbage 25	Plots have remained 20x40 m, prices have gone up as there is more demand. Onions 50 MZN/kg , tomato 50 MZN/kg , lettuce 10 MZN/per head, cabbage 50 per head,
Income from Jatropha	Not applicable	10 t at 5 MZN/kg sold to BBC. Most profit could be made with soap making, when they took seeds to process for 5 MZN/Kg to BBC and took back the oil for soap making: 1 kg of soap was selling at 80 MZN, (5 MZN oil+ 30 MZN caustic soda= 45 MZN profit). Some farmers could produce 20 kg of soap in one day to sell on the local market or for own consumption (avoided expenditure).	Less than 100 farmers supply ADM at 3 MZN/kg. The lucrative soap making is no longer possible, as no oil is available for farmers to buy as there is no press outside ADM and they won't sell oil to the farmers but use all for JATfuel blending. Seed price paid by ADM: <100 kg= 3-5MZN/Kg 100 -200Kg= 6 MZN/Kg >200Kg=7 ZN/Kg

Jatropha does not directly compete with food production, and as a source of additional income, it is a development opportunity for local farmers. The farmers were supported on getting additional support through better access to inputs and agricultural advice on food crops; so they achieved higher yields and better livelihoods. Jatropha has been a means to increase resilience and farming practices to improve livelihoods, recently especially through the sale of soap. Through the Jatropha program, farmers received government extension services. The Provincial Agriculture Directorate had 148 extension workers in Cabo-Delgado, serving 350 000 farmers in the province, out of which only 10 were in the Quirimbas National Park; moreover the local extension agents had no mobility so they could not reach many farmers. Low cost inputs and training in conservation farming was provided in addition to Jatropha seeds. The result resulted in an increased food crop yields plus Jatropha seeds. Maize yields have increased from 700 kg in BAU area to 1.5-2 tonnes/ha in both IFES systems.

The farmers we interviewed said that when they grow maize, the main purpose is for eating. They only sell the surplus; so, income generation is not a key purpose for growing of maize. On the other hand, sesame is grown for sale, because the price was good at about 50 MZN/Kg. Currently all farmers are involved in growing vegetables, especially in the dry season, where the price is high. It therefore appears that the farmers discriminate effort versus cash crops, and are fully aware that the effort spent on growing vegetables is better rewarded; Jatropha was not seen, at current prices, as being a high value crop. However, they did indicate that if they can get greater value, such as through making soap this would completely alter their attitude to Jatropha.

Energy access

Energy access is limited in the region. Electric grid is limited and is generally for only allocated to administrative posts. Neither LPG nor electricity is used for cooking. People rely on solid biomass fuels such as firewood for cooking. Three meals are normal and cooking with firewood is carried out on three stone stoves in not well ventilated kitchens. Jatropha has not influenced this. On the other hand, up to the recent arrival of a petrol pump, Jatropha was used for local productive uses. To date, the interest for that use has dwindled and replaced by a strong interest in making Jatropha soap

Household energy situation: In the national park area only a few major urban centres and are connected to the national electricity grid.

Cooking energy system: Due to the shifting cultivation practices there is always plenty of firewood available for cooking. Thus, all people cook with firewood, mostly on 3-stone stoves. Cooking is mostly done inside the houses in badly ventilated areas. Houses are square, with wooden poles in the 4 corners and the walls from bamboo, tied horizontally with strings, sealed with mud. The roofs have a structure from bamboo with 4 waters and are thatched with grass. There are few windows and a door. Mostly there is restricted ventilation in the cooking area. Burnt bricks and iron sheet roofs are very rare and not found in the villages, only alongside the tarmac road or in government buildings.

There are no chimneys and smoke is filtering through the thatched roofs. People store firewood outside the houses to have a stock of dry firewood for the rainy season. Firewood is easy to find, as the forests are just around the houses. Women walk longer distances to fetch firewood from certain species that they prefer as they are denser, burn longer and emit less smoke. Some people make charcoal for sale, yet nobody uses charcoal for cooking. A bag of charcoal costs 250 MZN at the market in Macomia, in the villages only 100 MZN. The same bag in Maputo costed 1 000-1500 MZN during the study period.

Energy saving stoves is not a priority here due to abundance of free fuelwood. The only arguments could be to save labour and make the cooking more convenient with less smoke. Therefore, the introduction of Jatropha into the local farming systems did not bring any change in the cooking energy system, since the Jatropha oil is not used for energetic purposes at household level, neither for cooking nor for lighting.

Adaptive capacity to climate change and variability: Based on the information gathered from the interviews, local climate variability has visibly increased since 2012. This justifies some attention to the resilience of local farmers to these changes. In that line, the introduction of Jatropha can be seen as a way to increase the adaptation/resilience capacity of farmers through an additional source of income through the sale of seeds for biodiesel and/or soap making by local women.

Employment

Table 33: Employment

Indicator	BAU	IFES 1	IFES 2
Employment created for the Jatropha planting (yes/no)	No, Normally each family has 5 members in the field crop activities, no Jatropha grown	Yes, four people were employed directly in the oil production workshop and 15 in the Jatropha nurseries and extension. Over 3 000 farmers were self-employed, no formal employment created.	Yes. ADM have employed a total of 20 people for their entire value chain of JATfuel production and marketing

In the case of IFES, the harvesting and de-husking are time consuming, but assuming that the crop gives good value, this issue can be overcome. Technical challenges mean that the oil needs quality control provisions if used in diesel engines, but not for other purposes such as soap making. As a local economic driver, Jatropha holds great potential.

However, farmers complained about the labour intensity of de-husking in particular and to a lesser extent the harvesting, while admitting they did manage to do this without compromising their other tasks. Generally speaking, farmers felt that if the oil could be used by them for some purposes, to alleviate their own household budget expenses, for instance, it would become a valuable proposition. Based on our observations, when intended to operate along the entire value chain (production-processing-marketing), with an average monthly volume of 900 litres (producing about 30 L/day), it would require about 20 workers, as is the case of ADM and ADPP.

In the field crop each family is composed by 5 members and most indicated that they were able to harvest the Jatropha at the same time as working other crops, and that they did the de-husking around the fire at night, although de-husking was hard; thus Jatropha was not too much of an extra burden on their subsistence activities.

Farmers also expressed a lot of interest in using the oil to make soap as this is an expensive household item and the surplus could generate more income than selling the unprocessed Jatropha. It appears that soap making would provide the greatest economic opportunity to the farmers at present as a value added processing activity. It also appears that this activity is not particularly difficult and the market for the soap is local thus not requiring logistical inputs. However, challenges arise when the oil needs to be expelled as the most efficient way is by using a powered expeller.

ENVIRONMENTAL PILLAR

Soil health

Table 34: Soil health

Indicator	BAU	IFES 1 and 2
Farmer perception of crop yields	N/A 0	Not quantified, but farmers observed increased yields due to better farming practices: row planting, planting holes with compost and manure, agroforestry for soil improvement, intercropping with different types of beans.

In terms of soil management for Jatropha production, there is small difference between the BAU and the IFES scenarios. The field assessment showed that in farmers' plots, where the fence exists, the quality of soil is better. The farmers observed increased yields due better farming practices: row planting, planting holes with compost and manure, agroforestry for soil improvement, intercropping with different types of beans. The two main weather factors that influence soil quality are are rainfall (water erosion) and wind (wind erosion). In In Mozambique, water is what cause the greatest impact, damaging the soil, when it is not properly protected. Therefore, crops rotation and other good soil and water conservation practices are a good way to maintain soil health, and this is what happens in the plots with Jatropha fences. Moreover, Jatropha press cake was used as ingredient to produce a natural fertiliser or compost. It could play a more prominent role if more press cake would be available to farmers. The current production by ADM is insignificant and sales to farmers are negligible. ADM uses the fertilizer mostly on their own plots.

Pollution

River water channels are not used in the Jatropha fences or Jatropha processing at the small factory, thus there are no effluents from the field premises. We observed no impact on water, soil or air quality in relation to the farming activities or the Jatropha processing. Farmers usually do not use conventional fertilizers or pesticides in the area; hence the water quality of nearby waterways is not affected.

As verified in the study area, fertilizers and pesticides are produced locally using organic material consisting of Jatropha seed residues, sawdust and chicken droppings. Pesticides are produced by blending soap with tobacco leaves and used on the farm fields whenever necessary.

The Jatropha seed has a high oil content, which is extracted by pressing. The processing of the oil produces biodiesel that has great importance regarding the use of renewable energy sources, besides presenting a lower pollution index than the fossil fuels (Pereira, 2009). According to this author, the oil that is extracted from the Jatropha seed is composed mainly of the following fatty acids: palmitic, stearic, oleic and linoleic.

According to the mills owns in same districts in Cabo-Delgado, the use of JatFuel produced based on the mixture of Jatropha oil and petroleum, in the processing of maize, affirm that they do not have health problems in respiratory terms. Like this, as for air pollution, there are no observed changes in air quality since the use of the JatFuel in the mills. The system seems to work rather smokeless, as no traces of soot were found that would indicate an incomplete combustion.

GHG emissions

Table 35: GHG emissions

Indicator	BAU	IFES 1	IFES 2
GHG emission from Jatropha planting (t CO_2eq)	n.a.	FACT calculated a saving of CO_2 reduction of 10 t per ha, considering the conversion of 1 000 plants per ha.	No concrete figures could be obtained from ADM, but it is estimated that there is no change in GHG: The percentage of Jatropha oil in the JAT fuel is estimated to be around 1 %, the rest is fossil petroleum. No data could be obtained on the extra input of fossil fuel in the processing of JATfuel or for transport of the oil from the field to Pemba for processing and the JATFuel back to the maize mills where used as diesel substitute (sometimes over 300 km from Pemba).

According to FACT end report (2011), a study of the carbon and energy balance was undertaken in collaboration with University of Copenhagen. It showed that Jatropha production in the area has a positive carbon and energy balance if undertaken on fallow land or in maize fields but not if primary forest is cleared in order to plant Jatropha. They calculated a saving of CO_2 reduction of 10 t per ha, take in account the conversion of 1 000 plants per ha.

Jatropha cultivation is pointed as a multipurpose option whether is used for biodiesel production reducing greenhouse gases (GHG) emissions when replaces the need for fossil fuels, and also for storing C in the soil. A study done by Freitas (2015), said that *Jatropha* cultivation preserved soil N and C stocks and contents, regardless of previous land use management (pasture, maize or native vegetation), proving to increase with cultivation time. Additionally, the isotopic analysis of C and N showed changes in SOM after two years with *Jatropha* cultivation. After 7 years of cultivation, the contribution of carbon derived from *Jatropha* residues to the total amount of the element stored within the 0-30 cm layer of soil reached 11.5 %. The *Jatropha* cultivation increased the C contents in SOM, the CMI and microbial C and N contents along with cultivation time, which highlights the potential of *Jatropha* cultivation to improve SOM quality in the long term. H_{FIL} of the areas with *Jatropha* cultivation showed lower values compared to the native vegetation. This indicates the increments of C contents for the areas planted with *Jatropha* are associated to the increase of the less stable portion of SOM and that the selective preservation is not the main mechanism responsible for C accumulation in soils under *Jatropha* cultivation. The N_2O emission factors ranged from 0.21 to 0.46 % for the doses up to 150 kg ha^{-1}. Considering the average N fertilization rates applied annually in commercial *Jatropha* cultivation (75 kg ha^{-1} yr^{-1}), the crop is responsible for the emission of 0.0362 Mg ha^{-1} yr^{-1} of C-eq. Moreover, the annual balance between soil

C storage and GHG emission indicated that *Jatropha* cultivation for 7 years is able to contribute to the carbon sequestration accounting for 0.6 Mg ha- 1 yr^{-1} of C-eq stored in the soil. This study is pioneer in Brazil and the results generated in this research are basis for life cycle analysis of the *Jatropha* as a feedstock for biodiesel production in Brazil.

Agro-biodiversity

Table 36: Agro-biodiversity

Indicator	BAU	IFES 1 and 2
Number of crop species on the same field	1-2: intercropped: maize, cassava.	Intercropping more than 2 crops in the same field: maize, cassava, beans, peanuts, sesame, vegetables, etc.

In the IFES the agro-biodiversity increased as there are more crop species found on the same plot.

ECONOMIC PILLAR

Profitability

Table 37: Profitability

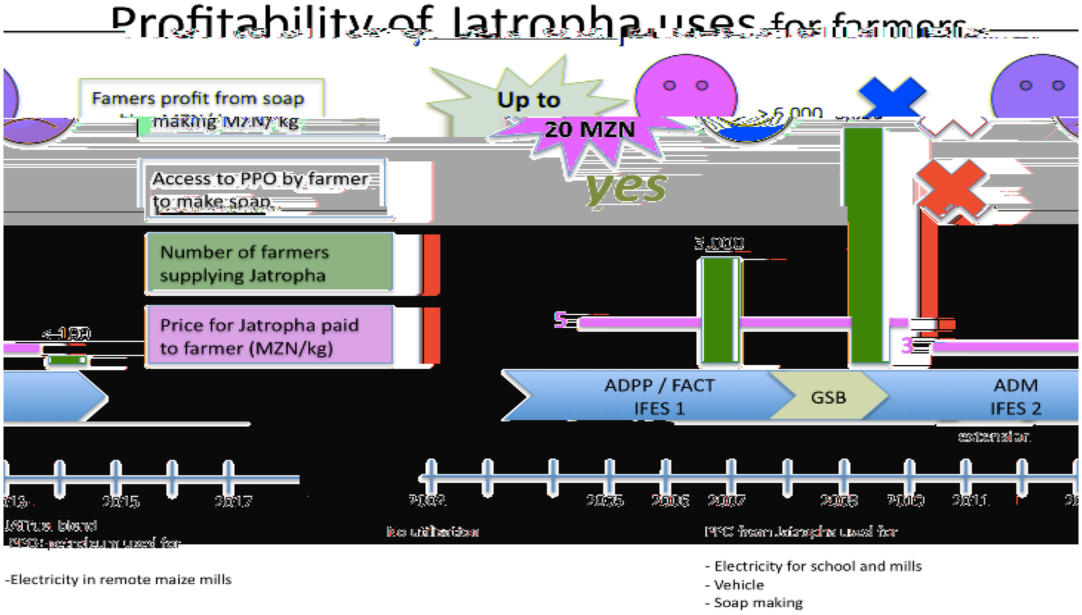
Indicator	BAU	IFES 1	IFES 2
Output – input costs/ha/year	n.a.	Yield per ha not applicable as Jatropha only grown in fencing. No inputs applied on Jatropha other than labour for planting. Once the plant is growing, there is no further maintenance or cost involved. The main input cost for the farmers to obtain Jatropha seed is their labour for harvesting, which is not measurable as costs/ha/year but in labour applied to harvest 1 kg of Jatropha seed.	
New indicator: profitability for farmer per kg of seed	Not applicable	ADPP paid farmers 5 MZN per kg of seed. Soap making most profitable: Net profit per kg of seed at least 7 MZN and therefore higher than if sold for PP for energy at 5 MZN. Result: Farmers considered the price offered as a fair deal so they sold a total of 10 t sold to BBC at 5 MZN/kg over the project period.	ADM pays farmers 3 MZN per kg of seed. Result: farmers consider this a low price that is not worth their effort to invest labour to harvest Jatropha seed. Thus the number of farmers interested to sell seed to ADM has decreased to under 100. The total seed estimated to be processed by ADM from 2013 to date is about 5 t, out of which only 3 t were received from farmers and 2 t from ADM-owned fields.

Table 37 (cont'd): Profitability

Indicator	BAU	IFES 1	IFES 2
Profitability for oil processor		The BBC was not driven by commercial interest, but it provided electricity to the TTC which otherwise would not have existed. Thus a direct costing of profits was not made for the generator. For the ADPP vehicle it was more profitable to operate on the PPO than on diesel purchased from the vendors.	Profits were not disclosed by ADM, but we make the following assumptions: JATfuel production= 100 000 L/annum JATfuel production estimate: Blending= 1 % Jatropha oil + 99 % paraffin + other non-disclosed chemical additives Cost of paraffin 1 L= 29.73 MZN JATfuel price= 45 MZN/L in the region (staggered pricing from 44-48 MZN/l to stay 1 MZN below nearest pump price and respecting bulk sales) Transport has to be factored in to deliver the JATfuel to remote mills. So there seems to be a very slim profit margins and not a big incentive to scale up the production e.g. by incentivising seed delivery with better prices to farmers.

The profitability for the farmer is the key criteria for sustainability of Jatropha processing and directly linked to the price paid per kg of seed to the farmer. The development is visualised in Figure 28:

Figure 28: Profitability of Jatropha uses for farmers



Farmers make most money if they can make soap from PPO, provided they have access to oil. The price per kg paid to the farmers by the oil processors went from 5 MZN in 2009 (at the time ca. 0.20 USD) to

3 MZN, which as per 2017 only equals 0.04 USD. This is equivalent is 20 percent of the price farmers were paid in 2009 or 2010. This explains the loss of interest by farmers to harvest Jatropha, therefore the dwindling supply of seed to the oil processors. If farmers don't see Jatropha as a fair income opportunity they dedicate their time to other more profitable activities or simply choose to rest and not do anything productive. Farmers referred to Jatropha as the 'leisure crop', meaning that they only harvest the seeds if they have nothing better to do. It should be noted that, under most circumstances, Jatropha is not a high income generating crop. In order for the oil to be competitive with fossil fuels, oil producers cannot pay very high prices for the Jatropha seeds.

Technical challenges mean that the quality control provisions regarding oil needs concern diesel engines, but not other purposes such as soap making. As a local economic driver, Jatropha holds great potential but is highly dependent on the price of seeds. All farmers indicated that they continue keeping Jatropha plantation on their own initiative. However, most of them also stated that they were unhappy with the price of 3 MZN/Kg applied by ADM and they expressly wanted to be able to use the oil themselves to make soap and sell it, as this generates more income.

Farmers want to have access to the oil, which at the moment is not feasible as the only functional press is at ADM and they do not allow the sale of oil to other customers than theirs. The economics and practicalities of using Jatropha oil for soap making:

- 5 Kg of seeds produces 1 litre of oil (cost in market of seeds 3-5MZN/Kg)
- BBC charged a processing fee of 3 MZN/kg of seed delivered by the farmer, so the cost to the farmer was 15 MZN per liter of oil
- You have to add water, caustic soda and another aromatic oil like lemon grass or coconut to make the oil smell nice, the price of these items is unknown but they are not expensive. The cost for caustic soda was 30 MZN
- 1 litre of oil is enough to produce 1 big bar of 1 kg of soap which or 15 smaller soap bars
- Total cost to make to make 1 kg of soap = 45 MZN
- A big bar of soap fetched approximately 80 MZN, meaning a profit of 35 MZN per kg of soap or 7 MZN per kg of seed invested. This was still 2 MZN more than if the farmer would have sold it to the BBC directly.

The market for soap is local and everyone buys soap. Therefore transport is not an issue as the market can be customers in the village. The FACT end-of-project report in 2011 noted that a family spent about 20 MZN a week on soap, so this is a large market. In addition, the soap from Jatropha has medicinal purposes. Some people knew that the soap of the Jatropha can help to heal wounds or have a positive impact on mycoses, eczemas, scabies and other skin diseases.

Prices of soap have gone up with the devaluation of the currency since 2011, while the buying price of 3 MZN by ADM has remained. These days it is estimated that the profit from soap making could be as high as 17 MZN/kg more when comparing to the option to sell to ADM at 3 MZN. This is a hypothetical calculation as ADM does not allow farmers to access PPO and there is no alternative pressing facility in operation.

Pressing the oil from the seeds is an issue, hand presses are not efficient at getting the maximum oil out, and other presses require a mechanical engine driven by a fuel. If the farmers make soap this will be far more lucrative than if they sell the seeds to the central processing facility for use as pure plant oil for engines as the processing facility can only pay between 3- 5 MZN/Kg of seed at the current fossil oil price. Apparently ADM pays better prices than 3 MZN/kg for deliveries of seed above 100 kg and 500 kg but no single farmer has seed to offer in that order of magnitude.

When it comes to the profitability for the oil processors, the BBC was not set up as a commercial operation. It had donor funding for the establishment and partially for the operation, but it was an experiment that proved the technical viability and provided an essential service to the TTC.

On other hand, in relation to JATfuel produced from jatropha oil, we found a good business opportunity for ADM Company, mainly for the sale of this fuel to the mills that are in locations with difficult access to fossil fuels, such as Mueda, Ancuabe, Macomia and Montepuez District. So, according to the managers of ADM, the average annual production of JATfuel in the last 3 years is 100 000 L and they sell at 45 MZN/L.

Resource use efficiency (Energy)

Table 38: Resource use efficiency (Energy)

Indicator	BAU	IFES 1 and 2
Processing equipment with energy efficient technologies in place (yes/no)	N/A	A local small industrial oil processing workshop has been developed, which buys the seeds from the farmers and produces oil to be used in power generators and mills in the region. The technology used doesn't impact negatively to the water quality. The wastewater from biomass processing uses little water quantity and it's far to the river.

CONCLUSION ON SUSTAINABILITY

The price paid for the Jatropha seed is the make-or-break incentive for farmers to harvest Jatropha. Farmers can maximise profits if they can make soap, but to do that they need access to PPO. If this is not possible, farmers lose interest to supply the oil processors with Jatropha seed, which compromises the overall viability of Jatropha farming and processing. So the economics of Jatropha is the aspect that compromises the IFES stainability in this case. This is clearly reflected in the drop in Jatropha seed supply by smallholder farmers to the oil processors between the IFES 1 and IFES 2 phase. With the current low prices for crude fossil oil on the world market, Jatropha biofuels are not economically viable. However, the fact that it is also possible to earn money from Jatropha soap keeps some interest in Jatropha cultivation in the area. This shows the interest of having a multipurpose feedstock, as it it allows for adjustments to changing local market circumstances.

REPLICABILITY ASSESSMENT

ENABLING OR CONSTRAINING PROJECT FEATURES THAT SIMPLIFY OR COMPLICATE THE REPLICATION OF IFES

Clarity and Credibility

There is scientific evidence of the benefits of Jatropha cultivation. There was trust and transparency with ADPP and the farmers felt treated fairly. But now with ADM, there is no transparency, no good relation with farmers, therefore loss of trust and interest by farmers, so that less than 100 people are selling seeds to ADM.

Legitimacy

The idea came from outside through ADPP, but was developed with farmers clubs in participatory process, farmers owned it and the energy component came later on request of the farmers. Now with ADM, farmers don't have any ownership and the participation is weak due the lack of community involvement.

Ease in assessing results

Immediate visibility of results after one season, very clear evidence of Jatropha as fencing, food harvest increased because of protection. Also for farmers to be together in one block has become habit and is practiced up to today.

The benefits of Jatropha as agroforestry – on soils and yields - are only visible after two or more seasons, but they are visible. Therefore so people still maintain the trees.

The biggest success is soap making with an immediate economic gain for the farmers. There is immediate sales, big local market, reduction of expenditure for soap for own consumption. Thus many wanted to replicate this up to today, but now the constraint is that the press is not accessible to farmers to produce oil.

Business model including financial viability

ADPP / IFES 1:

The main objective of ADPP/FACT was to prove the concept of the viability of Jatropha and then develop the business plan later. In the beginning not developed for full commercial application, it was a pilot project that depended on donor funding. Therefore, without donor financial input and technical support this pilot would not have been possible. ADPP energy component failed in the end, but their efforts on the extension services still bear fruit up to today.

Motivation was to provide energy/electricity for the school from a generator to substitute expensive diesel (from black market) which became obsolete in 2010 when the grid was connected to Bilibiza and in other hand, to provide fuel oil as substitute for expensive diesel for maize mills, became obsolete when a filling station opened in Macomia in 2012 and the diesel price went down at the pump and the black market was drastically reduced.

ADM /IFES 2:

ADM came in as a commercial for-profit entity not only focusing on Jatropha. From the beginning ADM also concentrated on the trade of other commodities with short-term income and higher profit margins than Jatropha e.g. rice, sesame and other cash crops as well on the sale of farming inputs to improve economic viability of the company.

JATfuel is a benefit for the operators of the maize mills who get the fuel delivered at 45 MZN. It seems to be of higher calorific value than the local diesel, so that they use less litres of fuel to mill the same maize. That is, the mills save about 20 % of the necessary diesel to run it and they benefit from the convenience to get it delivered.

Weaknesses: Enterprise ADM would not have been possible without the prior (donor funded) work from ADPP/FACT, who had proven the concept and mobilized farmers. Starting from scratch would not have been financially viable. Initial donor funding and technical assistance was crucial to make the private enterprise possible.

JATfuel for energy use as diesel substitute is limited by the diesel price, which used to be very high before Macomia filling station, thus price paid to farmers too low to be interesting. So, currently farmers are demotivated and only < 100 farmers left from over 6 000 in 2013. Not sustainable, no clear plans could be obtained from ADM.

ADM generates its own funds, seems to be just about to be viable as they blend a large proportion of government subsidized paraffin (29 MZN/l) into the JAT fuel which then can compete against fossil diesel (47MZN/l)

Long term financial viability could not be assessed as ADM was not enough open to disclose their profits. It is clear that farmer's motivation is still decreasing and ADM should have to grow Jatropha on their own fields for they supply. Information on pricing obtained in the field differs from what was communicated from the head-office. That concerns JATfuel retail prices and buying prices of seed from farmers.

It could be more profitable if they would allow farmers to press their seed for a fee with the press in Bilibiza, which is only working for about 2 months in a year. But ADM management does not allow that which is frustrating farmers.

Alignment and Linkages

Biofuel policy and strategy approved in 2009 which favours biofuel production as national priority. However, ADM model does not respect poor farmers' priorities and needs as they are denied access to the press and oil to make soap. Thus they get demotivated to maintain and harvest Jatropha.

Technical complexity, coordination and behaviour change

The Jatropha plantation, in principle it is a complex structure involving many stakeholders, but once is planted it only hinges around what benefits farmers see in harvesting Jatropha. It depends on the access to PPO which farmers want to use for soap making. The technical aspects of oil pressing for fuel use are complex (purity, acidity levels etc. of the oil) but for soap making low grade oil is sufficient. The food security aspects are not complex but need extension services to start mobilising farmers and create proof of concept. Once some farmers are successfully implementing recommended practices (horticulture, block farming fenced by Jatropha, advantages of rope pumps, sanitation practices etc.) it is copied by the neighbours. The proof of concept needs to be there. The beauty of the ADPP/FACT approach was that farmers can also pick only certain elements from the entire package that was offered and thus go according to their own preferences and means.

Not much attitude change regarding needs on the energy side occurred for farmers, as they never used the PPO for energy. That was purely at institutional (school generator) or small enterprise scale (maize mills). Basically today if there would be a commercial operator of a mill where farmers can take the seed to press their own oil this would succeed as there is big demand from the farmers, but this lacks and beyond the level of decision making of the farmers. An entrepreneur/investor is needed.

Acceptability in local knowledge systems and culture

Both Jatropha and food security aspects can be well integrated in the local culture, as many elements were developed together with the farmers according to their needs and building on their knowledge. Thus all the elements are well accepted. Jatropha oil is in high demand for soap making, but not available currently.

WHAT IS THE ROLE OF STAKEHOLDERS AND INSTITUTIONS IN THE REPLICATION OF IFES?

The Perspectives of each stakeholder group with regards to the implementation and replication of IFES are the follow:

Main actor

Farmers felt empowered by the ADPP/FACT project which gave them improved food security and better incomes, especially from agriculture and soap making. They still pursue agricultural practices but stopped harvesting Jatropha as the conditions are not interesting for them. Soon large parts of the planted Jatropha fences might disappear if farmers don't benefit from the fruits.

Implementing organization

The first implementing organization was ADPP/FACT who had good interactions with the farmers. Farmers livelihoods were their priority and this was welcome by farmers and they had provided own extension services for the farmers.

Supporting organization

FACT stopped their support in 2014 and GSB took over the role but currently is facing some difficult related to finance. CEPAGRI provided interim financial support but no organisation is currently providing support to extension services.

Champions

The champion organization was FACT foundation, but they closed with activities in Bilibiza in 2011.

Stakeholder interaction

ADPP and GSB were well accepted with the farmers. Good and frequent interaction with farmers, government, international organisations and technical support institutions. Farmers felt respected and benefited, thus farmers motivation was high.

ADM is not present in the field as their main office is in Pemba, they only have the press in Bilibiza, so interactions with farmers are limited. There is no trust and farmers don't feel treated fairly, thus the dwindling numbers of farmers supplying seed to ADM.

HOW DOES THE POLICY ENVIRONMENT ENABLE OR DISABLE THE REPLICATION OF IFES?

Research and development (R&D)

A lot of R&D has been done by ADPP/FACT and numerous project documents are available on the FACT website (http://www.fact-foundation.com/en/FACT/Publications). This is an invaluable knowledge base for future replication.

Also, national and international Universities, international organisations and the Department of Renewable Energy in the Ministry of Energy were involved and the knowledge continues. GSB is the major knowledge bearer for both technical and social community mobilization issues on the ground, based in QNP.ADM did own R&D with support from Japanese academia, but do not share the results.

Technology deployment

Other than the press not much technology is needed. Small funding could leverage deployment of presses to be operated by small entrepreneurs. Government has a supportive attitude to farmers Jatropha growing, but no funds to support. Lack of a press at district level is the major constraint for farmers to resume Jatropha harvesting.

Building of human capacity

ADPP trained own extension workers not only on Jatropha but on food security, farming and improved water and sanitation practices. They are still around but have no funds to do further community mobilization. Farmer field schools for farmer-to-farmer exchange were established by ADPP to take knowledge from one district to another.

Messages on food security Jatropha were spread on local radio, local government TV and print media. International media came e.g. Japanese radio (under ADM). Public awareness is there, only incentives for farmers to harvest Jatropha are lacking.

Communication networks, partnerships and strategies

Farmers clubs were organizing exchange of knowledge among themselves, even without project involvement. The communication is effective and spread fast even among farmers that were not directly in contact with such initiative, .GSB continues as a knowledge hub and resource for the farmers, but has no funding to expand or continue extension work with farmers.

Resource and property rights, including secure land and resource tenure

Land tenure is secure, and there is no land shortage. People can 'own' the Jatropha plants and other improvements on the field e.g. agroforestry trees. Improvements on the fields e.g. through Jatropha fencing, agroforestry, bio-fertilizer application are though counteracted by the practice of shifting cultivation. Only the irrigated plots are permanent.

The farmers have no stake in the ownership of the infrastructure to process Jatropha. They are not given access to the existing presses which is the major cause for the current frustration of the farmers.

Encouragement of good and discouragement of bad environmental behaviour

ADPP discouraged burning of fields once they were cleared. This is still partially adhered to on the block farms, where farmers are organized in clubs established by ADPP or in the initial year of ADM.Farmers with good agricultural practices were given access to latrines, rope pumps, water filters and were encouraged to install hand washing facilities and build raised shelves to dry the dishes to improve overall hygiene and decrease incident of diarrhoea. If farmers were not maintaining the rope pumps e.g. weekly greasing, the pump would be taken away and allocated to another farmer. Farmers clubs who have received agricultural inputs like seeds, watering cans etc. have to contribute 20 % of their production to the communal box of the club to raise funds for maintenance and improvements. Any farmer who refuses to contribute, will not be considered in the following year.

GSB only maintains relationship for continued support and advice with farmers who have at least dug a latrine, installed a water filter, water harvesting and hand washing facilities. This ensures that only the most proactive of the over 6 000 farmers reached through either ADPP/FACT or ADM still receive support. Thus they can be a role model for their neighbours and the little funds available to GSB are best utilized. There is no carbon credit programme or other incentive programme for farmers. ADM discontinued incentives for farmers like access to inputs and extension services that were previously granted by ADPP.

National or regional production targets

There is no national target as such. The company target by ADM was to produce 60 t of seed per year, which would give a yield of 12 t of PPO (20 % oil yield per kg), which would translate into ca. 12 000 liters of PPO per year. As per Jan 2017 ADMs total production since 2013 at the press in Bilibiza seemed to be 36 drums at 200 l = 7 200 l only in a period of 4 years. This would be equivalent of 1 800 l/per year or only 15 % of the envisaged yearly target. Reason: low supply of seeds by farmers.

HOW DOES HUMAN AND TECHNICAL CAPACITY SHAPE THE REPLICATION OF IFES?

Technical capacity

The equipment at ADPP/BCC is either no longer functioning or available in the district. Currently ADPP passed on the press to another province for other uses. However, the capacity and knowledge to press oil is still there at ADM but not accessible to farmers. For soap making there are no technologies needed. The existing mechanical presses were obtained in Tanzania, the equipment at ADM still works well, but is only used for 2 months in a year due to the lack of seed to process. It could be better utilised if ADM would allow farmers to bring their seed and process it at a fee.

Institutional know how and management capacities

GSB, in the person of Bachir Afonso and his team, provides continuation of the institutional memory and know-how of all improvements on Jatropha cultivation and processing including soap making, food security, and personal hygiene. Many farmers know how to make soap although farmers have no access to oil to make it available.

Education, training and knowledge transfer

There is the agricultural college and the Teacher Training Centre supported by ADPP, which did not continue the project and closed the BBC. GSB was created for continuation of knowledge transfer. GSB could do the extension, but has no funding and no press to continue the services to the farmers.

CONCLUSION ON REPLICABILITY

Jatropha as a smallholder crop needs to make economic sense to farmers, otherwise they will not grow it or at least stop harvesting the seeds. The entity that presses the oil needs to be trusted by the farmers so that prices can be negotiated in a way that farmers feel treated fairly. Farmers need to have access to oil to pursue soap making which is more profitable than the use of the oil as biofuel.

CONCLUSIONS

The field visits and the analysis lead to the following main conclusions regarding this IFES case:

- Production of Jatropha seems to be most viable on smallholder fields in association with food crops rather than as monocultures on large fields;
- There is no competition for land, rather a synergy as Jatropha can increase food crop yield through protecting fencing of the food crops;
- Jatropha for energy as diesel substitute is only viable where there is no or limited access to diesel (higher than world market prices e.g. due to long distance to next official pump, black market). With the current world market pricing it is not viable to pay fair prices for the farmers, thus there is no motivation for farmers to harvest, de-husk and sell the seed;
- Electricity generation is only viable for productive use or where there is no grid power available. For small scale electricity (pico)PV is more economical;
- Jatropha can be promoted under other aspects with non-energy related messages like the protection of fields with animal repellent fencing, erosion control etc. but not primarily as energy or cash crop;
- Jatropha is most lucrative for farmers if they can make soap. But for this they need access to oil pressing facilities and knowledge on soap making. Here the knowledge is available (training was done) as the other ingredients (caustic soda, fragrance), what is missing is the access to oil to the farmers as they have no viable processing facilities;
- There is significant potential for a commercially operated press that offers the service to press oil for farmers at a fee. This would eliminate the need to set a price per kg for the farmers, as they can be their own masters of the downstream product. Soap has a guaranteed local market and can be used for own consumption. More elaborated soap could find a niche market for export.

Summing up, in this IFES case, Jatropha does not present any risk to food security; it is a development opportunity for subsistence farmers and a vehicle to increase resilience and farming practices and improve the livelihoods of local communities. On the other hand, the production of soap and the use of the JATFuel produced from blending Jatropha oil and petroleum, for the operation of the mills, has shown a good profitability both for the manufacturers as well as the operators of the mills. Therefore, these factors, when well combined and developed on a small scale, can show good sustainability and replicability.

RECOMMENDATIONS

WHAT COULD BE CHANGED FOR THE FUTURE?

We recommend to change the language and messaging how to advertise Jatropha: Jatropha should not be advertised as a feedstock for liquid fuels to substitute diesel or similar oil-based fuels. We have found that with the currently low prices for oil on the world market, Jatropha as fuel is not competitive and economically viable at all or only in very limited cases. If farm gate prices are bound to the diesel price it is not economically interesting for farmers to harvest and shell Jatropha, unless they can sell the seed with the shell and get the press cake back or they can process the oil themselves.

The use in internal combustion engines needs quality monitoring of fuel (acidity levels, impurities) that needs larger machinery to achieve. It is viable for productive use e.g. maize mills, but not for household use as cooking fuel, as too much firewood around.

A conversion first into liquid biofuel and then to electricity is not economically viable since EDM has densified the grid and solar products have become available for lighting, cell phone charging and entertainment. Only if a dynamo would be attached to the existing motors of the maize mills that could be an option to reduce electric there. So, other non-energy uses of Jatropha are more important and need to be stressed as the major motivator for farmers to grow Jatropha.

WHAT OTHER ELEMENTS COULD BE ADDED / REPLICATED?

Make Oil processing facilities accessible to the farmers

So we recommend to install processing centres in each district for the Jatropha with shelling machines, presses, filters etc. like the previous BBC. If farmers had access to processing oil from their own crops, this would change the game and eliminate the dependency from buyers. Like in a rice mill the farmers can take their produce for processing and chose the level they want and need. They pay a fee for the use of each machine, but e.g. for soap making they don't need to filter the oil and only pressing is required. This makes pricing transparent and eliminates the setting of a price to be paid by a customer per kg or litre of oil. Then farmers are free to do with the oil what they want and even sell it to ADM if they feel like it.

The processing centres have to be operated commercially by a skilled entrepreneur, and not under the supervision of an NGO. It is unfortunate that this opportunity was missed by ADPP and the infrastructure sat idle since 2011 and that now a press was taken to another district instead of setting it up in the original district to satisfy the demand for oil pressing that was created through the project.

Create incentives for farmers to supply Jatropha to oil processors

Jatropha started as a 'flag-crop' and it is no longer, as if it started on the wrong foot. To take it up again it would need incentives for the farmers to make it economically viable, which, at the moment, given the current framework conditions, is not the case and Jatropha is referred to as the 'leisure crop' (meaning people only harvest if they have nothing better to do with their time).

One example of incentive could be the barter trade of seed against oil: farmers could receive e.g. 1 l of pressed jatropha oil in exchange of 10 kg of seed, that would make 1 l of oil for the farmer and 1 l of oil for the press (on the assumption that 10 kg of seed yield 2 l of PPO). This model is common at maize mills where people pay for the milling service in maize or maize flour.

With increasing demand for JATfuel in the remote areas in some districts of Cabo-Delgado for use in mills, it is recommended that ADM encourage farmers by attractive pricing policy in the acquisition of jatropha seed and also create models of exchange or make available the jatropha oil to the community for the manufacture of soap.

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INTERCROPPING PIGEON PEA WITH MAIZE ON THE SAME FIELD TO PRODUCE FOOD, FODDER AND FUEL

SYNOPTIC SUMMARY

Case study : Growing food, fodder, fuel and fertilizer in synergy with staple food: **Intercropping pigeon pea with maize on the same field**

Location : Manica Province

Actors : Small-holder farmers with support of UCAMA farmers union of Manica

Key element of IFES : Integration of drought-resistant pigeon pea in maize fields for increased resilience of existing farming system and higher profitability of smallholders

IFES – BAU comparison : Maize is normally grown by smallholder farmers without fertilizer, sometimes intercropped with green beans. The IFES is the systematic intercropping with pigeon pea on the same field where the staple crop is maize is grown. The self-reinforcing synergy between the plants also increases the maize yields and makes the farming system more robust and resilient for climate variability.

Benefits likely to make the IFES sustainable : Intercropping pigeon pea with maize has multiple benefits, and the perception of priorities depend on farmers. The major ones are

Resilience to climate variability improving household food security e.g. by **minimizing risk of crop failure due to droughts or floods**

- **High profitability** offering profits exceeding 1 000 USD per ha through increased maize yields and sale of pigeon pea to established traders.
- **Guaranteed market** through MoU with Government of India to export at least 100 000 tons of pigeon pea, promising higher and more transparent prices. Growing demand for pigeon pea will increase competition among buyers and expand capillary market infrastructure closer to the farmers, e.g. ETG is becoming a major buyer with transparent pricing and warehouses in the districts. Bulk marketing through farmers associations further reduces dependency on vendors offering low farm gate prices.
- Low-risk and ease of adoption is high as this IFES is **no drastical change of the farming system.** It builds on what exists through more and improved seed of a known crop with instant benefits after the first growing season.

	Benefits regarding energy access are less obvious in areas where there is still a lot of forest
Where and how can this IFES be replicated? :	This IFES can be replicated by any smallholder farmer in Mozambique: Short-maturing high-yielding varieties of pigeon pea can be integrated in any farming system without competition for land, water and labour resources. Pigeon pea can grow in a wide range of climates and soil conditions and can be intercropped with other rainfed staple crops. This IFES is easy to replicate: ➢ Known crop, decision for uptake is entirely with the farmer ➢ Low technology level: affordable, easy access, easy to use ➢ Low risk as no big investment is needed, feasible even on < 1 h of land
Challenges	Availability of appropriate seeds, better marketing structures and access to extension services sensitizing farmers to all aspects this highly profitable IFES can be enhanced with concerted support by various government agencies. This should also include the cooking energy aspect of this IFES.
Outlook	The recent agreement between Mozambique and India to supply pigeon pea to India guarantees a secure market for pigeon pea, which could become a leading export crop for Mozambique. This would uplift farmers' income, reduce poverty and increase food and nutrition security. Plant breeders should focus also on pigeon pea varieties with higher biomass yield, not only on shorter maturity times and drought tolerance. This can lead to potential self-managed subsistence of cooking energy supply in areas where firewood is becoming scarce. As cooking energy amounts to over 90 % of household energy, pigeon pea can play an important role to mitigate pressure on natural resources under threat for fuel generation. **Intercropping pigeon pea with maize is a low-risk, low-input IFES with a positive self-reinforcing synergistic impact on availability, accessibility and security of food, fodder, fuel and green fertilizer. This IFES has the highest potential for country-wide replication.**

SYSTEM AND CONTEXT

BACKGROUND

Vulnerability of crops due to depleted soils and increased climate variability has become a serious threat to food security at farmers and national level. Yet, more food production is needed to sustain the growing national and global population in many parts of the world. However, the availability of food alone is not sufficient to ensure food security, as most food needs to be cooked to be safe for human consumption. Therefore the access to cooking fuel is a major pillar of food security. According to the World Energy Outlook compiled by the International Energy Agency (IEA 2016) 96 percent of Mozambicans rely on a traditional use of solid biomass fuels for their daily cooking, which puts some pressure on the forest resources of the country leading to forest degradation and, sometimes, deforestation.

Synergistic approaches and good agricultural practices like Integrated Food and Energy Systems (IFES) are urgently needed to increase the resilience of farming systems and address the need for food as well as cooking fuels to ensure good food preparation. One example of such systems are intercropped pigeon pea maize fields which allow for both, production of food and the substitution of unsustainably harvested firewood.

Geist and Lambin (2002, p. 146), point towards the fact that deforestation is caused by combinations of multiple factors. At the global level, the most important direct driver for deforestation is agricultural expansion, which is associated with 96 percent of all deforestation cases they assessed. This includes both subsistence agriculture and commercial plantations for food, feed and biofuel production. Another primary driver of deforestation infrastructure is the development for settlements and transport (72 percent) and wood extraction (67 percent), both commercial for trade (52 percent) and fuelwood for domestic use (28 percent). In Mozambique the major drivers of deforestation seem to be the clearing of land for expansion of agriculture and/or the cutting of live trees for charcoal production. In contrast we refer to 'forest degradation' when natural forest resources are impacted by the collection of firewood (mostly from deadwood and natural regeneration) and the depletion of certain species accelerated by cutting of high-value timber outside of dedicated plantations.

Low population density in Mozambique currently allows the practice of shifting cultivation with long enough fallow periods to restore soil fertility and forest regrowth. However, land resources are beginning to become scarce, and the needed fallow period is shortening - hence affecting soil quality and the possibility to have secondary forest. Thus, more emphasis needs to be placed on maintaining soil fertility on a plot of land and avoiding the clearing of forest for expansion of new fields.

Firewood unsustainably gathered from local forests is the most common source of energy for cooking in most rural areas of Mozambique. Use of firewood as well as production of charcoal for cash income poses several challenges to the poor rural communities living in these areas. Firstly, collecting firewood is time consuming especially for women who traditionally take up this responsibility. It reduces the time available for more productive labour in the fields. With the shortening of cropping seasons resulting from climatic change, loss of productive labour directly impacts on the livelihoods of the people. Secondly, the ever-increasing demand for firewood puts pressure on the forests and impacts climate change patterns itself. Thirdly, scarcity of firewood resources is increasingly becoming a serious problem in many parts of Mozambique. So far the extent of deforestation has not yet reached the crisis levels as in the much denser populated neighbouring countries Malawi and Zimbabwe, but it is a matter of time. Alternative and sustainable sources of cooking fuels are also needed to mitigate the negative impacts on the natural resources from the daily necessity to prepare vital food while not entering in competition with the resources needed for the production of food crops.

On the food production side, international efforts have recently increased to promote the production of pulses as a high-value cash crop for farmers' income as well a contribution to local and global food security. One example is the Feed the Future programme of USAID, which has included the promotion of pulses as an important element in their effort to unleash the proven potential of small-scale agricultural producers to deliver results on a large scale since 2013.

2016 was declared as the 'International Year of Pulses' by the 68th UN General Assembly and FAO was nominated to facilitate the implementation of the year in collaboration with Governments, relevant organizations, non-governmental organizations and all other relevant stakeholders (FAO n.d.). With the focus to highlight the role of pulses for biodiversity, food security and climate change, the aim was to heighten public awareness of the nutritional benefits of pulses as part of sustainable food production aimed towards food security and nutrition. The initiative intended to create a unique opportunity to encourage connections throughout the food chain that would better utilize pulse-based proteins, further global production of pulses, better utilize crop rotations and address the challenges in the trade of pulses. In Mozambique, the Ministry of Agriculture coordinates these efforts.

STUDY OBJECTIVE: ASSESS AN IFES BASED ON PIGEON PEA AS A CONTRIBUTOR OF FOOD AND FUEL

The objective of this study was to apply the Analytical Framework (AF) elaborated by FAO to assess the sustainability and the replicability of Integrated Food and Energy Systems (IFES). In Mozambique, the AF was applied on farming systems that include Pigeon Pea (*Cajanus Cajan*), a leguminous crop with woody stalks that are very popular as firewood for cooking, thus providing both food and fuel from the same plant.

In 2016 a game-changing opportunity arose in Mozambique to promote pigeon pea, whose grains are an important part of the Indian diet. The Government of the Republic of India through the Ministry of Consumer Affairs, Food and Public Distribution (2016) and the Government of the Republic of Mozambique, through the Ministry of Agriculture and Food Security, signed a Memorandum of Understanding (MoU) on 7th July 2016 'on cooperation in the field of Production and Marketing of Pigeon Pea'. It acknowledges the complementarities between the markets of both countries. The two main objectives of the MoU are the promotion of the production of pigeon pea and other pulses in Mozambique through the respective ministries and the increase in the quantity of pigeon pea and other pulses traded between Mozambique and India, subject to the quantities produced and the consumption requirements of both countries.

Some of the actions points mentioned to be developed in the 5 year-period of validity of the MoU are:

- Support the production of pigeon pea in Mozambique
- Provide farmers with agricultural extension services
- Cooperate in the areas of research and production of seeds
- Promote the trade of pigeon pea from Mozambique to India

The MoU aims to double minimum export quantities from 100 000 tons in 2016/2017 to 200 000 by 2020/2021. Buying prices are supposed to be guided by the prices declared for public procurement in India, so there is hope that prices will be transparent and uniform. A joint monitoring committee is supposed to oversee the adequate implementation of the MoU including aspects of food security and quality assurance regarding phytosanitary and quarantine measures.

One of the major agendas for India for the MoU was to arrange a stable import for pulses. In 2016 India was facing an acute rise in prices of pulses getting as high as INR 170/kg (2.5 USD/kg as per July 2016), therefore the Indian government decided to import the grains from Myanmar and a few African countries, including Mozambique. In response to the MoU the Ministry of Agriculture and Food Security (MASA) through its National Directorate for Agriculture and Forestry (Direcção Nacional de Agricultura e Silvicultura, DINAS) was tasked to lead the joint efforts to produce the required amounts of pigeon pea. This is still a big task, although the total production of pigeon pea has already at least quadrupled in 3 years from 25 000 tons in 2012 to over 110 000 tons in 2015. In 2015 at least 60 000 tons of pigeon pea, more than half of the national crop was exported to India estimated to be equivalent to 40 Mio USD.

In August 2016 the MASA presented the 'Programa de Fomento da Produção da Cultura de Feijão – Boer' (we will refer to this programme as PFFB), a national 5-year plan to support the production of pigeon pea so that the demand for export created by the MoU can be met. The programme is yet to be officially launched[23], but it envisages again a further nearly four-fold to increase the total yearly production to 500 000 tons of pigeon pea by 2022, out of which at least 200 000 tons are promised for export to India.

These recent developments make the growing of pigeon pea as a cash crop more attractive to farmers. Yet, the important role of the other benefits including the energy aspect of pigeon pea as firewood source to mitigate pressure on natural resources could be promoted as well.

The promotion of pigeon pea has become a national priority through the MoU, but it was felt that all efforts concentrated on the food production side only and the biomass energy potential of the pigeon pea was completely ignored. Taking into consideration that the national support programme for pigeon pea is totally delinked from the search for alternative sustainable firewood sources, a study case for an IFES was sought, where food and energy production on smallholder farmer level included pigeon pea in synergy with staple crops.

Although pigeon pea is common in many farming systems in Mozambique, it is grown occasionally or as boundary planting than systematically intercropped on the same field with maize or other staples. Ideally, the intercropping is complemented with 'climate smart' agricultural management practices that minimise negative impacts on climate but enhance farmers' resilience and food security despite a variable and changing climate. Climate friendly practices include improve soil coverage with mulch, no burning of fields, and low or zero tillage.

In the Central and Northern regions of Mozambique, many farmers already intercrop pigeon pea with maize, but these cases have never been documented. In Manica and Angonia province, where pressure on the natural resources is exacerbated by demand for charcoal from the neighbouring countries, it was observed that pigeon pea intercropping is becoming a coping strategy for farmers to ensure better access to cooking fuel while enjoying a positive impact on their staple food production. This is in line with the definition of an Integrated Food and Energy System (IFES).

The objective of this report therefore is to systematically document a specific IFES case where the pigeon pea are intercropped with maize and the stalks are used as fuel for domestic purposes. Additionally, the report analyses the sustainability and replicability of this IFES case.

SITE AND CASE SELECTION

Manica province was chosen to study this IFES example because the farmers union, UCAMA, is actively promoting the intercropping of pigeon pea with maize as a measure for sustainable agriculture and climate change adaptation with scaling-up opportunities.

A training of trainers was organised by the Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) in 2013 in the framework of the Comprehensive Africa Agriculture Development Programme (CAADP) together with the New Partnership for Africa's Development (NEPAD), Business Foundation and the Southern African Confederation of Agricultural Unions (SACAU), enhanced this IFES. They had engaged in development technical assistance services from Malawi to share best practices from Malawi on synergetic food and energy production. This included the intensification of pigeon pea production and the introduction of appropriate energy saving stoves to enable the efficient utilisation of pigeon pea stems as a readily available, cheap, and renewable biomass energy resource. As per 2013 one aim was to develop plans on how to integrate this in National Agricultural Investment Plan (NAIP) interventions on Climate Smart Agriculture (CSA), anticipated to contribute to reduction in the demand for firewood and contribute to the mitigation of climate change, while increasing food

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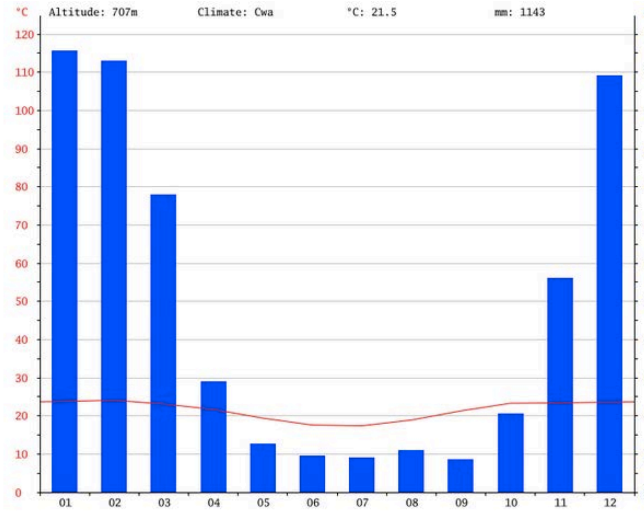
[23] A draft version of the 5 year plan was made available by the MASA to the consultants

availability and cash income from the crop sales. GIZ provided an initial lot of 30 simple ceramic stoves and 150 kg of two different pigeon pea seed varieties for multiplication.

UCAMA head office is based in the provincial capital Chimoio. UCAMA has since 2013 multiplied pigeon pea seeds in various locations in Chimoio and neighbouring districts Vanduzi, Makate, Sussendenga and Barué. UCAMA extension workers have continued to spread the messages among their members. As a result, more and more farmers are intensifying the cultivation of pigeon adding the special focus on IFES with pigeon pea as energy crop in their farming system.

Manica province is located in the centre of Mozambique and has 306 684 smallholder's farms who work in an area of 1 184 099 ha (Annual report of Provincial Directorate of Agriculture of Manica, 2015). The high mountain range in the west defines the border with Zimbabwe, so most of the rivers flow eastward towards the Indian Ocean. Please consult the map in Figure 30 for further details.

Figure29 Climate diagram of Chimoio



Source: Climate-data (n.d.)

Figure 30 Map of Manica Province

Source: Club of Mozambique (n.d.)

The climate is tropical and relatively humid, with rainfall of over 1 000 mm per annum, depending on the location. As visualised in Figure 29 there is one pronounced rainy season peaking from November to March and a more pronounced dry season from May to September. The province is considered the 'barn of the country'. Yet large-scale commercial farming is rare; most farmers practice subsistence farming, with most staple crops being primarily grown for own consumption, and only the surplus is sold. Maize is the major staple crop, complemented by cassava, sweet potato and sorghum. Major pulses are beans, cowpeas and pigeon pea. Vegetables, sesame, sunflower and fruits like banana, mango, citrus are grown partially for own consumption but mostly as cash crops. Farmers also have chicken, goats, pigs and cattle.

SETTING THE BOUNDARIES OF THE BASELINE (BAU) AND THE IFES VALUE CHAIN

The Business-as-usual (BAU) baseline case is defined as the prevailing farming system with occasional occurrence of pigeon pea in a farming system and the lack of systematic application of climate smart agricultural practice. We define the IFES as systematic intercropping of pigeon pea with maize, like promoted by UCAMA, regardless if the main motivation to grow pigeon pea is for food or for energy. In the described case study, the intercropping of pigeon pea is also associated to good agricultural practices contributing to conservation agriculture. Yet there are already benefits with intercropping alone. A summary of the case is presented at the beginning of Chapter 3.

MAIN STAKEHOLDERS INVOLVED IN THE IFES

The main actors involved in this IFES in the province are:

- Farmers as the main implementing stakeholders to grow and utilize the crop for food and cooking energy. They need access to extension services, seed and markets to sell the crop. They would benefit from improved stove technologies to replace open fires and better utilize the pigeon pea stalks as firewood for cooking.
- The Farmer Federation of Manica (UCAMA). It facilitates and supports the implementation of IFES since a training of trainers facilitated by GIZ on the IFES aspects of the pigeon pea-maize intercropping has taken place in Manica. Since 2013, UCAMA has been providing seeds and extension services to interested farmers groups in nine districts of the Manica province, although not under the ‘energy flag’ as the province still has rather abundant supply of firewood. The selling point and the motivation of the farmers has been the additional income opportunities coupled with Conservation Agriculture, climate change resilience and increased food security.
- UCAMA trainers: they provide extension services to its members to sensitize farmers for the opportunities of appropriate pigeon pea varieties highlighting the many benefits of pigeon pea e.g. food and cash crop potential, high demand on markets, benefits for soil health, potential for mitigation of climate change etc. The trainers assist farmer groups to establish demonstration plots and multiply seed material for distribution to the farmers. They also assist them to link with existing markets while trying to open up new ones. UCAMA is present in all 12 districts of Manica Province, with a total of 8,515 members of which 40 percent are female. UCAMA consists of 176 associations, which produce cereals, legumes (including pigeon pea), goats, beef and poultry on about 13 800 ha of arable land. So far UCAMA has promoted the IFES in nine districts with funding from various sources, such as member fees and various donors e.g. development funds from Norway (Apoio Popular da Noruega), Southern African Confederation of Agricultural Unions (SACAU), the Alliance for a Green Revolution in Africa etc. UCAMA represents the National Farmers Union (UNAC) on the level of the Manica Province.
- Private sector agricultural commodity traders (suppliers and buyers): they have an explicit role in the development of value chains, either as outlets offering inputs like seed, fertilizer, agro-chemicals etc., or products like machinery and tools. They can also be service providers or buyers and traders of farmers’ produce, thereby contributing to the development of markets.
- Buyers/traders of pigeon pea: the ETG Company has become the largest buyer for pigeon pea. It was founded in Kenya in 1967 and has emerged as one of Africa’s largest Agricultural Conglomerates. ETG’s footprint expands across sub-Saharan Africa, North America, Europe, the Middle East and South East Asian countries. ETG annually moves around 5 million tons of agricultural commodities around the world and directly employs more than 7 000 people globally. Their vast portfolio of commodities includes cashew nut, various types of oilseed crops, sugar, coffee, several types of pulses, wheat, fertilizer, rice, maize and sesame seeds.
- The Group’s supply chain penetrates deep into remote agricultural regions where they procure commodities from smallholder farmers through their strategically located centres. The commodities are then accumulated at ETG warehouses and/or transported to processing facilities, prior to reaching their customers. So, the company transports and stores all purchases through its logistic network distributed at the Manica province: they have a major warehouse in Chimoio and at least six warehouses in smaller cities along major roads.

- Seed suppliers: some suppliers of certified seed like MozSeed are today out of business but new suppliers have emerged like K2 in Chimoio. There is also a shop at the ETG warehouse in Chimoio that sells pigeon pea seeds. Once farmers have obtained seeds for improved varieties, they can also recycle seeds from their own harvest. UCAMA farmers groups multiply pigeon pea seeds to share in the following year among their members.
- The Government, through the Provincial Directorate of Agriculture and Food Security and the Institute of Agrarian Research. Its main role is to promote agriculture through the implementation of the existing legal framework for the development of the sector, with emphasis on extension services, research and availability of inputs (seeds, fertilizers, etc.). It also focuses on the promotion of food products in substitution for imports, and responding to the growing demand for food induced by rapid urbanization.
- Other Cooperation partners. They support government, NGOs and private sector through specific programs. Some agencies to highlight are:
    - The United Nations Food and Agriculture Organization (FAO),
    - The Alliance for a Green Revolution in Africa (AGRA), which advocates training in techniques and means of production in the family sector, responding to the gradual mechanization of the agricultural sector and regular and permanent monitoring of food and nutritional security,
    - Feed the Future programme by USAID, which is actively promoting pigeon pea and has supported the construction of the big ETG warehouse in Chimoio,
    - The International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) plays a major role in the research on suitable pigeon pea varieties and the multiplication of certified seed. Manica Province is serviced from the regional focal point for pigeon pea in Lilongwe (Malawi).

As mentioned in the introduction, the game changer on the demand side for pigeon pea has been the recent agreement signed in 2016 between the Governments of Mozambique and India on the export of pigeon pea to India. This creates access to an ever-growing export market for pigeon pea. While ETG is currently the largest market aggregator and exporter, the increased demand for pigeon pea also incentivises competition among buyers, which is likely to build better market infrastructure reaching closer to the farmers. As a result, farmers will benefit not only from guaranteed markets for their produce, but also from easier market access with higher and more transparent prices.

METHODOLOGY

FAO has developed an Analytical Framework (Bogdanski 2014) as a guidance document to assess which factors make IFES truly sustainable and which factors need to be considered when replicating such a systems - be it a pilot project, a business innovation or a research experiment. The underlying assumption is that good decision-making on bioenergy has to be based on a critical mass of evidence to inform decision-makers, at local, but also at national and global scales.

The Analytical Framework (AF) includes a set of criteria, indicators and measures to help screen IFES projects. The first part of the AF screens IFES projects based on their environmental, social and economic sustainability. The second part of the AF contains a set of leading questions and related features that will help to analyse which factors need to be built into new IFES cases to make them replicable and bring them to scale.

SUSTAINABILITY ASSESSMENT

The project team developed a list of indicators for each of the three sustainability pillars i.e. social, environmental and economic as suggested by the IFES Analytical Framework (AF). Indicators concerned either impact (quantitative) or performance (process or qualitative). No elaborate own measurements could be carried out due to cost and time constraints. Quantitative data on yields and other factors were taken from farmer's oral reports. Sustainability was assessed by comparing relevant indicators between a business-as usual scenario (BAU) and the IFES case.

REPLICABILITY ASSESSMENT

Replicability was assessed through a descriptive analysis of the extent to which the IFES meets four replicability criteria described in the AF –

1. Presence of promoting or inhibiting project features of the IFES,
2. Stakeholders that may promote upscale of the IFES,
3. Alignment of the IFES with national food and energy objectives and
4. Availability of capacity for up scaling.

DATA COLLECTION AND SAMPLING METHOD

Data were collected through a mix of methods: findings from literature studies were complemented by data collected on site in Manica Province. The field methods included semi-structured interviews with key informants from institutions and private sector stakeholders and participatory Focus Group Discussions (FGD) with farmers groups. Tools for the participatory assessment of the IFES pigeon pea-maize with farmers in the field were developed and refined to include seasonal calendars and other visualisation options.

The farmers groups to visit were identified in a Focus Group Discussion (FGD) with 11 UCAMA staff and other stakeholders who participated in the 2013 GIZ training. Farmers groups were selected based on the accessibility of the groups and the status of the introduction of the IFES approach. The Barué district with the most widespread evidence of this farming system prior to UCAMA interventions could not be visited for security reasons. In the other districts UCAMA so far mostly established demo plots to showcase the benefits and multiply seed, although yields were lower than expected due to the severe drought. This upcoming 2016/2017 season will be the first year to go to scale with many farmers starting to plant pigeon pea on their own fields.

From the associations belonging to UCAMA we selected four groups to be visited for FGD, according to the length of experience with this IFES (Table 38).

Table 39: Groups to be visited according to the length of experience with this IFES

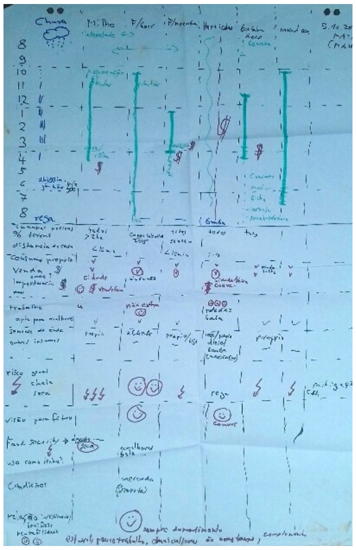
	Objective of Focus Group Discussion	Farmers Association	Participants
BAU **No demo plot**	To document the BAU scenario in a group that will only start their demonstration and multiplication plot with improved pigeon varieties in the upcoming season. Figure 31 shows the drawing of a seasonal calendar with that group.	Futuro Melhor Association and Augusto Mponesa Locality: Monoquera District: Vanduzi	30
IFES Year 1 **Demoplot from 2015**	To obtain farmers expectations before they get own seed but after observing the benefits from intercropping on the communal demonstration plot from the previous season.	Arinema Guzgoana Association Locality: Matamira District: Macate	25
IFES Year 2 **Demoplot from 2014**	To obtain farmers experience after they had gown the first season of pigeon pea intercropped in their own fields in 2015/2016. With them we elaborated the seasonal calendar in Figure 32.	3 de Fevereiro Association Locality: Marera District: Macate	19
IFES Year 3 **Demoplot from 2013**	To obtain experiences and perceptions from farmers around the area where the chairman of UCAMA, Mr José Basquete, had started to multiply the seed received in 2013 on his own fields for other demonstration plots but also shared with other farmers to grow.	Nhabanba Association Locality: Matica District: Sussundenga	30

Key informant interviews were held with the various service providers in Chimoio:

- Direcção Provincial de Agricultura: the crops officer and seed certification unit as well as the CEPAGRI branch Chimoio;
- Private sector stakeholders: commercial seed supplier K2 and the agricultural commodity trader ETG;
- The GIZ officer from the global Programme Energising Development was visited to learn about the production group of simple clay stoves in Chimoio.

Figure31: Drawing of a seasonal Calendar in a Focus Group Discussion in Monoquera

Figure 32: Seasonal calendar from Marera

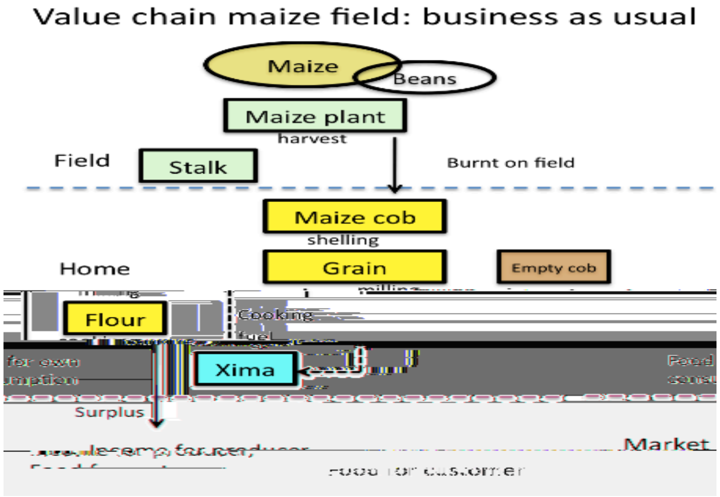


DESCRIPTION OF THE INTEGRATED FOOD – ENERGY SYSTEM

DESCRIPTION OF THE BAU SCENARIO

To capture the situation of the business-as-usual scenario, the seasonal calendar shown in Figure 32 was elaborated in Monoquera village, where the IFES was not yet introduced. The gathered observations were confirmed in another community that had seen the pigeon pea on the demonstration plot and was about to plant it for the first year on their own plots. The information was validated in all Focus Group Discussions that involved in total over 150 farmers (90 men, 60 women).

Figure 33: Business-as-usual Value chain of maize



Source: Elaboration by C. Roth

All farmers interviewed grew maize and beans intercropped on their main field, which comprised normally over two hectares and was within less than ten minutes walking distance from their houses. This is an indicator that land scarcity is not a limiting factor in the area.

To clear the land for the next season, maize stalks are burnt on the field and not removed or mulched into the soil. Empty maize cobs are partially used as cooking fuel to supplement firewood. Surplus maize was sold. Hardly anybody applied inorganic or other fertilizer to his or her maize crop, so yields are generally low and maize is perceived a high-risk crop, which is extremely vulnerable to drought.

Cash crops varied, but most farmers grow sesame, sunflower, fruits and vegetables on a different field for sale. The most common income generating activity was charcoal production, either from forests or when clearing land for shifting cultivation.

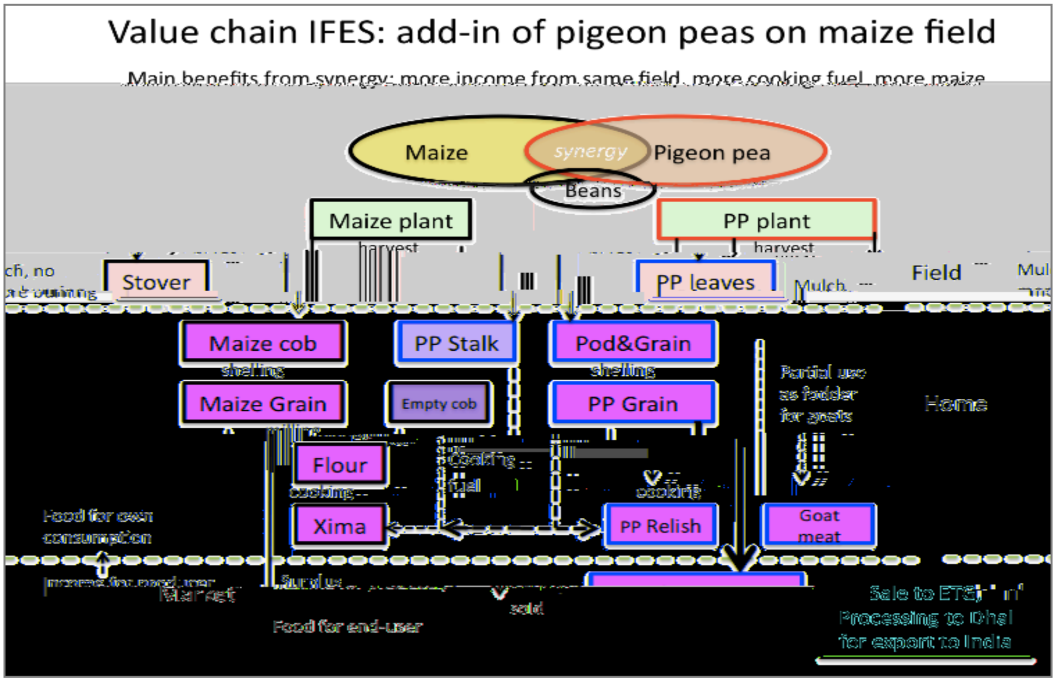
DESCRIPTION OF THE IFES SCENARIO

The IFES is defined as ‘pigeon pea intercropped with maize, coupled with climate smart agricultural practices’. It is a very simple IFES based on existing farming practices and does not require any new technology introduction. It is an ‘add-in’ of pigeon pea integrated onto the same main field where maize is grown. It does not displace any maize or other food crops. The beans can still be grown in the same farming system. The details of the farming system are also described in more detail in the seasonal calendar in Table 40 further in the report.

Figure 34 shows the use of pigeon pea as a synergistic crop that even reinforces the growth of the staple crop maize. The maize value chain remains the same, only that more maize can be harvested as the plants yield more grain due to the fertilizing effect of the pigeon pea: as a legume the pigeon pea roots fix nitrogen in the soil and when the soft nitrogen-rich pigeon pea leaves fall on the ground, they are mulched in and add both biomass and more nitrogen to the soil. The pigeon pea grows together with the maize and stay on the field when the maize is already harvested. Goats like to raid the pigeon pea fields for fodder. This may diminish the crop and biomass availability for mulching, but it creates other benefits as the goat droppings serve as manure on the field and the goat meat as food for people.

The burning of maize stover is replaced by mulching. The pigeon pea stalks are very woody and would not decompose easily in the field, so they are taken to the homesteads to increase the cooking fuel available from the farm. The grain is used to improve the own nutrition and to obtain considerable income from the sale on a nearly guaranteed market.

Figure 34: IFES Value chain of maize and pigeon pea



Source: Elaboration by C. Roth, Legend: PP = Pigeon Pea

The only inputs needed are seed and extension services to raise awareness for this IFES and the potential benefits coupled with recommended climate-smart farming practices.

There is a strong motivation for farmers to grow pigeon pea as a promising and drought-resilient cash crop to increase on-farm income. People observed on the demonstration plots and on own farms that the 'pigeon pea is protecting the maize'. The market and an ever-growing network of buyers with warehouses in the districts is there. Market expansion is politically supported, the access to seed and extension services is facilitated through the farmers' association UCAMA (União de Camponeses de Manica) and people have the own land where they anyhow grow their staple crop maize.

No extra labour is required for this IFES other than seeding and harvesting of pigeon pea. The provision of firewood through pigeon pea is seen as a welcome added benefit, but it is not a major motivation in the Manica province as there is still abundant firewood to be found in vicinity to farmers' houses.

COMPARING BUSINESS AS USUAL (BAU) WITH IFES

Table 40 reflects both the seasonal calendar of the BAU and the IFES scenario with the pigeon pea intercropping already integrated to show how well the pigeon pea intercropping fits into the existing seasonal calendar of the farmers. Intercropping of the staple crop maize with beans takes place in both scenarios on the main field. In the IFES scenario pigeon pea is merely added to the same main field, planted at the same time as the maize, but harvested up to four months later. This ensures longer soil cover and reduces both water evaporation and soil erosion due to wind or surface runoff. There is no change by the IFES for the activities on the secondary fields and, if available, the irrigated plots alongside the streams in the valley where vegetables are grown.

Table 40: Seasonal Calendar showing Activities for the main crops

		Rainfed					Irrigated
		Main field (intercropping, > 2 ha)			**Secondary field:**		**Valley plot**
Month	Rain	Maize	Pigeon pea *(feijão boer)*	Beans *(feijão nyemba)*	Cassava	Sweet potato	Vegetables
Sep			$$$$				$
Oct	(x)	Field preparation			Field preparation		$
Nov	X	Planting seeds			Planting cuttings		$
Dec	XX	Weeding				Planting cuttings	$
Jan	XX			Planting seeds			$
Feb	XXX						$
Mar	XXX			Harvesting			$
Apr	X	Harvesting		$$		Harvesting	$
May		Sale $$					$
Jun					Harvesting		$
Jul			Harvesting				$
Aug							$

Table 41 shows that the main motivation of farmers to grow maize is their own food supply as they rely mostly on maize as the main staple crop. Apart from vegetables, all other crops are grown for own food needs; farmers only sell the surplus. The main sources of income are the vegetables (for those who have access to adequate plots in the valleys) closely followed by pigeon pea. The main motivation to grow pigeon pea is mostly for cash, followed by food and to a certain extent for energy, as it is a convenient fuel. The motivation rises if other sources of cooking fuel are scarce.

Although vegetables are a money-spinner, they are not seen as the most profitable crop, as they are very labour intensive, requiring daily attention and hard work for watering while it is also very costly to run the motor pump. The pigeon pea were seen as the most profitable crop with the least labour, no other inputs as seed retained from own harvests and there is minimal risk for crop failure due to the high resilience of the crop. Therefore, the perception those pigeon peas offer the best return on investment.

Table 41: Farmers' perceptions and motivations to grow different crops

Main motivation to grow the crop						
	Maize	Pigeon pea *(feijão boer)*	Beans *(feijão nyemba)*	Cassava	Sweet potato	Vegetables
Own Food	XXXX	X	X	XX	X	
Sale / Income	X	XXX	X		X	XXXX
Fuel / Energy		(X)				
Other perceptions by farmers						
Labour intensity	**High**	**No extra labour**	**No extra labour**			**Very high**
Other inputs needed	**None**					**Motor pump, diesel**
Seed source	**Own seed**	**UCAMA/ Own seed**	**Own seed**	**Own seed**	**Own seed**	**Purchase from shops**
Risk of crop failure	**Very high**	Very low	**Medium**	Low	Low	**Medium**
Major risk factor	**Drought, floods**	Goats	**Drought**	**Drought, disease**	**Drought**	**Drought, Pests&disease**
Profitability (return on invest)	X	XXXXX				XX

In Table 42 we compare the value chains for both BAU and the IFES. If there are no differences, the fields are merged in one line.

Table 42: Comparison of value chains for business-as-usual with the IFES scenario

	BAU: Maize without pigeon pea intercropping on the main field	IFES: Maize with pigeon pea intercropping on same main field, complemented with improved management practices
1. Biomass production		
Average farm land size	2-3 ha for main field, where maize is grown. Other fields depend on households. Land is not yet a limiting factor in the area.	
Land preparation (incl. seasonal calendar)	The agricultural season starts in October. All field labour is done manually, mostly with a hoe, some people use ox-ploughs. There is no motorized mechanisation. Field preparation involves clearing with a hoe. In place where there is still plenty of forest, shifting cultivation is still practiced: if soil fertility has a gone down after 45 years, a new plot of forest is cleared and the felled trees used to make charcoal. Most farmers practice no till planting, they only dig small planting holes.	

Table 42 (cont'd): Comparison of value chains for business-as-usual with the IFES scenario

	BAU: Maize without pigeon pea intercropping on the main field	IFES: Maize with pigeon pea intercropping on same main field, complemented with improved management practices
1. Biomass production		
Planting	Maize is sown in rows, with 90 cm distance between stations and rows, 2-3 seeds per planting hole, maize seed is either recycled traditional varieties or hybrid from the shops.	
		Pigeon pea is planted in holes between the maize planting stations 1-2 weeks after maize planting. Although this requires some additional labour, it is done in combination with weeding of the maize and farmers did not perceive it as 'additional' labour. Certified pigeon pea seed is obtained in seeds shops in Chimoio and as well as through the pass-on-multiplier exchange system within the farmers' association: for 5kg received each farmer returns 10kg to UCAMA to share with other farmers for the dissemination of the pigeon pea crop.
Water management	No irrigation, all rainfed agriculture with the main rainfall between October and March.	
	No water management, prone to droughts and high risk of crop failure	Pigeon pea provides ground cover for nearly the whole year. It covers the space between the maize rows and reduces soil water evaporation already in the first year of planting. The leaves also add organic matter in soil and over time increase water retention in soils, decreasing the risk of crop failure.
Soil fertility management	No mineral fertilizer used. Beans *(feijão nyemba)* are intercropped between maize from January to March	
		Pigeon pea belongs to the family of the legumes, and as such is able to replenish soil mineral nitrogen through its ability to biologically fix atmospheric nitrogen. UCAMA promotes three pillars of Conservation Agriculture practices: ➢ no or minimum tillage, ➢ soil cover with mulching of dead residues from the field, or by live crops and ➢ crop rotation, in this case intercropping of cereals and legumes on the same field.
Weed management	Manual weeding from December to March	Less weeding as pigeon pea provide more soil cover, suppressing weed growth

Table 42 (cont'd): Comparison of value chains for business-as-usual with the IFES scenario

	BAU: Maize without pigeon pea intercropping on the main field	IFES: Maize with pigeon pea intercropping on same main field, complemented with improved management practices
1. Biomass production		
Pest and disease management	No pesticides are used. For more than 5 years farmers do not have records of having major pest invasion in their main fields that would have required the use of pesticides.	
		In Ghana and Malawi farmers interviewed by the authors observed less disease pressure on both maize and pigeon pea when two crops were intercropped rather than planted as pure stand fields.
2. Biomass logistics	Maize (same logistics for BAU and IFES)	Additional crop: Pigeon pea, maize logistics remain the same
Harvesting	The maize cobs are harvested fresh in May by hand.	Pigeon pea pods are harvested from June-September by hand, depending on variety
Collection & **Transport from field to farm**	The cobs are taken in bags or baskets to the nearby homes for drying, the stover is left on the field and most commonly burnt on the field.	The pods are transported in bags or baskets to the nearby homes for drying. The leaves and smaller branches are left on the field to mulch, the larger stalks are taken to the house as firewood.
Storage at farm	The maize is sun-dried on the cob on the ground. The required yearly supply for the family is then stored on the cob in traditional silos, some silos are above the fireplace in their houses to avoid pest outbreaks.	Pigeon pea pods are sun-dried on the ground, then shelled to take the grain out. The dried grain is stored in bags until it is sold. Some bags are kept for own consumption during the year.
Transport from farm to the market	The surplus maize is shelled and sold to vendors at farm gate. The maize can either be lose, then measured in standardised tins or packaged in 50kg polyethylene bags.	Pigeon pea are rarely sold on the local markets. Previously vendors would come to buy at farm gate but now with the ETG warehouses in the district, farmers sell directly to ETG.
Sale	Each farmer sells maize individually. Some farmers also take maize to the markets for sale instead of waiting for vendors, which offer lower prices.	Pigeon pea are sold in 50kg bags and consolidated on farmer's group level for bulks sales directly to ETG to get better prices.
Transport from the market to the company & storage	Transport depends on means of the farmer and distance to the market. Normally no transport is hired for maize, but maize bags can be carried on bicycles or in public or private transport provided by pickups and minibuses ('chapas').	Farmers hire pickups, minibuses ('chapas') or small trucks from private individuals to the ETG warehouse or a negotiated meeting point with trucks belonging to ETG. Pigeon pea are collected at the main ETG warehouse in Chimoio to consolidate container loads for further transport in bulk.

Table 42 (cont'd): Comparison of value chains for business-as-usual with the IFES scenario

	BAU: Maize without pigeon pea intercropping on the main field		IFES: Maize with pigeon pea intercropping on same main field, complemented with improved management practices	
3. Biomass processing	Maize (same for BAU and IFES)		Pigeon pea	
	Food (grain)	**Fuel (Empty cobs)**	**Food (grain)**	**Fuel (woody stalk)**
Processing	The grain is taken off the cob and taken to small mills to make flour.	n.a.	ETG transports the grain to its mill in Beira to make split peas ('dhal'). The mill has a capacity of 750 tons/day. Excess grain is exported to India for processing in larger factories there.	No processing, only drying at the homestead.
4. Logistics	Food (grain)	Fuel (Empty cobs)	Food (grain)	Fuel (woody stalk)
Storage	Flour is only milled for immediate consumption, no extended storage.	No storage, as maize is shelled only when needed to take grain to the mill.	Dhal is stored at the ETG warehouse in Beira to consolidate larger shipments.	Stalks are stored at the house, sometimes under a shelter
Transport	To the mill on the head or by bicycle.	n.a.	By ship mostly to India	No transport, used at the house.
Packaging	n.a.	n.a.	In shipping containers (mostly 40')	n.a.
Sale	Surplus is sold as grain, but not as flour.	n.a., cobs are not yet a commodity.	For export, mostly to India.	n.a., stalks are not yet a commodity.
5. End-use	Maize (same use for BAU and IFES)		Additional crop: Pigeon pea	
	Food (grain)	**Fuel (Empty cobs)**	**Food (grain)**	**Fuel (woody stalk)**
End-use	Maize flour is used to prepare the staple food 'xima' (cooked maize pap). The bran is used as feed for chicken and as raw material for home-made beverage production. The shelled cobs are used to complement firewood as cooking fuel in the open fires, or they are left to rot.		Food: some pigeon pea is used by farmers for their own consumption. But the bulk is sold for income, then used as food by the population at the final destination (mostly India)	The pigeon pea stalks are used to complement or substitute firewood as cooking fuel in the open fires. The supply of one harvest can last for 2-8 months, depending on use.

Based on the interviews with over 50 farmers we found that Pigeon Pea fits very well into the current farming system and the seasonal calendar. More will be discussed at a later stage in the chapter for replicability and conclusions.

SUSTAINABILITY ASSESSMENT

This chapter presents the results of the sustainability assessment guided by the modified analytical framework. Appropriate criteria and indicators were selected to assess the difference between the BAU and the IFES case. The criteria are grouped into social, environmental and economic aspects. The information is condensed in overview tables and discussed in more detail below the tables.

From a methodological point of view:

- If there is no change between the BAU and the IFES the fields in the tables are merged, major changes from BAU to IFES are highlighted with a cell shaded with grey background;
- Prices are as per October 2016, converted to USD;
- Exchange rates as per October 2016: 100 MZN = 1,28 USD (obtained from OANDA currency converter);
- We applied conservative estimates and used lower figures if a range of data was reported e.g. on yield per ha; and
- For time and cost efficiency of the study yield data were not measured by the study authors, but self-reported by farmers in the focus group discussions held. We feel that yield data reported for the pigeon pea might be slightly overestimated, but we interpreted this as an expression of appreciation of the crop by the farmers.

SOCIAL CRITERIA

Food security

The measurement of this indicator is summarised in Table 43.

Table 43: Indicators for Food security at farmer level

Indicator	Basis for calculation	Business as usual	IFES
Farm land size	main field only	0.5 - 3.0 ha, average 2 ha	
Maize yield	per ha/ per year (one harvest per year,)	1.2 – 1.5 t/ha	**2.4 – 3 t/ha**
Income or avoided expenditure for own consumption (maize) per year	30 MZN/kg (=0,38 USD) field size average 2 ha	922 USD	1,843 USD
Pigeon pea yield	Planting pattern at 90x90 cm between maize, one harvest/year		2.0 t/ha*
Income or avoided expenditure for own consumption (pigeon pea) per year	38 MZN/kg (=0,48 USD) price paid by ETG in 2016) and total harvest of 4 t from the field		1,946 USD
Avoided expenditure for fuelwood and charcoal when using pigeon pea stalks for cooking (per year)	Fuelwood collected for free, local price for charcoal bag 140-200 MZN (1,8 – 2.5 USD), consumption in rural areas 1 charcoal bag per month		22 - 35 USD

** This was reported by farmers, even though it might be slightly overestimated*

Yields for the pigeon pea were reported either from the demonstration plots or from farmer fields. A demo plot of 50x20m yielded on average 70-100 kg, enough to provide each member of the farmers associations with at least 2.5 kg of seed. This would translate to 0.7 tonnes/ha when first planted. With improved management practices, soil nutrients are building up over time and in the second or third year yields increase. Some farmers from Sussundenga district, where the first improved pigeon pea seed was multiplied by UCAMA since 2013, reported to have sold more than 30 bags of 50 kg from their fields. As the field size was not specified, this does not serve to calculate the yield per ha, but it gives an indication of the income obtained from the new crop. This is rather a projection of the potential of the IFES. Moreover, some communities are only in the starting phase of intercropping pigeon pea and have not yet applied the IFES to their entire maize field. In the following tables, the average field size of the main field is assumed to be 2 hectares.

The IFES concerns the main field of farmers with an assumed average of two hectares. There is no direct change and impact of the IFES on the other fields where other cash and subsistence crops are grown as explained in the seasonal calendar. The major benefits of the IFES regarding farmer's food security are the additional crop from the same land with a high commercial value and the reported doubling of the maize yield due to the soil improvements from the intercropping. This can add up to 2,867 USD per year in income or avoided expenditure for own consumption for a field of two hectares, or 1,433 USD/ha. So even if farmers have less land, this IFES is highly profitable with little investment (see also profitability section below).

The contribution of the energy component is not yet considerable but will become more important with increasing scarcity of firewood and charcoal (see Malawi example in Table 44).With better varieties, densified planting patterns and better crop farming practices, yields could still be raised. Field trials of pigeon pea grown in pure stand (not intercropped) from IIAM (Instituto de Investigação Agrária de Moçambique in Manica) indicate that pigeon pea yields can go up to 6 t/ha. There is still more research to be done on the optimization of the most appropriate varieties and farming practices (e.g. ratooning or coppicing of pigeon pea versus annual planting etc.).

From the group discussion with farmers it also emerged, that the pigeon pea is perceived the fall-back' crop that can fill the gap if the maize fails. It can provide additional food or it can be sold to buy maize on the market. Porridge can be made out of pigeon pea that is similar to the staple food, xima' (maize pap). It is nutritious and can also be given to children when they cry. This is what they defined as food security' in one area: to have something to give to the children when they cry. In the Nhanguzue community (Sussundenga district), where pigeon pea was so far rather unknown, the food insecurity is critical due to recent severe droughts. With the IFES they feel food secure again as they will no longer experience hunger periods, they can use pigeon pea for own consumption and the income from the sales of surplus in order to purchase additional food or other essential goods.

Table 44: Example of a similar IFES from Mulanje District (Malawi)

The Integrated Food Security Programme (IFSP) implemented by GIZ in 185 villages in Mulanje District distributed seed 2 kg of seed of late maturing varieties (ICEAP 00040 and 00020) per household starting from 2 000 onwards. 10 years later after the introduction of pigeon pea in local farming systems a post-programme assessment by Webb (2011, p. 12) revealed that *'Pigeon pea are in evidence in every community visited for this review, and while not planted on every single farm, they are sufficiently widespread as to be classed as a staple crop of the district'.*

Nearly every farmer grew pigeon pea, but no longer the initial varieties, which according to Orr (2013) made ICRISAT curious to find out more about situation:

'The original seed varieties did not spread, despite being palatable and easy to de-hull. By contrast, Nthawajuni is not so palatable, but it matures early and is the first to provide food security, and the stems are bushy and if ratooned it gives many branches that people use as firewood. Early-maturing varieties are preferred because of increasingly erratic rainfall patterns and damage from livestock, which range freely after harvest of maize. Early maturity reduces risk because if there is no rain in August and September then yields from local varieties will be poor.

Farmers were unanimous that they grew two varieties – one early maturing, and one late maturing – in order to reduce risks. If rains are good, then local varieties do well. If rains are heavy, Nathwajuni sheds leaves, and the yield declines. If rains are short, then Nthawajuni does better than local does.

Pigeon pea is planted with three seeds per planting station but in cropping patterns:

- *Intercropped in a separate row with planting stations 20 cm apart;*
- *Intercropped between maize planting stations, 75 cm apart*
- *Pure stand, planting stations 75 cm apart*

Seed of Nthawjuni and local varieties is readily available in the market. Out of a harvest of 10 bags of pigeon pea, farmers will sell 7 bags and keep 3 bags for home consumption. Nthawjuni grain fetches a higher price at farm gate (100 MK/kg of dried grain compared to 60 MK for local). The price premium may reflect earlier harvesting of Nthawajuni. ETG paid 140 MK/kg delivered and scales are accurate. Vendors often tamper with the scales.

Maize was still considered the main staple crop to grow, but pigeon pea had become second only to maize in importance and they fetched more money than maize. Pigeon pea has had positive impacts on household food security, cash income and soil health and fertility.'

In 2011 FAO co-financed field surveys on pigeon pea that later led to the publication of Orr (ORR et al 2014). For many farmers interviewed in Mulanje during the surveys the main criteria to choose pigeon pea varieties are early maturity for risk mitigation and firewood yield. In combination with the simple locally made Chitetezo Mbaula clay stove they can use the pigeon pea stalks and other residues from their farms like sorghum stalks and maize cobs easily to substitute scarce firewood. In a normal year with average rainfall many people claim to be self-sufficient on cooking fuel and don't need to rely on forest resources. People have transitioned from net firewood consumers to energy subsistence farmers mostly independent from external fuel sources for daily cooking.

They see advantages of the pigeon pea stalks as fuel:

- Already near the house, no added labour or time to fetch
- Storage close to the house
- Readily available after harvest
- Easy to prepare, comes 'ready to use', no splitting needed, dries quickly,
- Easy to light, gives fast heat
- Makes us independent from sourcing firewood elsewhere (collection or purchase)

Energy access

Access to electricity is particularly restricted in the area, due to the fact that households are not connected to the grid. For lighting, the population uses flashlights based on alkaline batteries. They use six medium batteries per month (spent 200 MZN/month, ca. 2.5 USD). According to GACC (n.d.) the average daily income is 1.69 USD, which would mean that 1.5 daily income-equivalents are spent on lighting. For farmers who do not grow cash crops this expenditure might be relatively more significant. For cooking and heating, people are using wood-based fuels, mainly firewood and agricultural residues including sorghum and pigeon pea stalks, collected for free close to their house to fulfil the most basic cooking and heating needs. In the season dried maize cobs are used to complement firewood. They prefer to collect certain hardwood species that burn for a long time and provide intense heat for cooking.

The disadvantage is that the wood needs to be split. They all used pigeon pea stalks already for up to six months, depending on the size of the household and the pigeon pea varieties planted. Although people produce charcoal for sale they hardly use it for cooking, only for special applications like roasting.

Table 45: Indicators for energy access on household level

Indicator	Business as usual	IFES
Electricity access	No change. No households are connected to the grid. For lighting they use battery flashlights.	
Accessibility of fuel (time and effort invested to obtain necessary quantity)	Firewood available in less than 30 minutes around the houses.	Additional fuel available from pigeon pea stalks at less than 10 min from the homes. This fuel replaces or complements firewood in 2-6 months, depending on household.
Availability of fuel (quality)	Hardwood firewood from the forest has high calorific value and thicker logs last longer in the fire. For initial ignition logs have to be split or complemented with twigs.	Pigeon pea stalks are easy to dry but they have more ash content, they don't develop the same heat as indigenous firewood and they are consumed quicker in the fire, yet they are ideal to start fires or for short cooking tasks.
Affordability of fuel	No money, only time invested for collection and preparation.	Less time for fuel collection and preparation.
Affordability of stove	No change: for firewood three stones are for free.	
Exposure to smoke	Very little as people cook outside or in well-ventilated shelters.	
Safety	No change.	
Convenience: reliability	No change.	
Convenience: Hassle factors	Need to split collected indigenous wood, but less time for feeding the fire.	No need to split the pigeon pea stalks, but higher frequency of tending the fires.
Convenience: quality of heat	Better heat from indigenous wood.	Less intense heat from pigeon pea stalks.

Apart from increased access to cooking fuel from pigeon pea stalks, the current IFES as observed in Manica implies no change regarding cooking energy system. Simple firewood stoves were not yet rolled out as it was not seen as a need yet. But this could be an added incentive in areas where scarcity of firewood is already felt as a burden on time, labour and money resources of the households.

The prevailing stove is a three stone fire located outdoors, either under the open sky or in a well-ventilated shelter. Therefore, the exposure to smoke from cooking fires is minimal, as there is good ventilation and fumes get diluted. Users know how to avoid the smoke and never sit down-wind from the fire. Normally they cook three times a day (breakfast, lunch and dinner) in all year. The preparation of the main meals takes on average about two hours.

In 2013, the members of UCAMA were trained on the sustainable use of biomass energy and in rationalizing forms of firewood and charcoal during the meal preparation process. At that time, 30 Chitetezo Mbaula clay stoves from Malawi that save up to 40 percent fuel were donated to UCAMA members, who appreciated them for the convenience and safety of use, the speed of cooking and the portability of the fire. They did observe that it was saving firewood, but that was not a priority feature for the users, although some claimed that the stove was still in use even after 3 years.

Examples from Malawi show that in areas with extreme firewood scarcity the households can become self-sufficient in cooking fuel as they only use resource from their own farms like pigeon pea, sorghum stalks and maize cobs when they use the stoves.

Initially it was expected that this technology would to spread throughout the Manica province. However, it was found that there was a very low demand for stoves, as there is still abundant woody biomass locally found close to people's homes and communities do not feel the need to rationalize the natural resources. Due to low demand the stove production group in Chimoio is currently nearly dormant. If in the future the stoves should become more in demand, the production capacity of the simple stoves would need to be built up.

Adaptive capacity to climate change and variability

The suggested indicator of 'Percentage of years without failure due to droughts or floods' could not be quantified, as the last years were mostly characterized by severe and long-lasting droughts. So as a proxy indicator the farmers were asked to estimate the risk of total crop failure.

Table 46: Indicators for the capacity to climate change and variability

Indicator	Business as usual	IFES
Estimated risk of total crop failure and partial crop loss by farmer	Total failure: High risk (50 %) Partial loss: Very high risk (80 %)	Total failure: ZERO risk (0 %) Partial loss: Very low risk (20 %)
Share of cropland under good adaptation practices (in % of main field)	0 %.	100 % of the main field with conservation agriculture practices increasing resilience of the farming system
Income diversification expressed in number of sources of income	N/A	Only one source of income added, but this source is substantial. Pigeon pea is now a reliable and major source of income with a good prospect to find a secure market in the future.

Maize is very vulnerable to both droughts and floods and there is a high risk for a complete crop failure when the drought attacks at the early growth stages. Even later in its development the maize plant can die and not yield any food crop. For the BAU scenario, without pigeon pea the perceived high risk of severe or total crop failure for maize was estimated at 50 percent while the risk for a reduced maize yield due to drought estimated at 80 percent based on observations for the last years. In the drought-stricken year 2016, some farmers had harvested only 10 percent of the maize they would have normally harvested in a year with good rains. Farmers who observed the demo-plots in the communities or had already grown pigeon pea as IFES system mentioned that the plant was protecting and enhancing the growth of their staple crop maize and that especially in the last season with extreme drought the resilience of pigeon pea to drought was very high.

Farmers also reported increased water infiltration and retention capacity of the soils with the IFES, so that more water from scarce rainfalls was available for the plants for a longer period of time. This might be also be due to the 'bio-drilling' through the deep roots of the pigeon pea, which open vertical channels for the water to infiltrate. These effects were recently also observed in an ongoing research by Ms Princess Adjei-Frimpong under the supervision of Prof Sieg Snapp. They observed considerably increased soil moisture levels up to about 120 cm depth in the soil profile. The paper is expected to be published towards December 2017.

For the IFES the perceived risk for total crop loss was rated to be reduced to zero, as the drought-tolerant pigeon pea would always produce something and not die. Farmers also indicated that pigeon pea mitigated the risk for a total loss for maize as the pigeon pea seem to protect the maize. During Focus Group Discussions farmers said that with the IFES they perceived their households as 'food secure' as they would not starve. There would always be enough food in the house to survive. Their main perception was that the IFES was a resilient and robust farming system that they will keep up. Pigeon pea was referred to as 'saviour if the maize goes wrong'.

This is probably one of the most important benefits and criteria for the sustainability of the IFES and resonates with observations from Malawi by Webb (2011, p. 12) that 'pigeon peas are sufficiently widespread as to be classed as a staple crop of the district'. This wide adoption is very likely to happen in Manica province as well.

Human Health

The most significant health related impact reported by farmers was the increased use of pigeon pea in their diet. This was not directly quantified but has likely positive impacts on the overall nutritional status, although severe long-term malnutrition was not obvious in the visited communities.

Table 47: Indicators for human health

Indicator	Business as usual	IFES
Exposure to indoor pollution (cooking)	Cooking is done mostly outdoors or in well-ventilated places. There were no cases of diseases reported to be caused by firewood smoke. There are no changes to indoor pollution through this IFES.	
Better nutrition through a more diversified diet	NA	Farmers said that they eat pigeon pea more often. The increased availability of protein-rich pigeon pea leads to a more a diversified diet and less maize-based diet, thus better nutrition for people.

There were little signs of stunting in children caused by long-term nutritional deficits. Yet farmers declared to suffer 'hunger periods' when they are vulnerable to acute malnutrition in times of crop failures. This is mitigated with this IFES through increased resilience as stated above.

ENVIRONMENTAL PILLAR

Soil health

In the IFES the pigeon pea provides soil cover for most of the year, thus reducing surface run-off and wind erosion, which assist to reduce depletion of soils. Soil nutrients are not only preserved but also actively added to the soil from the mulch and the additional nitrogen fixing pigeon pea, which have a much bigger root system than the beans. They provide the bulk of the nitrogen that lead to the substantial yield increment of the maize. Farmers also reported increased water retention capacity of the soils. The practice of ratooning or coppicing the pigeon pea and leaving the roots in the ground also increases soil carbon.

Table 48: Indicators for soil health

Indicator	Business as usual	IFES intercropping pigeon pea
Months of soil cover	6 months: Nov-April: Maize stover is burnt in the field, no soil cover from May-October, fields are partially tilled	11 months: Maize stover and pigeon pea leaves left in the field as mulch for soil cover, no tillage, pigeon pea stalks cover soil until clearing of field in October before planting in November
Soil nutrient availability (qualitative assessment)	Nitrogen is fixed through roots from intercropped beans only. Soil nutrients are often depleting fast, so that new fields have to be opened up under shifting cultivation	Additional nitrogen is fixed through roots from intercropped pigeon pea and through the incorporation of nitrogen-rich pigeon pea leaves. The leaves decompose easily. With the mulch from stover and stalks they add biomass (and soil carbon) into the soil, increasing water retention and microbial activity in the soil.

The head of Sussundenga Station (operated by IIAM) observed that the good agricultural practices promoted by UCAMA assist to improve soil fertility and avoid uncontrolled forest fires as they discourage burning the fields. In contrast to the BAU where depleting nutrient levels in soils over time are forcing farmers into shifting cultivation, with the IFES including improved management practices, soil nutrients are building up over time and in the second or third year yields even increase. This allows farmers to maintain farming on the same plot instead of shifting to a new plot.

Pollution

Pesticides are not used in the area, so this indicator was not relevant. With the IFES the entire main field is now under nutrient management practices and no chemical fertilizer was used. Thus, it is estimated that the pollution of leaching nitrogen is minimized.

Table 49: Indicators for pollution

Indicator	Business as usual	IFES
Fertilizer applied per unit of arable land (tons of nutrients per hectare of arable land)	Most farmers do not apply fertilizer on their main maize fields, only if they can afford it.	Fertilizer is never applied as nutrients come from pigeon pea roots and leaves.
Share of agricultural land under nutrient management practices (percent of main field)	0 percent. No nutrient management practices, no application of animal manure or green manure, sometimes still shifting cultivation practice. Maize Stover burnt in the field.	100 %: Nutrient build-up through green manure from pigeon pea roots and leaves add to nutrients, mulch from corn stover adds to nutrient conservation

Climate change mitigation

It was not feasible within the study to quantify GHG emissions so the share of farm area is taken as an indicator for the performance of farming practice. UCAMA promotes conservation agricultural practices intending to eliminate burning of fields after harvest. All farmers adopting the IFES have stopped burning of biomass on the field. Farmers that use pigeon pea as perennial crop leave the roots in the ground for better growth and reduced risk, leading to added carbon sequestration. Arguing that pigeon pea stalks are replacing unsustainably harvested biomass as cooking fuel, there is a plausible reduction in GHG emissions. It can only be quantified, if the percentage of unsustainably harvested biomass in that area is determined. The default value for the fraction of non-renewable biomass published by the UNFCCC (n.d.) for Mozambique is 91 %. Assuming that the heating values of pigeon pea stalks and firewood are in similar ranges, this means that 1 tonne of annually grown pigeon pea stalks used for cooking will replace ca. 910 kg of unsustainably harvested, non-renewable biomass.

Table 50: Indicators for climate change mitigation

Indicator	Business as usual	IFES
Share of farm area with agricultural GHG emissions mitigation practices (percent of main field)	0 %; stover burnt in the field	100 %; field is under conservation agriculture practices: No burning in the field, but maize stoves and small branches and leaves of pigeon pea left as mulch. Pigeon pea stalks are used as firewood, so they replace unsustainably harvested biomass as cooking fuel.

The total consumption of firewood and pigeon pea stalks will depend on household sizes and firewood management practices. Farmers were unable to provide exact figures on how much firewood they used per day, and this could not be measured within the context of this study, as an extended study involving at least 100 households would be needed to get meaningful data. However, we can derive some estimates from assumptions based on data from a Carbon Credit Programme in a similar area in Malawi where a simple ceramic stove, the Chitetezo Mbaula, was introduced. Based on the experience of the study author with firewood use in rural Malawi compared with our observations in the field, we assume that the total firewood consumption in the area of the case study is higher than in Malawi. Thus the comparisons with Malawi will yield more conservative estimates and the potential reduction of wood use in Mozambique can be higher. According to the Goldstandard Project Design Document of the Hestian Integrated Biomass Energy Conservation Project the test results from a survey with 300 households demonstrated that the baseline fuel consumption was on average 2.561 tonnes of fuelwood p.a. or ca. 7 kg per day. With the simple portable ceramic stove the woodfuel consumption was reduced by 38.8 % to 4, 35 kg firewood per day. Theses fuel savings correspond to greenhouse gas emissions reductions of 1.53 tonnes of CO_2eq per year per household.

The figure of 1.53 tonnes was based on the assumption that the firewood source is 73.8 % non-renewable biomass. In Mozambique the default value is higher at 91 %, so we can make a rough estimate that one stove in the Mozambican context could reduce GHG by up to 1.77 tonnes CO_2eq per family per year.

Based on the examples from Malawi we conclude that GHG emissions could further be reduced in Mozambique through the introduction of fuel-saving firewood stoves like the ‘fogao poupa-lenha’. Its design is based on the Chitetezo Mbaula so we assume that the performance will be comparable. The stove can be produced in Chimoio by some groups that were trained through GIZ some years ago.

Agrobiodiversity

Agrobiodiversity is already high as UCAMA encourages farmers already to go beyond their usual farming system based on maize, beans, cassava and sweet potatoes. Thus, they intercrop and rotate various species on their fields, such as cowpeas, groundnuts, sesame, sunflower, etc. as a way to increase their self-sufficiency and income. The intensification of pigeon pea intercropping has been the latest addition since 2013, with no negative impact on the agrobiodiversity.

Table 51: Indicators for Agrobiodiversity

Indicator	Business as usual	IFES
Share of farm area with more than one type of species of crops, trees and domestic animals; excluded are soil biota, spontaneous vegetation or other plants and animals (percent)	There is already intercropping and a diversity of crops, fruits, and trees. Even pigeon pea is present.	No change in share of farm area or number of different species grown, only extent of pigeon pea growing increased through systematic intercropping without negative impact on overall agrobiodiversity.

ECONOMIC PILLAR

Profitability

The input for pigeon pea is only for the seed. Even improved seed varieties are not ‘hybrid’ but open pollinating varieties that can be recycled in the next seasons. Seed is thus often obtained from own multiplication or not needed at all if the plants are ratooned so that they can re-spout in the next season. Even if certified seed is bought, the seed costs per hectare would be around six USD. The highest price in Chimoio was 180 MZN per kg at K2. Farmers claimed that with 5 kg they can plant the entire field of two hectares, so they would require 2.5 kg per ha. This sounded feasible, as the planting pattern is 90x90 cm, so that there are ca. 1 200 planting stations per ha. If they use up to two seeds per station they would need ca. 2 400 seeds/ha. There are ca. 1 000 - 1 200 seeds in one kg, depending on the variety.

Table 52: Indicators for profitability

Indicator	Basis for calculation	Business as usual	IFES
Output – input costs/ha/year (from main field) in USD	Maximum Input cost per ha: 2.5 kg of pigeon pea seed at 180 MZN = 6 USD total; Increment through improved yields of maize: 461 USD	No change in maize, no pigeon pea grown	Input for pigeon pea seed: 6 USD Output pigeon pea: 973 USD Additional maize: 461 USD Total surplus /ha: 1,428 USD

Without intercropping income from maize is very variable, as maize harvest is affected by drought, so very often there is no surplus for sale, so no income from maize. Yet we calculate a normal year with a normal yield of 1, 2 t per ha for maize without intercropping and the double for the intercropping with maize. This would mean a surplus of 1 200 kg of maize at 0, 38 USD/kg coming to 461 USD added income from maize. Of all the cash crops that the farmers are growing the pigeon pea intercropping offers them the highest return-on-invest: with only 6 USD for seed they can get up to 1,428 USD surplus at a minimized risk with hardly any additional labour. In the group discussions that was the most interesting farming option for the youth who are often in search of a better life in town with less physical labour involved.

Two game changers happened in 2016 to make the frame conditions for the profitability significantly more conducive:

- ETG emerged as a major bulk buyer of pigeon pea with transparent pricing and warehouses in the districts, additional to the main warehouse in Chimoio. The expansion of capillary market infrastructure closer to the farmers creates a reliable and accessible market infrastructure for pigeon pea. Bulk marketing through farmers associations further reduces dependency on vendors offering low farm gate prices.
- Since the Governments of Mozambique and India signed an agreement on the export of pigeon pea to India, there is access to an ever-growing export market for pigeon pea. This also increases competition among buyers and the farmers benefit from higher and more transparent prices. So far Mozambique was not among the major export nations for pigeon pea, but the country could become a leading exporter of the commodity given the enormous land resources, the huge number of smallholder farmers mainly operating on a subsistence basis with the potential of becoming active members in a market-driven economy that can lift them out of poverty.

Together with the increased drought resilience of the IFES the high profitability was the major motivation for the farmers to adopt this IFES of intercropping improved varieties of pigeon pea on their maize fields. There is little threat that the market will be saturated soon, so the nearly limitless demand on the market removes a big barrier for countrywide promotion of this IFES.

Resource use efficiency

There is no change in water withdrawn from ground water resources, as the agriculture is rainfed. Yet with the IFES rainwater is better utilised as infiltration rates are higher with mulch preventing surface run-off, which contributes to reducing flood risks. The higher biomass content in the soil improves water retention, thus reducing the potential need for irrigation. The 'bio-drilling' by the deep routes of the pigeon pea adds to that effect: once the roots decay, they create new macro and micro-porosity in the soil, thus further increasing the water infiltration rate.

Table 53: Indicators for resource use efficiency

Indicator	Business as usual	IFES
Water use efficiency: biomass production vis-à-vis water withdrawn (qualitative description)	Not applicable because agriculture is rainfed.	Rainwater is better utilised as both infiltration rates and water retention in the soil are higher. Zero tillage practice assist in water conservation.
Biomass efficiency: share of used biomass (percent) referring to non-edible parts of the plant (as opposed to biomass burnt or left to decay)	0 %, Maize stover burnt on field No pigeon pea grown	70 % for pigeon pea plant, where main stalk is used to substitute non-sustainably harvested firewood as cooking energy.
Land-use efficiency: crops produced per hectare of cultivated area (kilograms of edible crop produced per hectare of land per year)	1.2 – 1.5 t/ha of consumable food (maize grain)	4-5 t/ha of consumable food (2 – 3 t/ha maize, 2 t/ha of pigeon pea grain). Not only quantity increased, also nutritional quality of food.
Energy-use efficiency: increment of biomass produced with the same energy invested	Not applicable	Firewood from pigeon pea stalks estimated to be 0.5 – 2 t/ha when intercropping.

Concerning biomass use efficiency, it was applied only to non-edible biomass production yet it is difficult to estimate as the weight of the biomass from the maize is not weighed. The stalk of the pigeon pea is estimated to be 70 % of the non-edible biomass. It used to substitute non-sustainably harvested firewood as cooking energy. The land use efficiency of the IFES is considerably increased, both in terms of food and fuel: the combined food production from maize and pigeon pea is 4-5 t of food per ha versus 1.5 t of maximum food production in maize only. This does not reflect the higher nutritional value of the pigeon pea, which contains more protein and minerals as maize. As a side effect of the IFES that allows farmers to maintain farming on the same plot instead of shifting to a new plot, clearing of forests for new agricultural land can be avoided or at least reduced.

Depending on the variety, one pigeon pea plant can yield between 80 g – 1 600 g of dry stalk per plant. The 80 g are from the very thin stalks of e.g. the ICRISAT variety 00040 while the 1 600 g (dry weight after 8 months of drying) were measured from a non-specified white variety found in Barué district in 2013, where it was grown as a perennial crop with 2x2 m distances between plants. An average stalk of a variety with a compromise between crop and biomass yield can be 200-400 g per stalk. Even taking the lower figure of 200 g and a plant density of ca 2 500 plants/ha (2 plants per station) this would be 500 kg of useful firewood.

With more plants per station and/or a denser cropping pattern, and varieties with a thicker stem, this amount can easily exceed 2 t/ha. In Malawi farmers estimated stalk yields over 4 t/ha, but more data needs to be generated by farmers and by research institutions, who so far hardly measure biomass yields. A recent study from Malawi (ORR et al, 2014) has alerted ICRISAT as the main researcher and collaborator with national plant breeding programs for pigeon pea to better consider the firewood aspect, as it can be an important factor for farmers' preferences and decisions, which varieties to grow.

REPLICABILITY ASSESSMENT

The replicability of the IFES was assessed using guiding questions as suggested in the AF.

WHERE AND HOW CAN THE IFES BE REPLICATED?

This IFES can be easily replicated in most parts of Mozambique, especially where maize is already a staple crop. The interest will be stronger if farmers have experienced the vulnerability of maize by drought and/or suffer from scarcity if firewood for cooking and heating. Pigeon pea can also be intercropped with any other cereal like sorghum, millet and even with cassava. In short: we come to the conclusion that the IFES is replicable in most parts the country.

ENABLING OR CONSTRAINING FEATURES FOR THE REPLICATION OF IFES

Clarity and credibility

There is evidence from both farmers and science about the reinforcing benefits of the IFES intercropping pigeon pea with maize. UCAMA is members-owned with leadership that is highly **respected and trusted,** which makes them an ideal replicator for agricultural innovations among smallholder farmers. Demonstration plots and farmers long experience from neighbouring districts like Barué show clear advantages of the IFES. The advantages become evident and convincing once farmers have seen with their own eyes from demonstration plots or through exchange visits and farmers field schools that from the same field with little effort they can get more food, income and firewood.

Legitimacy

Recommendations through UCAMA have a high legitimacy among the farmers. The strategy of the demonstration plots and the farmer field schools organized by UCAMA are a powerful tool as farmers can clearly see the benefits of this IFES from other fellow farmers. So this IFES is seen as a highly credible home-grown initiative and not an outside intervention. Participating farmers assumed **ownership** of the project idea when running the first trials on their own farm.

Pigeon pea is known in the area, but the IFES aspect originated from a co-operation between UCAMA and the Southern African Conservation Confederations Agricultural Unions (SACAU) on a programme of Conservation Agriculture. SACAU, at that time, was cooperating with the Comprehensive Africa Agriculture Development Program (CAADP) implemented by the German International Cooperation (GIZ) supporting the replication of an IFES intervention in Malawi where pigeon pea – maize intercropping was complemented with the introduction of simple firewood-saving clay stoves.

The members of UCAMA have been actively involved and informed about the benefits of pigeon pea. A crucial event was a training held with UCAMA in November 2013, where lessons learnt from Malawi were presented. As part of the training experts from Malawi brought stoves from Malawi that are still in use and some initial seed from MozSeed for demonstration plots. Calendars showing lessons learnt and opportunities regarding IFES from Malawi were received as an authentic and credible example of good practices to which the UCAMA farmers could relate to.

Demonstration plots in Barué district showed that people make a lot of money from selling pigeon pea; which encouraged farmers from other districts to adopt and replicate these IFES systems on their own land.

Ease in assessing results

One factor that greatly enhances the speed of replication of this IFES is the clear visibility of **immediate results of increased yield and plant resilience;** which can be observed and assessed already in the first growing season on demonstration plots or on fields of early adopters of the IFES. The demonstration plots also serve to multiply seed to give to interested farmers. This is an ideal situation to encourage farmers to replicate the intervention on their own land. Soil improvement is expected to become evident only from the second or third season on, as was experienced in other regions.

Business model including financial viability

For a successful business model all elements along the entire value chain need to function from inputs, production, to trade and market linkages to sales. Often the sales and access to (export) markets is the most difficult part, but in this case the opposite is true. The **big potential income from pigeon pea as a cash crop for export is probably the biggest pull factor for a quick replicability of this IFES.** The game-changer is the MoU signed between the Government of Mozambique and the Government of India in July 2016, which provides a **guaranteed and growing market for pigeon pea** to export at least 100 000 tons pigeon pea per year **with promising high and transparent prices as the prices are linked to the public procurement price in India.** In 2016 the price peaked at 2, 50 USD /kg in India, while the price in Mozambique was at 38 MZN or almost 0.5 USD/kg. The total yearly demand by India is currently estimated at 900 000 tons, and this is likely to increase with the fast-growing population in India. Therefore, there are good prospects that the Indian market will absorb any surplus that the Mozambican farmers will produce. This is a very unique and comfortable situation that will enhance the replicability of this IFES and benefit many farmers. Having the end of the pigeon pea marketing chain sorted out, the upstream elements are already in place or easy to achieve with some support addressing the bottlenecks on seed supply and extension services:

Input supply: multiplied improved seed can be accessed from UCAMA or certified seed from commercial suppliers. Input costs for seed are low (< 5 USD/ha) or zero if the seed has been obtained from multiplication on the own fields or within the UCAMA communities.

Production: pigeon pea is becoming a known crop that can easily be produced, as long as the initial seed is available. With the added IFES aspect and the proven benefits of the synergies with the maize crop, this is likely to spread on its own, even faster with appropriate extension services.

Market linkages and traders: ETG is already in place with 6 warehouses in the Manica province and the vision to expand its presence. With the envisaged growing demand for pigeon pea more traders will come in which will not only increase access to markets for farmers, but create competition for the commodity. This will shorten marketing chains, reduce the number and dependency of middlemen and increase profitability for farmers, which will suddenly be catapulted from subsistence farmer onto a very promising export market.

Under the Pigeon Pea Support Programme by the Ministry of Agriculture, many institutions are mapped out to play their role in the lubrication of this marketing chain for export of pigeon pea. It is in the national interest to maximize on this opportunity to obtain much-needed foreign exchange. Pigeon pea export is likely to climb near the top of the export commodities.

Therefore, no external funding is needed for farmers to grow pigeon pea as buying structures are encouraged and likely expand through market demand. Strengths of marketing power to achieve better farm gate prices through joint marketing of larger quantities as association. Direct individual income after first season guaranteed for each farmer is a very strong incentive.

Alignment and linkages

There is strong support of the entire value chain through the National Plan for the Production of Pigeon Pea (PFFB) to increase the production of pigeon pea in response to the MoU with India. Other players like FAO, USAID etc. also strongly support the pigeon pea value chain, not only for export but also for national food security and climate change resilience.

The IFES pigeon pea intercropping is also in line with recommendations and programs implemented by UCAMA on climate smart conservation agriculture.

The IFES pigeon pea intercropping could also become part of a National Appropriate Mitigation Action (NAMA), as the Government of Mozambique intends to start the development of a NAMA in the AFOLU sector (Agriculture, Forestry and other land uses).

Technical complexity, coordination and behaviour change

This IFES is very **simple** as it is mere intensification of a known crop added into the existing farming system. Pigeon pea grow on the same land and without additional labour than that for the field preparation for the staple crop maize. No other inputs than seed is needed which can be obtained from other farmers, through UCAMA input and the seed multiplication programme or from vendors in town (Chimoio).

No behaviour change is needed as pigeon pea integrates into the existing farming system if it is not already part of it (Barué district), or practiced with another leguminous crop. It was seen as added benefit that on the same land with the same labour for field preparation a sure added income could be achieved. Pigeon pea is already part of the diet in some areas that served as example in exchange experience visits. The government provides extension services to farmers and so does UCAMA. This support is needed to replicate the IFES in other areas.

Goats that can destroy the crop are a threat to the IFES, but it is a problem that can be managed through bylaws by the communities themselves. Early maturing varieties can mitigate that as the crop is ready to harvest before goats get released into the fields.

Acceptability in local knowledge systems and culture

Cultural acceptance is extremely high, no constraints were mentioned. Intercropping maize is common practice with (green bean. Only some tricks in the management of pigeon pea to improve yields are need to pass on like the ratooning and coppicing to induce ramification and yields of both crop and biomass. The energy aspect of the IFES is only of interest in those communities where firewood is becoming scarce. No cultural taboos or resistance were observed that would prevent the uptake of simple firewood stoves for daily cooking. Only the need is not yet felt acute enough to actively look for solutions to reduce firewood or general cooking fuel needs.

PERSPECTIVE OF THE MAIN STAKEHOLDERS AND INSTITUTION IN THE REPLICATION OF IFES

The main actors are the farmers and entrepreneurs who see this IFES only positively and as a big additional income opportunity with little additional work. Farmers who observed the demo-plots or had already grown pigeon pea mentioned that the plant was protecting and enhancing the growth of their staple crop maize and that especially in the last season with extreme drought the resilience of Pigeon pea to drought was very high. The crop was called 'The saviour, if maize goes wrong'. In addition to increased income, farmers can expect improved soil health and increased resilience in times of drought. Farmers perceive the additional income from the same field as a ‘free gift’ from the crop. Firewood from the pigeon pea stalks is seen as an added advantage but not a crucial aspect, as there are still abundant fuelwood resources in this region.

UCAMA is both the implementing and the supporting organization in this case. The responsible leaders at UCAMA see this IFES in line with their efforts to make agriculture more climate smart and resilient. UCAMA got into the promotion of this IFES through the observation of the practice in one of its districts in Barué, where people make a lot of money from pigeon pea. Sometimes pigeon pea is their biggest money-spinner. UCAMA wanted farmers in the other districts of the province to have equal benefits. They see pigeon pea intercropping as a big chance to provide meaningful services and open opportunities to lift up livelihoods for their members. This is their main motivation to set up demonstration plots since 2014 to promote pigeon pea. Due to the success of the previous years, UCAMA plans to keep promoting this IFES and intends to establish 60 more plots in total for all districts in the coming season. There are now demonstration plots in 9 out of the 12 districts of the province. UCAMA does the extension, brings the initial seed and does seed multiplication. There are private plots and communal plots. The associations are in charge to select the individual farmers. They receive 5 kg of seed and have to repay 10 kg after the harvest. This system is accepted by the communities, and the members we interviewed were eager to receive their seed for planting on their own fields.

There is also seed multiplication on communal plots. One community (3 de Fevereiro in Macate district) harvested 70 kg of seed on a 50x20 m plot even in this dry year. They have shared this among the 19 members, so that every member has enough to plant in the upcoming season. UCAMA is the only organization providing support to farmers so far. More help is needed, especially from the Ministry of Agriculture. There are no ‘outside champions’, the Coordinator of UCAMA, José Basquete, is the most visible home-grown champion. He is active role model as he himself has harvested 25 bags in this last season and he can talk with authority and leadership on the benefits of intercropping Pigeon pea with maize. He also shares part of his seed with other farmers. There is a lot of interaction between the stakeholders within the province as UCAMA has regular meetings on association level, with the facilitators and technical officers. The coordinator Mr José Basquete participates in meetings with the local farmers’ associations and gives credibility to the programme. What is still lacking is the platform to bring all relevant stakeholders together like the farmers, private sector and government agencies. Even the interaction between government agencies is not yet well established as crosscutting issues always require specific political will for inter-sectoral cooperation.

This is likely to increase as two platforms for this inter-sectoral topic of IFES are emerging: One is the national action plan for the promotion of pigeon pea (PFFB) that foresees the creation of a platform for interaction of the various stakeholders. The other opportunity arising is the request by The Department of Environment (DINAB) to develop a National Appropriate Mitigation and Action (NAMA) in the agriculture and forestry sector. This platform will already bring the required various sectors together.

Summary: All stakeholders in this IFES are convinced about its benefits and highly motivated to support the replication, not only in their province but if there is interest also beyond at a larger scale.

THE EFFECT OF THE POLICY ENVIRONMENT ON THE REPLICATION OF IFES

Policy instruments

The policy framework has never been as conducive and favourable for the replication of this IFES as now. The PFFB is the strongest available policy element specifically supporting the pigeon pea value chain under the food aspect. It is trying to align other policies and instruments from other government sectors, but with a focus on food security, export trade and environmental aspects. Currently the biomass energy aspect of the IFES is not reflected in the stakeholder platform, FUNAE and the Ministry of energy are only mentioned for the provision of electric energy.

Research and development (R&D)

Parts of the 2 Mio USD envisaged to be allocated to the PFFB lead by the Ministry of Agriculture and Food Security for the development of the pigeon pea value chain are supposed to go also research and seed multiplication, so there should be active support in this field. However, there is more talk about technical support and new seed varieties from India while some stakeholders like ICRISAT with experience in the Mozambican context are not mentioned. They are the main plant breeder for pigeon pea in the region. All varieties released so far in Mozambique are from ICRISAT: two long-maturing varieties ICEAP 00020 and ICEAP 00040, while ICEAP 000554 and ICEAP 00557 are medium-maturing varieties. There are also longer maturing local varieties, but no really short-maturing ones that could be harvested before July. This might be a gap to fill in the future in participatory process between farmers and research.

Breeders should be reminded that there are other preferences by users than only crop yield and suitability for export to India. Institutions involved in plant breeding, seed selection and multiplication should be made aware of the IFES aspects of pigeon pea and also consider the firewood yield and the risk spread between different varieties as potentially important aspects for adoption of varieties by farmers. So far, plant breeding is only focusing on crop yield, biomass yield was neglected, but should get higher on the agenda.

Seed selection and multiplication should be more participatory in close cooperation with the concerned farmers. This can enhance a quicker and more cost efficient spread. There is the example from the variety MtwaJuni in Malawi that was never officially released, not promoted by any organisation but only spread among farmers passing on seed or buying the seed from the food supply on the local markets.

Under the seed multiplication program, private seed companies operating in the provinces will be involved. The production will be made under outgrower schemes with the involvement of small and medium producers.

In order to increase the availability of certified seed, in addition to commercial production, local seed production will be carried out in coordination between Government through the allocation of quality seed to the associations of small and medium producers for their multiplication.

Technology deployment

For this IFES no special technologies need to be deployed, which make it easy to replicate. Simple fuel-efficient firewood stoves were part of the original concept of the IFES. The people who received the first lot of stoves in 2013 found them useful and some are still using them, but overall the need for more fuel efficiency was not yet felt as there is no scarcity of cooking fuel yet.

Still it would be useful to get prepared for the future as the stoves complement very well with the use of pigeon pea stalks as firewood, as can be learnt from the example in southern Malawi.

Building of human capacity

Human capacity for supporting the development of pigeon pea intercropping is currently weak. There is lack of extension services which can support farmers. UCAMA already has trained extension staff, but for the replication in a new area extension staff would be the first to be trained about the IFES. The PFFB also foresees investment in training of extension capacity.

Communication networks, partnerships and strategies

UCAMA has a good communication network among their affiliated farmers, they have regular meetings and enhance participatory learning through farmer field schools. They have developed extension material on good practices and the growing of pigeon pea to share among their members. They partner with some NGOs, government agencies and other stakeholders in the province. A platform for information sharing of knowledge and success stories and means of multiplication through media is key for the rapid spread of messages that can lead to a replication of the IFES. UCAMA is looking for broadcasting opportunities through print media, radio and TV and public events.

The PFFB also foresees the creation of platform for coordination among different stakeholders in the value chain:

- MASA (IIAM, DINAS, INIR, DINAB and FDA);
- MIC (BMM, ICM, and INNOQ);
- MEF (AT);
- MOPHRH (ANE and DNGRH);
- MIRENE (EDM and FUNAE);
- Association of producers, cooperatives and small producers;
- Private Sector (Companies of agricultural inputs, processors, developers and exporters);
- Development partners (donors and NGOs); and
- Local Governments (DPASA's and SDASA's).

Resource and property rights, including secure land and resource tenure

Farmers use the land, based on the rights envisaged in the Mozambican Land Law (Law nr. 19/97), that gives them the right to use land according to customary practices. There are no other natural resources or assets involved in this IFES that would be needed for replication.

Encouragement of good and discouragement of bad environmental behaviour

UCAMA encourages their farmers to apply climate smart conservation agriculture practices. The uptake by farmers is rewarded in the sense that seed multiplication plots are only set up in farmers clubs that adhere to the recommended practices. There is discouragement of bad environmental behaviour like field burning, shifting cultivation, etc. and messages are spread by UCAMA but there are no punishment mechanisms.

National or regional production targets

The 5 year national PFFB coming into force in 2017 aims at increasing production targets to reach 500 000 ton/year by 2022, to satisfy the export market to India but also national and regional demand.

Summary: The policy environment has never been as favourable and enabling for the replication of this IFES as at the time of the case study. Most frame conditions are supportive, even if they have a bias towards the food production side. With sensitization about the energy side we feel there is a big opportunity to replicate this IFES nationwide and beyond.

THE EFFECT OF HUMAN AND TECHNICAL CAPACITY IN THE REPLICATION OF IFES

Technical capacity

Technical support for pigeon pea is currently provided mainly by UCAMA. The 5-year PFBB provides an important opportunity to prioritise pigeon pea and get other stakeholders more involved which will speed up replication beyond the province and help to improve the extension network for all strategic districts of pigeon pea production, including other crops in the community.

Seed suppliers are there, but more seed multiplication on farmer level as is needed for the rapid replication of the IFES, although pigeon pea is very robust and even food grain can be used as planting material still giving good yields. Nevertheless, it is recommended to start with certified seed material in new communities.

In the 5-year PFFB there is talk of hydro-mechanical equipment to enhance pigeon pea seed multiplication but the success of the farmers of UCAMA give clear evidence that high yields and profitability can be reached without technical equipment when pigeon pea is intercropped with maize. This offers a bigger potential for faster and cheaper replication than envisaged in the strategic plan.

As regards stoves, the current producer group in Chimoio should be strengthened and other producers encouraged to take up the production of the simply ceramic stoves.

Institutional know how and management capacities

UCAMA is the main institutional knowledge bearer in the province with limited coordination with other stakeholders. The 5-year national PFFB will create a platform at national level for the development of knowledge and coordination among the actors along the value chain, in order to ensure overall coordination, monitoring, and evaluation. It will also be tasked to enhance supply of quality basic and certified seed and its timely allocation in the provinces.

Education, training and knowledge transfer

There are many educational institutions[24] , which to a certain extent already address the issues of food production versus renewable energy production from bioenergy, yet there is no holistic view of IFES. Therefore, there is the opportunity to increase the awareness among the multipliers of education with targeted sensitization for IFES e.g. regarding the benefits of using pigeon pea as an additional source of income and to improve soil fertility, so they can pass the messages on to the population of Mozambique and create broader awareness. For regions where charcoal and fuelwood is very expensive, the use of pigeon pea stems as alternative to wood-fuels will be an additional benefit.

SUMMARY ON REPLICABILITY

The replicability of this IFES is rated to be very high.

For all indicators there were answers showing strengths and enabling features of the IFES. Only minor constraints were identified that can easily be overcome. The entire assessment points to strong advantages of the IFES over the BAU, which should enhance the replicability of this IFES:

There is strong evidence that the IFES intervention can be successfully replicated, as it is clear, credible, with tangible economic benefits and prospects to high income. It does not require new technology or

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[24] For instance - Eduardo Mondlane University, Polytechnic Institute of Rural Development of Gaza and Niassa, and all Agrarian Institutes of the country)

a significant behaviour change. The IFES has the potential to spread and replicate on its own, but the speed of replication can be greatly enhanced with the provision of seed and extension services.

Human capacity is already availably but more extension agents are needed and more awareness about the holistic approach of the IFES, especially the energy side is recommended to speed up the replication of the IFES on national level.

CONCLUSIONS

The assessment shows that the integration of pigeon pea into existing maize fields is simple. The uptake is higher if people have already experienced the vulnerability of the maize in drought situations, as the pigeon pea, protects' the maize crops, reduces risk of loss and increases yields and soil fertility through the positive impacts on the chemical and physical properties of the soil. The simplicity of the system is very visible and clear, as it is an add-in, on the same land and without additional labour than that for the field preparation for the staple crop maize. No other inputs than seed is needed which can be obtained from other farmers, through UCAMA input and the seed multiplication programme or from vendors in town (Chimoio).

MAJOR ARGUMENTS LEADING TO THE POSITIVE ASSESSMENT REGARDING THE SUSTAINABILITY OF THE IFES:

The IFES scored better than the BAU for the majority of criteria and indicators, with clear advantages and benefits to the farmers. Sometimes no change could be detected. Except regarding the quality of the burning material (hardwood performs better than pigeon pea), IFES outperformed the BAU case.

The main incentive for farmers to adopt and maintain this IFES is the economic and overall benefit through the additional income or avoided expenditure from the sales to a guaranteed market. In case markets fail, they can still consume the crop themselves. This is reflected in the positive assessment of the interlinked indicators regarding food security, adaptive capacity to climate change and climate change mitigation ad profitability, supported by the positive assessment regarding indicators contributing to the yield increase soil health, resource efficiency regarding land, labour and water.

Farmers are convinced about the benefits of the IFES for their livelihoods. They feel that the IFES increases their food security and resilience while minimizing their risk to face hunger. They have a very positive attitude towards pigeon pea and high esteem of the crop.

Perceived synergies on requirements for land and labour:

- The IFES does not require extra land, as it is planted intercropped with the maize at the same time on the same main field.
- It does not require extra labour as the weeding is undertaken anyway. The only extra labour is the seeding, harvesting and removing of the stalks at the end of the season when clearing the field for the next planting season.
- Pigeon pea can be grown as annual crop or coppiced or ratooned as a perennial crop.
- It does not need additional watering or fertilizing once established in the field.
- At no time are there labour or land conflicts with the staple maize or other food crops.

Added benefits perceived by farmers from intercropping of pigeon pea:

Low-risk additional income with low inputs:

- Income from pigeon pea was perceived nearly as ‘free and secure money’.
- There is an added high-value crop from the same field with very little extra labour. Demand is growing so that the purchasing structure develops. Farmers no longer rely on vendors passing by their farm gates but they now can negotiate transport as a group and fetch better prices for bulk sales. Markets have become easier accessible with ETG purchasing at warehouses also outside the district capitals.
- Growing pigeon pea is easy. It does not require other inputs than the initial seed and has very little risk of failure through adverse weather conditions. Especially when intercropped there were no major threats observed by pests. Diseases were not known.
- Pigeon pea is extremely drought tolerant and there is little risk of losing the crop neither to drought nor to floods, unless they wipe out the entire field.

Pigeon pea has been observed to improve the maize yields and increase the resilience of the maize crop to climate change impacts:

- It physically protects the maize from wind damage
- It creates a microclimate in the field reducing moisture losses and soil evaporation. Even if there is more biomass that could transpire water, pigeon pea leaves develop only after the maturity of the maize and thus hardly compete for water during the maize cob-filling period.
- Pigeon pea roots can go beyond 120 cm of depth in to the ground. This has two main effects: the plant functions like agroforestry tree and brings nutrients to the surface from deeper soil layers that the shallow maize roots do not reach. Pigeon pea roots also naturally till the soil and leave holes that increase the porosity of the soil. Water can better infiltrate into the soil through those pores and get deeper in the ground through vertical channels opened by the roots of the pigeon pea. This is effect is also referred to as bio’-drilling’, making mechanical tilling unnecessary.
- The increased soil porosity also decreases the bulk density of the soil. This makes the soil lighter and softer; which eases the manual labour required to make planting holes.
- The roots fix nitrogen in the soil and reduce the need for extra fertilizer
- Leaves also cover the soil after the maize is harvested, thus reduce soil erosion and top-soil loss through surface runoff or wind, which helps to maintain soil fertility
- Pigeon pea leaves also have a high nitrogen content, they decompose quickly and incorporate organic matter into the soils. This improves not only soil fertility but increases water infiltration (thus again contributing to mitigate flood damage) and water retention capacity of the soils (mitigating drought effects and increasing survival rates in dry spell periods)
- Some farmers reported that they observed the following changes on maize plants grown in association with the pigeon pea: plants looked generally healthier and better developed, they had a better root development, thicker and greener stems, broader and darker leaves, bigger cobs with bigger and heavier grain per cob etc.

They did observe differences in yields, both concerning the grain and the biomass, depending on the variety and the plant management. They found that coppicing the main trunk at the time the maize is harvested and the pigeon pea is left alone on the field, enhances ramification and crop yield.

When comparing pure stand pigeon pea with intercropping they reported that locusts would rather attack the pure stand field than if the pigeon pea were ‘hidden’ in the maize. We asked what they would recommend to young people who want to start their own farming activities, maximise their income to lead a good life and minimise their investment and labour. The answer was unanimous that had already experience with pigeon pea.

The rating regarding the adaptive capacity to climate change, where the IFES also scored high, supports the above: farmers refer to the pigeon pea as the saviour 'fall-back' crop that can fill the gap if the maize fails and make them more resilient to climate change impacts. As droughts are occurring more frequently in recent years, farmers increasingly felt that their food security and livelihoods were under threat. With the pigeon pea they feel they will be much more food secure and will no longer experience hunger periods, as they have additional food from pigeon pea or they can use proceeds from sales to buy maize on the market. A porridge can be made out of pigeon pea that is similar to the maize-based staple food. It is nutritious and can also be given to children when they cry, which is an important element in their definition of 'food security'. The pigeon pea has no stigma or negative attitudes associated with it, thus no major resistance for the uptake of this crop is expected.

The perceived increased resilience is probably one of the most important benefits and criteria for the sustainability of the IFES for years to come as the climatic situation is not expected to improve exacerbating the vulnerability of farmer's livelihoods if they are not adopting the IFES.

Agrobiodiversity, pollution and employment are indicators where no change was seen or where positive aspects of the IFES did not matter to the farmers.

As regards the energy access aspect, the importance for sustainability depends on the environment of the community: in areas where firewood is still abundant the energy aspect of the IFES is not going to be a major pull-factor for the sustained use of this IFES. But as natural resources are dwindling and biomass fuels are becoming scarce, this aspect will rise up the list of priorities for farmers and increase the sustainability of the system. In the study area there was rising interest in the fuelwood from pigeon pea but it was not the decisive factor for farmers decision-making. In the neighbouring Malawi where access to biomass cooking fuels is an issue as important as access to food, the energy aspect was one of the two major drivers of the sustained adherence of farmers to the IFES.

The replicability of this IFES is rated to be very high in Mozambique.

For all indicators there were answers showing strengths and enabling features of the IFES. Only minor constraints were identified that can easily be overcome. The entire assessment points to strong advantages of the IFES over the BAU which should enhance the replicability of this IFES. There is strong evidence that the IFES intervention can be successfully replicated as it is clear, credible, with tangible economic benefits and prospects to high income. It does not require new technology or a significant behaviour change. The IFES has the potential to spread and replicate on its own, but the speed of replication can be greatly enhanced with the provision of seed and extension services. If pigeon pea is already known, extension services having better information on farming practices (intercropping in rows, 2 seeds per planting station, coppicing at branching stage once the maize has been harvested to create more branches and more fruiting, not burning of the fields but use the leaves and small branches for soil coverage in line with the recommendations of conservation agriculture…) can lead to increased production and thus increased income as the market is there.

The big potential income from pigeon pea as a cash crop for export is probably the biggest pull factor for a quick replicability of this IFES. The game-changer is the MoU signed between the Government of Mozambique and the Government of India in July 2016, which provides a guaranteed and growing market for pigeon pea. This can be enhanced if the IFES can be considered in the framework of the upcoming development of NAMAs in Mozambique. All stakeholders in this IFES are convinced about its benefits and highly motivated to support the replication, not only in their province but if there is interest also beyond at a larger scale.

The policy environment has never been as favourable and enabling for the replication of this IFES as at the time of the case study. Most frame conditions are supportive, even if they have a bias towards the food production side. With sensitization about the energy side we feel there is a big opportunity to replicate this IFES nationwide and beyond. No technical capacity constraints were identified. Human capacity is already availably but more extension agents are needed and more awareness about the holistic approach of the IFES, especially the energy side is recommended to speed up the replication of the IFES on national level.

Summing up this IFES is very sustainable and has significant potential for replication in Mozambique.

RECOMMENDATIONS

This is the IFES case with the highest potential to be replicated so our recommendation is to find ways how best to do this as soon as possible with the means available. At this point we feel that we can give some recommendations what we think could or should be done to replicate and scale up the IFES, however we feel that the recommendations should be elaborated by the stakeholders themselves based on the information obtained from this report.

The rationale is that there is no new funded IFES programme with an own budget coming up to fund specific IFES replication and scaling up, so any recommendations will have to be implemented within existing programmes and ongoing work. This is a typical scenario for mainstreaming of a topic that enables stakeholders to achieve their own goals in a better way if they take into consideration the respective topic in their programming.

SENSITIZE ALL POSSIBLE STAKEHOLDERS ABOUT THIS IFES

Sensitize all possible stakeholders from Government, NGOs, faith-based groups, donors, private sector players and other relevant stakeholders **about the concept of IFES in general and of this particular synergy of pigeon pea incorporated into existing farming systems, providing food, cash and cooking fuel.**

USE THE OPPORTUNITY OF THE NATIONAL PLAN FOR THE PROMOTION OF PIGEON PEA (PFFB)

The PFFB targets to increase the production of pigeon pea by a fourfold factor in the next five year. The PFFB foresees the expenditure of 2 million USD for hydro-mechanical equipment (50 % of the overall budget). While irrigation might provide potential opportunities for intensification of production, there are risk of bottlenecks with equipment supply and cost and it might not be needed everywhere: Pigeon pea is very resilient to climate variability and there are numerous varieties to suit different climatic and soil conditions. As the Manica case proves that production of pigeon is feasible without irrigation and hydro-mechanical equipment if the IFES approach is taken.

On the basis of the above one should envisage various complementary implementation strategies. The ambitious target of 500 000 tons by 2020 is likely to be achieved with a diversified approach putting more emphasis on smallholder farmers. They can produce the pigeon pea on their existing fields without additional inputs other than seed and knowledge. The successful Manica example shows that it is possible with very little input and no hydro-mechanical equipment to grow pigeon pea successfully in combination with staple food crops on the same field. Farmers reported less disease pressure when pigeon pea when intercropped with maize. One that basis one recommendation is to integrate the IFES perspective into the upcoming and already funded programme: IFES offers an opportunity to fast-track the implementation of the PFFB at even half the budget while removing some potential bottlenecks of implementation.

As many smallholder farmers as possible should be empowered and enabled to benefit from this historic opportunity if they get to know about it and can get access to seeds and markets with fair prices. Farmers should acquire more ownership in the value chain. Rather than becoming dependent outgrower farmers they should be supported to become self-reliant entrepreneurs using their farmers associations for better market integration. With the enormous market opportunity through the MoU with India, this is probably the most important opportunity for smallholders to move from subsistence farming to entrepreneurs with nearly directly access to world markets without a long chain of middlemen.

If one farmer who so far had limited access to markets in the last years could produce 40 bags of 50 kg pigeon pea for sale, this would be 2 tons per farmer. The target of 500 000 tons of pigeon pea or the equivalent 10 million bags of 50 kg by 2020 could be achieved if 250 000 smallholder farmers produced 40 bags for sale on less than 2 ha of their land intercropped with maize. With the added incentive of a guaranteed market farmer might even produce and sell more than 'only' 40 bags as some farmers claim that their potential yield of a 2 ha field could be 80 bags or 4 tons. The supply of seeds to 250 000 farmers can be carried out over several years, starting in the first year with 1 kg per farmer, who can multiply the seed him/herself on the own field. This would require 250 tons of seeds. If, in the first year, only 10 % of the farmers get 1 kg, they can multiply the seed and pass on 1 kg to another 10 farmers, who would then multiply the seed on their own field in the second year. This would require 25 tons of seeds in the first year. If seed multiplication would be undertaken through demonstration plots with farmer clubs like at UCAMA, an input of 5 kg of seed in the first year could reach 100 farmers in the second year, only 12,5 tons of seeds would be needed in the first year to reach 250 000 farmers in the second year.

This shows that a pass-on-multiplier approach can reach many farmers in a short time and yield good results already after 2 years. This approach would reduce the time and burden to import or multiply seeds through seed companies. Involving smallholders from the start promises increased food/nutrition security, soil fertility, climate change adaptation, economic empowerment and poverty reduction with less pressure on natural resources for fuelwood. This all should be in the interest of government, NGOs, donors and other stakeholders.

USE THE OPPORTUNITY OF THE INTENDED AFOLU NAMA TO INCLUDE THIS IFES

The NAMA committee lead by the DINAB should be well-sensitised about the opportunities to include the aspect of GHG emission reduction through this IFES on a larger scale as a contribution of the agricultural component of a national NAMA. There is a request already from the DINAB for FAO to support the development of a NAMA in the Agriculture, Forestry and Other Land Use (AFOLU) sector. From the experiences during the recent Africa-wide workshop on NAMA in April in Ghana, the IFES concept in general but more specifically the intercropping of pigeon pea emerged as a welcome opportunity to include in NAMAs.

In Manica province pigeon pea stalks are already used for firewood in the prevalent conventional 3-stone fires. As long as firewood shortage is not a felt as an acute need, the introduction of improved firewood stoves will not make much sense in this area. Still, the linkage of the producers of simple ceramic firewood-saving stoves (so far supported by GIZ) to the UCAMA should be carried out in order to facilitate future linkages. In other regions with already existing firewood shortages, the stove should be introduced as an additional element of the IFES.

RECOMMENDATIONS FOR THE MINISTRY OF AGRICULTURE:

- Focus on existing farmers associations e.g. UCAMA and other UNAC members to organise outgrower farmers to significantly speed up see multiplication because seed availability is likely to be the biggest bottleneck for expansion and implementation of the PFFB.
- Farmers should be involved to bring in their perspective on preferences and experiences with seed varieties including the added energy aspect on selection criteria of varieties. One should also allow on-farm seed multiplication in coordination with IIAM for control purpose.
- Realization of the inventory of existing and adapted varieties that can maybe released. As a matter of example, the variety of NthawaJuni in Malawi; which is the most successful variety officially released or introduced). Farmers spread it themselves because they like it, it is early maturing, high yielding, tasty and has a good biomass production for fuel.
- Training of extension agents and farmers on good practices of production, processing and storage, and integrate field experience created by UCAMA. Moreover, organise farmers field schools (FFS as a good learning example combined with the establishment of demonstration plots.
- Creation and dissemination of incentive packages for pigeon pea production and highlight the energy aspect of the biomass for cooking and process heat as part of the energy mix.
- Use the multi-stakeholder platform foreseen in the PFFB to enhance and coordinate true inter-sectoral efforts for resource management (both food and biomass energy)
- Acknowledge that biomass energy is here to stay and will not be replaced in the near future by alternative energy carriers especially for thermal energy. Biomass is a renewable energy if the sources are managed sustainably, and the pigeon pea can add to this and reduce pressure on unsustainably managed resources like communal forests etc.
- Develop a joint vision on how best to promote the IFES aspect among stakeholders.

RECOMMENDATION FOR CIVIL SOCIETY ORGANIZATIONS AND DEVELOPMENT AGENCIES:

- Participate in the formulation of public bioenergy policies and strategies, as well as in the monitoring and evaluation of their implementation.
- Participate in the creation of institutional and technical capacities in the design and evaluation of bioenergy initiatives.
- Promote research and analysis on raw materials for the production of bioenergy, as well as support efforts to draw up sustainable projects and their respective dissimilarity.

The Communities should benefit of:

- Better inclusion along the production chain, with the generation of new jobs for the national workforce, from the increase of production and productivity, both food and energy.
- Greater participation in bioenergy project decisions, including associations and leadership, reducing the risk of conflict and promoting social improvements for the local community

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