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 1: Main Findings

FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS

Rome, 2018

ISBN 978-92-5-130350-4

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ACKNOWLEDGEMENTS

This publication presents the results of the FAO Trust Fund project "Moving Ahead with Integrated Food Energy Systems: Assessing the Sustainability and Replicability of Integrated Food Energy Systems in Africa and Brazil (IFES-AF Project)", financed by the Federal Ministry of Food and Agriculture (BMEL) of Germany. The project was coordinated by Anne Bogdanski at FAO's Climate and Environment Division under the supervision and with support of the Energy Group Leader, Olivier Dubois. A particular thanks to Sharon Darcy who supported the project administratively.

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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.

We would also like to acknowledge the work of Carla Cuambe from FAO Mozambique and Benjamin Adjei from FAO Ghana for their support in the field.

Many colleagues provided valuable comments, views and information that enriched the project and this document. In particular, we would like to thank our FAO colleague Tiziana Pirelli for revising the draft case studies and Alessandro Flammini for the final editing of the report. Special thanks go to Veronika Kitty from the ASA Initiative and Mr Ahmed Tijani from the Ministry of Agriculture in Ghana and Gervasio Mendonça from Empresa Orizicola Zambêzia, José Basquete from UCAMA and Bachir Afonso in Mozambique for the outstanding support and facilitation of the field work and revision of draft case studies.

ABBREVIATIONS AND ACRONYMS

AF	Analytical Framework
BEFS	Bioenergy and Food Security
FAO	Food and Agriculture Organization of the United Nations
GBEP	Global Bioenergy Partnership
IFES	Integrated Food-Energy Systems
NAP	National Adaptation Plan
NAMA	National Appropriate Mitigation Action
NDC	Nationally Determined Contributions
PRA	Participatory Rural Appraisal
RE	Renewable Energy
SDG	Sustainable Development Goal

EXECUTIVE SUMMARY

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

The following conclusions, recommendations and possible ways forward can be drawn from the analysis of these IFES cases:

(i) Regarding the analytical methodology

Due to the short timeframe of the project and the limited financial resources, the most important requirement was the practicality of the indicators used; while not jeopardising the quality of the results: Indeed, timely and cost-effective measurement were imperative for this assessment. This led us to combine impact and good practice performance indicators. The results this combination give a sufficient and solid indication on the quality and potential for replication of IFES. Based on this experience, we would argue that such conclusions are worth exploring beyond IFES, i.e. in all areas concerned with the measurement of the sustainability and potential for replication of biomass production and use. These include the conventional biomass sectors such as agriculture, forestry and fisheries, but also the production of non-food/feed goods such as bioenergy and bio-based products in the context of bioeconomy, NDC implementation, and, more broadly, SDGs.

(ii) Regarding the sustainability and replicability of IFES

It is clear that IFES is a promising approach towards sustainable socio-economic development. However, it is also clear that in order to develop a successful IFES that guarantees environmental and agricultural sustainability, an understanding the local context is essential. This points towards the need for IFES to be developed ground up; adequately involving all stakeholders, including farmers.

The following lessons have been drawn from this work:

- If the raw energy feedstock is produced in the field, one should choose raw material that have multiple uses (as in the case of pigeon pea and jatropha), as a way to limit risks by allowing for adaptation to different local circumstances, and offer more income opportunities for the raw material producers;
- Favour the use of renewable biomass (crops and residues) instead of non-renewable biomass (standing forest);
- Proceed with great caution in the expansion of IFES; justified by great market opportunities as was the case with jatropha, and possibly pigeon pea in Mozambique. When such opportunities appear, one should:
    - Start from what exists, is known and proven, and keep the proven advantages that such systems have on a small scale (for example those of the pigeon pea- maize mixed cropping system);
    - Guarantee the flexibility of the IFES system to allow for adaptation to changes in local conditions (market, needs, policies, etc);
    - Scale up incrementally, through "learning by doing';
    - Take into account not only the requirements of the new markets, but also local needs and experience (e. g in the selection of varieties of pigeon pea for the Indian market in Mozambique).
- Keep in mind that IFES systems grow organically and overtime. Especially those systems that involve perennial crops are likely to take time and resources to grow and flourish. The initial hurdle until the first harvest as seen in agroforestry systems for instance often needs financial support;
- Capacity building is key to the establishment of IFES as seen in the case of maize-pigeon pea in Mozambique or the improved cook stove programs in Ghana. Institutions or "champions" that can fulfil this task are therefore an important requirement to the upscaling of IFES.
- The application of the IFES concept should not be seen as an additional task to others or a stand-alone project. Instead, IFES should be 'mainstreamed' and integrated into the tasks of relevant programs (agriculture, energy, rural development and the environment) that already exist to improve the performance of these programs by ensuring better integration and to providing opportunities to take advantage of possible synergies. Given the nature of IFES systems, their implementation requires a holistic approach and cross-sectoral coordination. This is a major challenge because in most cases it is not institutionalized.

Given the possible contribution of sustainable and replicable IFES to both food and energy security as well as climate change adaptation and mitigation, the deployment of sustainable IFES is quite relevant to many NDCs, especially those that have identified both agriculture and bioenergy as major measures to implement these commitments the case in most African countries.

These conclusions and recommendations point out the value of promoting sustainable IFES to support the implementation of both the SDGs and the Paris Agreement. The following ways forward in that direction are proposed:

- Draw the attention of decision makers at all levels on the importance of biomass in achieving both the SDGs and the Paris Agreement on Climate Change;
- In parallel, highlight the positive role sustainable IFES can play in that respect; this should stem primarily from countries where successful IFES have been implemented and assessed;
- Linked to the above point, support more testing on the sustainability and replicability of IFES in different countries. The cost effective yet robust methodology used in this project can be of use, and perhaps complemented by other tools if need be;
- The above proposals should start from a dialog between national stakeholders groups, including country delegations of possible bilateral and/or international partners, concerned and involved in the implementation of national commitments as regards NDCs and SDGs

1. INTRODUCTION

1.1 THE IMPORTANCE OF BIOMASS IN ADDRESSING GLOBAL CHALLENGES

Building a low-carbon economy and reducing greenhouse gas emissions to keep climate change within relatively safe bounds will require increasing use of biomass, while not compromising food security. Indeed, 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. A recent paper (IASS, 2015) highlights the key role of biomass in achieving several Sustainable Development Goals (SDGs):

- SDG 2: End hunger, achieve food security and improved nutrition, and promote sustainable agriculture;
- SDG 7: Ensure access to affordable, reliable, sustainable, and modern energy for all;
- SDG 9: Build resilient infrastructure, promote inclusive and sustainable industrialization, and foster innovation;
- SDG 12: Ensure sustainable consumption and production patterns;
- SDG 13: Take urgent action to combat climate change and its Impacts;
- SDG 15: Protect, restore, and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss

This key role of biomass in these SDGs explains the increasing worldwide interest in and development of bioeconomy[1] to produce both food and non-food goods out of biomass.

However, achieving sustainable bioeconomy that leaves no one behind is quite a tall order, and this topic has been the object of a lot of debate. Indeed, biomass is hardly a 'silver bullet' to achieve low carbon economy (SEI, 2012). Biomass is ubiquitous and even abundant in some places; it is also renewable. But it is not an unlimited resource, and therefore requires to be produced and governed appropriately. In addition, there are also competing uses for biomass: for food, soil management, animal feed, bioenergy and bio-materials, and the functioning of natural habitats. Climate change adds another constraint, due to both its possible influence on biomass availability and the need to produce and use biomass in a climate-smart way. Finally, one should capture more value from existing biomass without compromising the needs and possibilities of small-scale and less-endowed biomass producers.

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. Constructive debates around biomass prospects are welcome. However, given that its production and use for multiple purposes is here to stay, action now is needed now to make sure that it is carried out in a sound way. This requires knowledge, an enabling environment, inclusive stakeholder dialogue and collaboration. Promoting agreed good practices for biomass production and use is a complementary and often less demanding way to ensure "no-regret" pathways in that respect.

[1] Bioeconomy is defined in different ways around the world. In the context of this report, we have used the definition agreed at the Global Bioeconomy Summit in 2015, as it shared by many: "Bioeconomy is the knowledge-based production and utilization of biological resources, innovative biological processes and principles to sustainably provide goods and services across all economic sectors' is shared by many." (GBS 2015)

1.2 SUSTAINABLE INTEGRATED FOOD-ENERGY SYSTEMS AS A GOOD PRACTICE

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.

Integrated Food-Energy Systems (IFES) incorporate agrobiodiversity and build on the principles of sustainable production intensification. There are two non-mutually types of IFES:

- Type 1 optimize land use efficiency by combining food and energy crops on the same land, such as agroforestry systems, and
- Type 2 optimize biomass use in a cascading sequence through the recycling of all by-products, such as biogas from livestock manure.

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. Barriers to the implementation and wide-scale dissemination are manifold, and concern various aspects at both farm and beyond farm level (Bogdanski et al, 2010):

- The complexity of some IFES requires high levels of *knowledge* and skills.
- *Technical support* is essential, but not always available;
- *The technology* used needs to be reliable and economical. Ensuring good quality of the conversion device is crucial for the success of IFES, and has often been overlooked in systems aimed at being rapidly scaled up, e.g. some large-scale biogas programmes in the past;
- *Financing* is mostly related to the investment required for the energy conversion equipment. Very often, the better they are from an energy and GHG point of view, the more expensive they are; This is often not affordable for individual small-scale farmers, and *access to financing mechanisms* such as micro-credit schemes is not always given;
- The increased *workload* often experienced with IFES makes the systems less attractive to farmers. Where multiple crops are grown on one piece of land, as in Type 1 IFES, or where there is a diverse array of inter-connected crops and livestock, as in Type 2 IFES, there tends to be less scope for specialization and mechanization, and therefore IFES often require significant manual input;
- *Competition between different uses of residues* refers to the fact that the use of residues for energy production should not negatively affect their use for soil fertility and protection and/or for feeding animals. *Trade-offs* in the use of resources (land, water and nutrients) are becoming increasingly hard to balance, as competition for biomass for food, feed, fertilizer and fuel increases;
- *Access to markets* for agricultural and/or energy products is often a key factor to ensure economic viability of the IFES, since most of the time IFES operators earn the bulk of their revenues from the sale of their agricultural products. However, adequate access to markets and product competitiveness should not always be assumed;
- *Access to information-communication and learning mechanisms* regarding the above-mentioned factors is as important a production factor as “classic” land, labour and capital. Difference in levels of access to information is a well-known power factor in rural development;
- *Politics*, i.e. how things really work and are decided at local level, might influence the above-mentioned factors. *Few government policies* encourage all aspects covered by IFES, and some

sectoral technical support policies even play against the *replicat*ion and scaling up of IFES, especially more complex ones.

Possible ways to overcome these 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. This has been the justification for this project, whose objective is presented in turn.

1.3 Project objective: assessing the sustainability and replicability of IFES

Given the global relevance of IFES, FAO has developed the IFES Analytical Framework; which gives guidance on how to select and assess indicators of IFES sustainability. The Framework further suggests a set of factors that need to be considered when replicating such systems - be it a pilot project, a business innovation or a research experiment (Bogdanski, 2014). 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 make IFES replicable. This is particularly important, as in the bioenergy sector and the growing bioeconomy many questions related to how to implement sustainable biomass solutions and how to bring them to scale still remain unanswered.

In order to upscale sustainable biomass production, it is important to understand the drivers and the barriers that encourage or limit the long-term adoption of sustainable biomass production practices such as IFES. The question at stake is: Can an IFES 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? One needs to recognize that there are large differences between different IFES, on the one hand, and different geographical and cultural areas where the replication might take place, on the other. Yet we argue that there are some common denominators or features that lie within the project and that create an enabling environment for the uptake of a specific IFES project. These features need to be built into and adapted to the specific context of an IFES when replicated elsewhere.

The ultimate objective of this project is to help stakeholders in Mozambique and Ghana to better understand which IFES options are sustainable and how to bring them to scale. More specifically, to reach this objective, the following questions were used as guidance:

1. Can integrated food-energy production such as IFES be an innovative approach to make food systems more sustainable and efficient?

2. Are assessment frameworks and certification schemes, which are based on sustainability indicators enough to ensure that combined food and bioenergy production is indeed sustainable? In other words, can monitoring and evaluation of sustainability during the different stages of the food system guarantee that biomass production, processing and use are indeed sustainable as current biomass assessments and certification systems suggest? Or do we need alternative and complimentary measures to indicator frameworks in order to evaluate and distinguish between sustainable and less sustainable food systems?

3. How can a successful and sustainable IFES be scaled up, i.e. how does the enabling environment need to look like in order to support IFES adoption long-term and on a larger scale?
4. Given that bioeconomy is knowledge-based production and utilization of biological resources, innovative biological processes and principles to sustainably provide goods and services across all economic sectors' – what are the lessons we can draw from innovative biomass production systems such as IFES?
5. Can the upscaling of sustainable IFES support the conversion of Nationally Determined Contributions (NDCs) into implementable mitigation actions?

1.4 STRUCTURE OF THE REPORT

The report is structured as follows

- The report starts with an introduction on the global bioenergy status and the objective of the project;
- The second section briefly presents the IFES context in Mozambique and Ghana;
- Section 3 introduces and discusses the six IFES case studies in Ghana and Mozambique. Each case study has been structured as a stand-alone document, and hence can be read as such;
- Section 4 ventures into conclusions and a potential way forward.
- A set of recommendations is formulated in the last section of the report.

2. COUNTRY CONTEXT: IFES IN GHANA AND MOZAMBIQUE

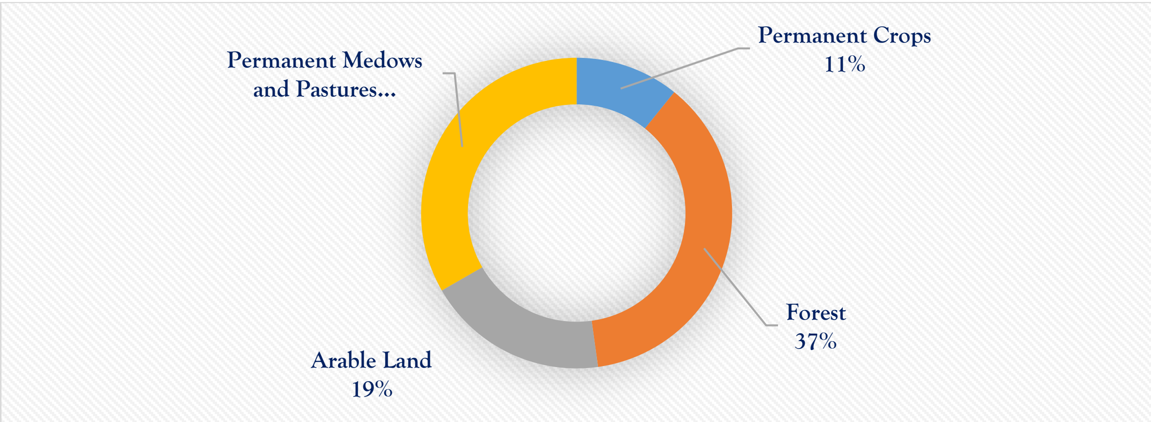
To understand the potential of upscaling sustainable IFES, it is important to have a good overview of both agriculture and bioenergy sector in Ghana and Mozambique.

2.1 GHANA

2.1.1 Agriculture in Ghana

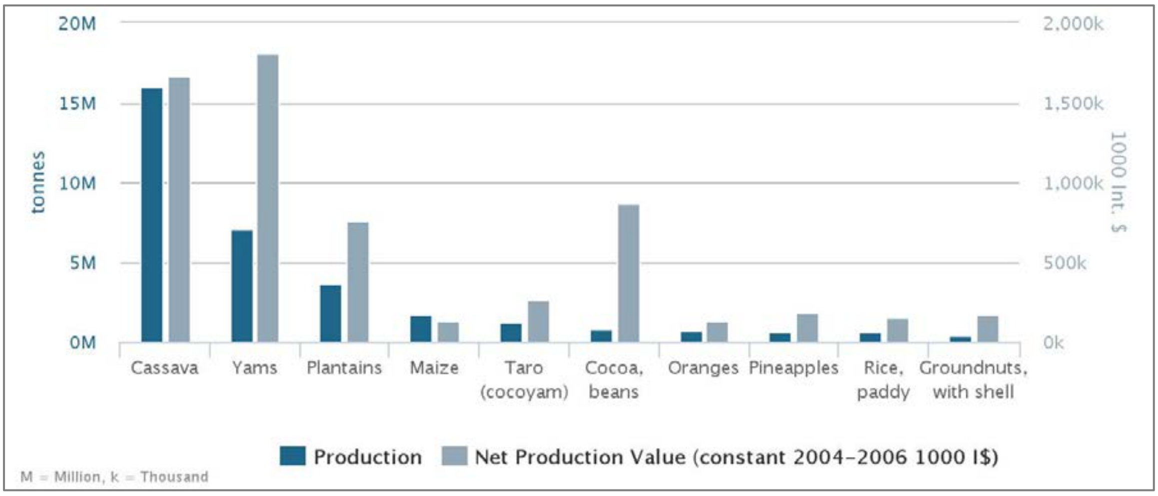
Ghana's total land area is 23 854 000 ha of which 37 percent is covered by forests, 33 percent by permanent meadows and pasture, 19 percent by arable land and 11 percent by permanent crops (FAOSTAT, 2016). Ghana's top 10 agricultural commodities are cassava, yams, plantains, maize, taro, cocoa, oranges, apples, rice and groundnuts (FAOSTAT, 2016). About 90 percent of farms in the country are less than 2 ha in size. Ghana's main types of livestock are goats, sheep, cattle, pigs and chicken.

Figure 1: Landover in Ghana



Source: FAOSTAT, 2016

Figure 2: Top 10 commodities of Ghana in 2013



Source: FAOSTAT, 2016

2.1.2 Bioenergy in Ghana

Ghana has approximately 23 million inhabitants. In Ghana, the TPES is based on biomass, mainly firewood and charcoal (64 percent), petroleum (27 percent), and electricity (9 percent). As in Mozambique, the wood fuel demand is very high. In 2013, Ghana produced 41 448 000 m^3 of wood fuels and 1 771 000 m^3 of wood charcoal (FAOSTAT, 2016). Other biomass resources include agricultural crops and crop residues, food processing residues, municipal solid waste, and animal wastes such as manure or slaughterhouse wastes. Most of the biomass for bioenergy in Ghana concerns wood energy. It is mostly produced and harvested unsustainably and predominantly used in inefficient traditional cookstoves or open fires, despite the fact that the country has developed bioenergy strategies and policies in the past eight years that highlight the importance of its sustainability.

Other bioenergy carriers apart from wood fuels that are produced in Ghana include municipal solid waste, human excreta, animal manure and fruit processing residues (Duku, 2011). Yet statistics on their transformation to produce biogas are not recorded. The use of wood and crop residues through pyrolysis as an alternative process to generate electrical power has been pilot tested, but was not successful. Still it is used to generate thermal energy for productive uses (Duku, 2011). Ghana does currently not produce any biofuels for transport, and there is no indication that it will in the near future. Despite Ghana's recent bioenergy policy that aims at blending 20 percent of biofuels into the transport fuel mix by 2030 (Iddrisu and Bhattacharyya, 2015, based on preliminary results of an ongoing FAO assessment), overall, meeting a biofuel blending mandate in Ghana will be very challenging.

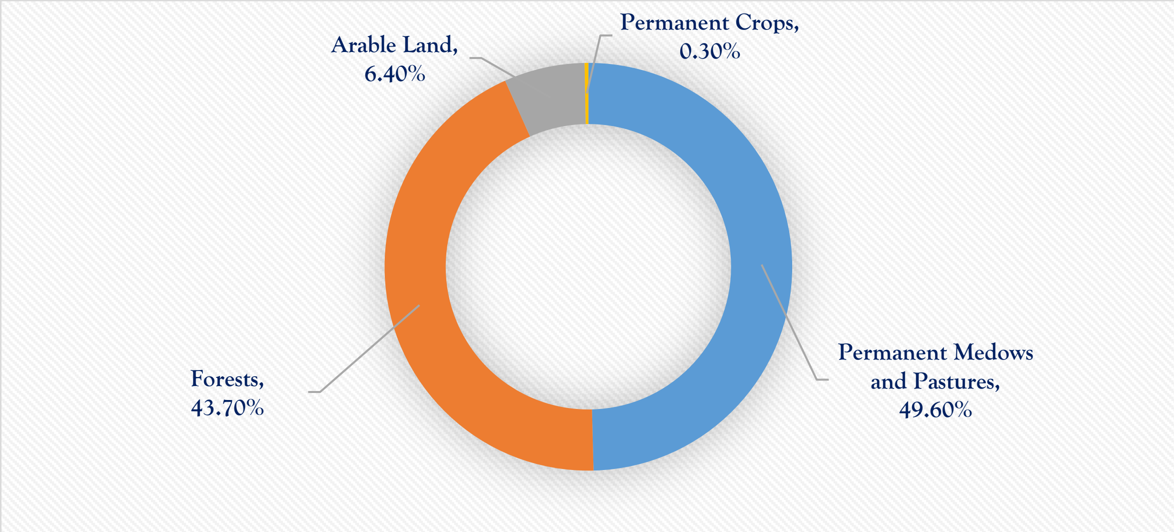
2.2 MOZAMBIQUE

2.2.1 Agriculture in Mozambique

Mozambique's total land area is 80 million ha of which 44.6 percent are covered by forests, 49.6 percent by permanent meadows and pasture, 6.4 percent by arable land and 0.3 percent by permanent crops. According to Mozambique's last national agriculture census in 2010, the cultivated area in Mozambique has increased by 45 percent between 1999/2000 and 2009/2010, to a total of 5.6 million hectares. This means that only a very small percentage of land is actually in productive use. Nonetheless, agriculture is the backbone of Mozambique's economy, employing more than 80 percent of the workforce and contributing around 25 percent of the GDP. According to Mozambique's last national agriculture census in 2010, more than 97 percent of the cultivated area is worked by the family sector. Productivity and production is very low. Only four percent of the producers used fertilizers and only seven percent use any pesticides (GOM, 2013).

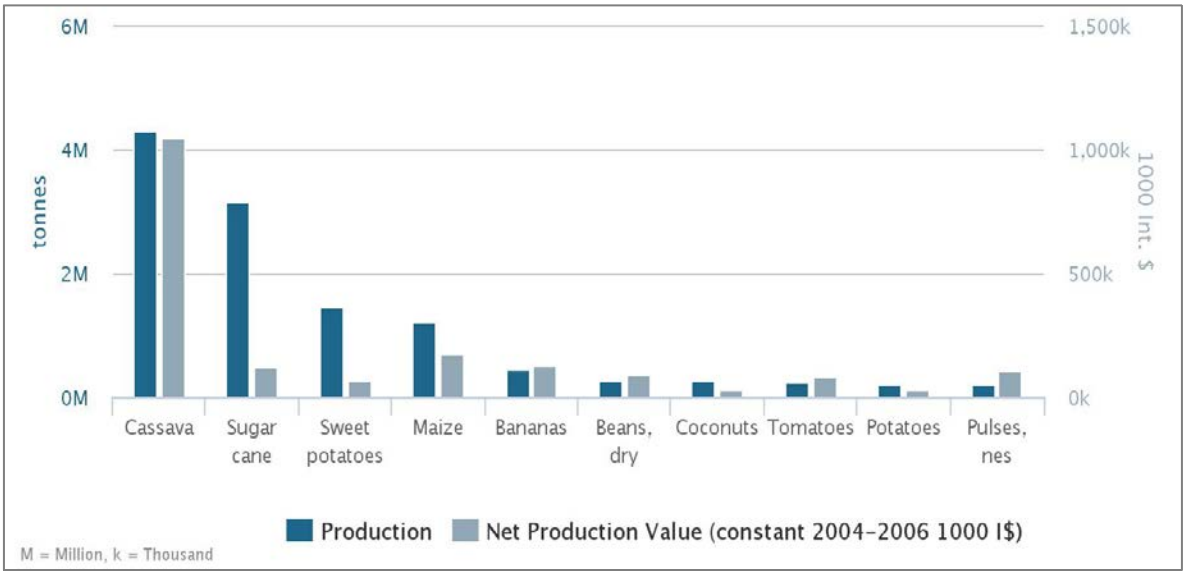
Mozambique's top 10 commodities are cassava, sugar cane, sweet potatoes, maize, bananas, beans, coconuts, tomatoes, potatoes, and pulses (FAOSTAT, 2016). Mozambique's predominant livestock are goats and sheep, pigs and cattle (FAOSTAT, 2016).

Figure 3: Land use in Mozambique in 2011



Source: FAOSTAT, 2016

Figure 4: Top 10 commodities of Mozambique in 2013



Source: FAOSTAT, 2016

2.2.2 Bioenergy in Mozambique

Mozambique is a country in southern Africa with 23 million inhabitants. Bioenergy contributes 78 percent of the total TPES of Mozambique, followed by hydro (14 percent) and petroleum (7 percent) (IRENA, 2012). The total demand for wood fuels is very high: approximately 16 724 000 m^3 of firewood, and 259 000 m^3 of wood charcoal are consumed per year (FAOSTAT, 2016 showing data from 2013). Indeed, 96 percent of the population depend on wood fuel for their daily cooking (Global Alliance for Clean Cookstoves, ND).

While the rural population almost entirely depends on fuelwood, and some charcoal, the urban population relies mostly on charcoal, but 70 to 80 percent of urban dwellers complement charcoal with LPG and electricity (Brouwer & Falcao, 2004). An average urban household in Maputo still consumes 3kg of charcoal per day (Risseeuw, 2012). Charcoal prices range from 13 US$ in Beira to 26 US$ in Maputo for a 70 kg sac (NL Agency, 2012).

A negligible part of bioenergy produced in Mozambique belongs to the so-called modern bioenergy forms: transport biofuels and bioelectricity. There are two small ethanol plants in the country for domestic consumption, but it is unclear whether this is actually used for transport fuels. Mozambique is currently entirely dependent on imports for transport fuel, which is an incentive to develop domestic sources of supply to reduce both costs and exposure to price volatility. It has implemented a fuel blending mandate which phases in bio-ethanol to 10 percent by 2012–2015, 15 percent from 2016–2020, and 20 percent from 2021. For diesel, the blending is three percent, 7.5 percent and 10 percent over these timeframes (IRENA, 2012). Mozambique's level of access to electricity has increased significantly both on- and off-grid in recent years, but is still below 32 percent (IRENA, 2012). Bioelectricity does not play a significant role.

3. METHODOLOGY

The methodology of analysis is based on a structural approach to evaluate the sustainability and replicability of IFES, as laid out in the IFES Analytical Framework document (Bogdanski, 2014). The framework serves as a tool to assess which factors make IFES truly sustainable and which factors need to be considered when replicating such systems. For the purpose of this study, the framework has been adjusted to local circumstances in the two case study regions. Additionally, it should be noted that due to the time constraint, the possibility to collect primary data was limited to interviews and group discussion. Additionally, most quantitative data was gathered through direct questions posed to farmers or other stakeholders. Secondary data sources, such as literature reviews were also used to gather quantitative data that could not be measured or obtained during the field visits. Consequently, the scope of analysis is to provide a rapid yet scientifically –valid appraisal of the sustainability and the potential to replicate the IFES in question in both countries. It provides robust results based on sound methodology that would form the basis of a detailed study, which includes comprehensive social, economic and environmental analysis based on primary data, to verify and validate the results.

3.1. SITE AND CASE SELECTION

Sites and cases were selected during a participatory stakeholder workshop where members from national governments, the private sector, civil society and academia discussed relevant IFES cases in both Ghana and Mozambique.

3.2. SETTING THE BOUNDARIES OF THE BASELINE AND IFES BIOMASS CHAIN

In this report the analysis is conducted at the system level. This means that the unit of analysis is not the individual or household but rather different IFES identified in the study area. Depending on the local context, one or two IFES biomass chains are compared to a Business As Usual (BAU) biomass chain. The biomass chain includes the biomass production, harvesting, collection, transport, storage, biomass, processing and use. The two scenarios (IFES versus BAU) constitute the basis for the sustainability and the replicability assessment.

3.3. SUSTAINABILITY ASSESSMENT

Sustainability of a system is a multi-dimensional concept. A completely sustainable system would ideally be socially acceptable, economically viable and environmentally resilient. Therefore, the IFES scenarios in this study are analysed based on these three pillars. Additionally, the IFES scenario is always compared to a business and usual (BAU) scenario to determine the sustainability of IFES in question. This is imperative because determining sustainability is a matter of perspective, i.e. it is a relative concept. "Sustainable compared to what" is the question to ask. Sustainability indicators should be able to do more than only describe the current situation. Absolute values as such do not tell much if it is not compared to reference values chosen by scientists or policy-makers. It is therefore not the absolute values of the indicators that reveal whether a system is sustainable, but rather the distance between these values and the reference values. Reference values can be historic data of the same site (e.g. Wattenbach and Friedrich, 1997), or they can be so-called normative policy- or science-based reference values, as commonly found in many sustainability studies (e.g. Van der Werf and Petit, 2002)). Policy-based values refer to targets or limits set by policy, while science-based values relate to scientifically founded targets or limits. Most of the IFES case studies described use historic data for the comparison, as further detailed in each case study section of this report.

The assessment is structured along criteria and indicators, which are the "tools" that help assess the selected IFES. A criterion is defined as a standard on which a judgement or decision may be based. Each criterion is specified by a set of different indicators. An indicator is a qualitative or quantitative measure that reflects a criterion.

The indicators for each criterion belonging to the three pillars of sustainability - social, environmental and economic - were developed based on local circumstances of each case study. Indicators were either impact (quantitative) or performance (process or qualitative) in nature. The indicators were chosen based on their relative advantage compared to other indicators in each respective field. Due to the short timeframe of the project and the limited financial resources, the most important requirement was the practicality of the indicator used: timely and cost-effective measurement was imperative for this assessment. However, care was taken to ensure that the practicality requirement would not negatively affect the technical soundness of indicators. The need to consider both practicality and technical soundness requirements led to the use of two types of indicators:

- On the one hand, impact indicators concerning environmental, economic and social aspects, where their measurement would not be too resource- consuming in terms of costs, time and knowledge;
- On the other hand, where impact indicators would require too many resources, proxy indicators in the form of performance indicators concerning compliance with the implementation of recognized good practices.

The Table in Annex illustrates this approach by giving an idea on the type of impact and/or performance indicators that were used in the assessment of the sustainability of IFES.

The values of the indicators for each case result from the combination of field assessments and, when needed, cross-referencing with findings from literature review.

The assessment itself followed a stepwise process, briefly presented hereafter:

1. The first step was to define the IFES and the baseline system. We found this step crucial for the further development of the sustainability assessment. It was important to detail each step of the biomass value chain, from biomass production to end-use, in order to clearly show where sustainability indicators were necessary and appropriate. It was further needed to describe the context and the involved stakeholders at the different stages of the value chain. Last but not least it clearly showed the core element of each case study and the specific objective of the analysis – the comparison of an IFES with a business-as–usual crop production value chain.
2. In the second step, we selected appropriate criteria and indicators for each case study, and determined the baselines and reference values. In the ideal case, this selection would be done in workshops with all identified stakeholder groups as discussed in Dale, et al (2015) for instance. Yet, unfortunately, this was out of scope for the project. A lesson learned for future projects is that there should clearly be a budget up front for the costs and time related to such a participatory indicator selection. This would also allow for the identification of potential conflicts between different goals, and hence indicators, which are very likely to occur when environmental, social and economic aspects of sustainability are measured. A transparent process which involves all stakeholders in the indicator selection process is therefore vital for the success and acceptance of a sustainability assessment. Trade-offs need to be found, and clearly communicated up-front.
3. In a third step, we conducted the assessment in the field and at the same time identified gaps and challenges encountered with the previously chosen indicators. Depending on the case study, and the data availability for each case, some indicators were found to be not appropriate

for the selected criterion and study objective. In most cases, the limiting factor was found to be time as even indicators with supposedly simple data requirements required significant survey needs. For instance, one of the proxy indicators for food security was selected to be "Yield of crop(s) and/or crop residues (kg/ha/season) in combination with farm land size (ha)". This apparently very straight forward measurement or survey needed to obtain this data was more challenging than expected. Involved stakeholders such as the smallholder farmer him/or herself would report their own way of measuring agricultural output – a way which would not match the data requirements needed for the chosen indicator. An alternative way to obtain this information was hence to take production averages of the survey region, which turn was less accurate than what was ideally required.

4. In a last step, we validated the results of the indicator assessment with the stakeholders. A workshop organized at the end of the project – one in Maputo, one in Accra – allowed the different involved stakeholder groups to discuss the effectiveness of the indicators used.

3.3.1. Social sustainability

(i) Food security

Food security exists when all people, at all times, have physical and economic access to sufficient, safe and nutritious food that meets their dietary needs and food preferences for an active and healthy life (WFS, 1996). According to the Food and Agriculture Organization of the United Nations (WFS, 1996), food security has four dimensions, namely: availability, access, utilization and stability. While the overall concept of food security easy to grasp, food security is very difficult to measure as data is hard to obtain (Kline et al., 2016). Studies therefore often use "improvement of rural household income" as a proxy indicator (Dale et al., 2013).

(ii) Energy access

Ensuring access to affordable, reliable, sustainable and modern energy for all is one of the 17 goals that make up the 2030 Agenda for Sustainable Development. Reliable and affordable energy is needed to improve living standards, increase rural incomes, support delivery of health and educational services, and improve gender and social inequality. As regards more specifically access to cooking energy we used indicators derived from the holistic approach applied by the global programme 'Energising Development' (EnDEV) implemented by GIZ. They look at cooking in the context of an entire cooking energy system (CES) that comprises the user, the fuel, the stove and the context where cooking is done. The EnDev CES system integrated some of the elements considered in the Global Tracking Framework elaborated under the lead of the Sustainable Energy for All initiative of the World Bank, but it goes beyond and is less focused on stove technology. It is developed to characterize the qualitative change of services delivered to households through an intervention.

(iii) Health

The issue of human health primarily concerns those IFES that use solid woody biomass as energy component such as crop residues or woodfuels. Cooking with solid biomass such as firewood or charcoal on traditional fireplaces might have negative impacts on human health. Four million premature deaths are attributed every year due to smoke exposure from traditional cookstoves or open fires (Global Alliance for Clean Cookstoves, 2013). According to the World Health Organization (WHO, 2006), inhaling indoor smoke doubles the risk of pneumonia and other acute infections of the lower respiratory tract among children under five years of age. Women exposed to high concentrations of indoor smoke over longer durations are three times more likely to suffer from chronic obstructive pulmonary disease, such as chronic bronchitis or emphysema, than women who cook with solid fuels in open environments or use zero-to-low-emission cooking systems based on electricity, gas or liquid fuels. Use of fossil coal was found to double the risk of lung cancer, particularly among women. Moreover, some studies have linked exposure to indoor air pollution to asthma; cataracts; tuberculosis; adverse pregnancy outcomes, in particular low birth weight; heart disease; interstitial lung disease, and nasopharyngeal and laryngeal cancers. Yet, the impact on human health depends on duration and intensity of the exposure to harmful emissions, which is influenced by many factors of the entire cooking system including the stove, the fuel, the user habits, the cooking environment and ventilation scenario.

(iv) Adaptive capacity to climate change and variability

Farmers are beset by a number of risks, be it too much rainfall leading to floods, too little rainfall resulting in droughts, temperature fluctuations, periodic occurrence of extreme weather events such as hurricanes and other tropical cyclones, severe pest and disease outbreaks, food safety hazards related to production systems and risks due to the market insecurity. Increasing a farmer's adaptive capacity to these risks is therefore crucial, particularly considering the uncertainties related to climate change. Adaptive capacity is "the ability of a human or natural system to adapt, i.e. to adjust to climate change, including to climate variability and extremes; prevent or moderate potential damages; take advantage of opportunities; or cope with the consequences. Adaptive capacity to extreme events is enhanced through diversified production systems such as IFES. More diversified production systems have been shown to be more adaptable to change than traditional monoculture production systems (Woods et al., 2015).

Both policy and academic communities have developed a sheer variety of different indicators which claim to capture adaptive capacity of farming systems. At the same time, they are increasingly criticized however, as they often fail to meet their targets or they are too complex to measure (Hinkel, 2011).

3.3.2. Environmental sustainability

(i) Agro-biodiversity

Biodiversity forms the basis for ecosystem services to which human livelihoods are intimately linked. It is defined as "the variability among living organisms from all sources including, inter alia, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part; this includes diversity within species, between species and of ecosystems" (Millennium Ecosystem Assessment, 2005). Effects of bioenergy production on biodiversity can be either positive or negative, depending on location, agricultural and forestry practices, and previous land use (CBD, 2008). A subdivision of biodiversity is agrobiodiversity. Agrobiodiversity is "the variety and variability of animals, plants and micro-organisms that are used directly or indirectly for food and agriculture, including crops, livestock, forestry and fisheries. It comprises the diversity of genetic resources (varieties, breeds) and species used for food, fodder, fibre, fuel and pharmaceuticals. It also includes the diversity of non-harvested species that support production (soil micro-organisms, predators, pollinators), and those in the wider environment that support agro-ecosystems (agricultural, pastoral, forest and aquatic) as well as the diversity of the agro-ecosystems" (FAO, 1999).

Agrobiodiversity has an important role in farming systems. For instance, it increases productivity, food security (see criterion on food security), and economic returns (see criterion on profitability), reduces the pressure of agriculture on fragile areas, forests and endangered species, makes farming systems more stable (see criterion on adaptive capacity to climate change and variability), robust, and sustainable and contributes to sound pest and disease management. Agrobiodiversity was chosen as a criterion instead of the larger field of biodiversity as the direct impacts of IFES can be primarily seen, and more importantly, measured, within the farming system. This does not mean however that IFES do not have any impacts on biodiversity in general. To the contrary, positive landscape effects through diversified and integrated farming systems on surrounding biodiversity are a logical consequence of increased agrobiodiversity.

(ii) Soil health

Soil health is defined as the capacity of soil to function as a living system. Healthy soils maintain a diverse community of soil organisms that help to control plant disease, insect and weed pests, form beneficial symbiotic associations with plant roots, recycle essential plant nutrients, improve soil structure with positive repercussions for soil water and nutrient holding capacity, and ultimately improve crop production" (FAO, 2008). Furthermore, healthy soils do not pollute the environment but contribute to mitigating climate change by maintaining or increasing its carbon content (FAO, 2010a). Today, many soil management practices are unsustainable. Two of the most common problems are related to excessive or other inadequate fertilizer use. On the one hand, in some regions there is an overuse of fertilizers which can lead to soil and water acidification, contamination of surface and groundwater resources, and increased emissions of greenhouse gases. On the other hand, there is an underuse of fertilizer leading to soil nutrient depletion, and as a consequence to soil degradation and, consequently, declining yields.

Soils can be degraded through three processes: i) physical (e.g. erosion, compaction); ii) chemical (e.g. acidification, salinization); and iii) biological degradation (e.g. declines in organic matter). These degradation processes are linked to changes in farm management practices, climate and technology. The physical state can be described by the extent to which soils exhibit (a) sealing and crusting, (b) erosion by both water and wind, and (c) compaction. Chemical processes in soils are related to (a) soil nutrient mining, (b) soil pollution and (c) soil salinization (OECD, 2001). To assess how different IFES practices affect the productive capacity of the land, it is therefore important to assess how soil quality is affected by IFES. Some IFES practices might increase soil fertility through intercropping the main food crop with leguminous bioenergy crops that add nutrients and organic matter to the soil such as in intercropped pigeon-pea maize systems (Bogdanski & Roth, 2012). However, certain IFES practices might also cause soil degradation, for example when (too many) crop residues are removed from the field to produce bioenergy.

(iii) Pollution

IFES might impact water quality when excess amounts of nitrogen (N) and phosphorus (P) from inorganic fertilizers and livestock waste enter surface waters and lead to eutrophication. Runoff of pesticides may lead to poisoning of wildlife and fish which may also eventually enter into the human food chain. The contamination of waterways with livestock waste can also result in a release of pathogens, which could pose a serious threat to human health. Wastewater from biomass processing can also contain high levels of nutrients and other pollutants. Furthermore, wastewater might cause changes in pH, salinity and temperature affecting aquatic fauna and flora. However, when IFES are designed in a way that wastewater is recycled, it may be beneficial for both waterways and soils. For instance, when wastewater is treated by anaerobic digestion and both liquid and solid residues are recycled through the installation of biogas systems, water pollution is prevented, and valuable nutrients which would be otherwise lost, can be brought back to the fields to safeguard soil fertility.

Other factors that cause pollution for land and water are the excessive use of pesticides. Air pollution is another criterion which needs to be considered.

(iv) GHG emissions and carbon storage

Many agricultural practices have the potential to mitigate emissions in the farming sector through reducing emissions, enhancing removals or avoiding (or displacing) emissions. However, calculating this potential is not as straightforward as in many other sectors. One agricultural practice often affects a couple of gases. While some practices might mitigate emissions, others might increase them at the same time. It therefore depends on the overall net effect (e.g. Koga et al., 2006). Furthermore, some emissions may be reduced indefinitely, while others are only reduced for a limited amount of time (Six et al., 2004). Another factor to consider are the indirect effects of certain agricultural practices on other ecosystems, for example when increased productivity in existing croplands leads to avoided deforestation and its respective emissions (Smith et al., 2007).

Bruce et al. (1999) describe several practices that promote carbon (C) sequestration, including a reduction in tillage disturbance, intensification of cropping rotations, improvements in crop yields, and replacement of annual crops with perennial vegetation. In general, these practices increase soil organic carbon (SOC) storage by enhancing C inputs to the soil through improved productivity and residue management. Smith et al. (2007, Table 8.3., p. 507) list an overview of measures for mitigating greenhouse gas emissions from agricultural ecosystems, their apparent effects on reducing emissions of individual gases where adopted (mitigation effect), and an estimate of scientific confidence that the proposed practice can reduce overall net emissions at the site of adoption. Measures with a high mitigation effect and of relevance for IFES are, for example, related to improved cropland management through agroforestry and residue management, or to manure and bio solid management through the process of anaerobic digestion and through more efficient use of manure and bio solids as nutrient sources.

3.3.3 Economic sustainability

(i) Profitability

Profit is generally one of the most common and accepted criteria determining the success of an economic activity. Integrated Food-Energy Systems must be profitable in the long term for them to be adopted on a meaningful scale.

(ii) Resource use efficiency

Resource efficiency allows the economy to create more with less, delivering greater value with less input, using resources in a sustainable way and minimizing their impacts on the environment (EC, 2011). Integrated farming systems such as IFES have shown the potential to decrease production costs by using residues and by-products of the different farm components, leading to improved incomes and employment opportunities (Behera and France, 2016).

Resource -use efficiency is broad concept which in the agricultural context can refer to land-use efficiency, water-use efficiency, fertilizer use efficiency or energy use efficiency among others. Because land is an essential resource when producing biomass, land-use efficiency is of uttermost importance to the production of bioenergy feedstock as the ongoing debate about indirect-land use change proofs. However, in some cases it might equally interesting to assess the water-use efficiency of IFES, especially when the project is located in a drought prone area. Likewise, fertilizer-use efficiency can be a crucial aspect of sustainability, for example when a crop is chose which only performs well when appropriate amounts of fertilizers are used, for example like in the case of Jatropha which has shown suboptimal performance when no fertilizer was applied despite the claim that this "miracle" crop performs well on depleted soils, where it still grows but with low yields.

3.4. Replicability assessment

Replicability is the property of an activity, process, or test result that allows it to be duplicated at another location or time (Business dictionary, n.d.). We define replicability as the potential of a project, innovation or pilot test to be replicated, scaled up, expanded, or adapted. A term which is often used interchangeably is scalability. Testing the replicability of project will help us identify whether one can achieve a certain outcome at scale. In the context of this analytical framework, the desired outcome is the sustainable agricultural production of both food and energy. Hence, the replicability assessment should be understood as the first step in deciding whether one can upscale a certain project or not. The question of interest it: 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?

One needs to recognize that there are large differences between different IFES projects, on the one hand, and different geographical and cultural areas where the replication might take place, on the other. Yet we argue that there are some common denominators or features (both terms are used interchangeably in the following text) that lie within the project (internal features) and that create an enabling environment for the uptake of a specific IFES project (external features). These features need to be built into and adapted to the specific context of an IFES when replicated elsewhere.

The methodology for replicability is based on a set of descriptive analyses belonging to four pillars[2]:

1. The presence of promoting or inhibiting project features of the IFES,
2. Stakeholders and institutions that may promote upscale of the IFES,
3. Alignment of the IFES with national food and energy objectives and
4. Availability of local capacity for upscaling.

[2] *Details are listed in the IFES AF (Bogdanski; 2014)*

4 OVERVIEW OF THE IFES CASES

This section presents the overview of case studies in tabular to provide a snapshot of the major characteristics of the systems and key results. Detailed case studies can be found in Part 2 of this study.

4.3 GHANA CASE STUDIES

4.1.2 Utilization of stalks from millets and sorghum to substitute firewood cooking fuels

IFES Case	Utilisation of millet and sorghum stalks as cooking fuel
Location	The case study was carried out in Tolon Kunbubgu, Savelugu, West Mamprusi districts (Northern Region) and Nabdam and Bongo districts (Upper East Region of Ghana).
Main actors	Households who farm the crops millet and sorghum, to a certain extent also pigeon peas
Key element of IFES	Millet and sorghum stalks substitute or complement firewood to various degrees as fuel for household cooking, without replacing the conventional three stone stoves. The crops are grown in a defined sequence on the same plot of land starting with early maturing millet followed by sorghum and late maturing millet.
IFES – BAU comparison	The IFES is compared with a 'business as usual' scenario where households have to rely on firewood for cooking because stalks are either sold or left as fodder.
What are major benefits that make this IFES likely to be sustainable?	**Social criteria:** ➢ Energy access: Northern Ghana has relatively fewer sources of firewood. The IFES serves as reliable source of easily accessible fuel from November until May or June. Outside this peak period, households must walk a minimum of 15 miles, for 3 times a week to get firewood. ➢ Food security: Using the stalks allows households to save expenditures on cooking, thereby improving household food security. For the six months that households rely on stalk, they make a weekly saving of at least GHC¢ 10.00 (US$ 2.5) per week on reduced firewood purchases. **Environmental criteria:** ➢ Climate change mitigation: Even though firewood is in principle a renewable biomass – and hence carbon neutral, the reality in the Northern Region is that firewood is mostly sourced from unsustainably managed indigenous forests and not from farmers-owned or communally managed woodlots or energy plantations that are replanted. 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. ➢ Soil health: the process of generating the stalks leads to soil fertility improvement. First, after harvest, animals are allowed to graze through the fields, leaving their droppings. After that, the uneaten stalks are harvested and the remaining residue is ploughed together with the droppings into the soil.

Economic criteria:

- Extra income from sale of stalks: In some communities, households sell extra stalk to support household expenditure from June when other households are in short supply.
- Additional benefits: A by-product of burning the stalks is saltpetre (Potassium Nitrate), which is used to boil and soften beans.
- Resource use efficiency: The millet/sorghum crop is efficiently utilized under this IFES, as no part of the crop is wasted.

There are two challenges with this IFES:

Challenges

- Farm holdings tend to be small, so there are not enough stalks to last the whole year, hence the need to supplement with firewood to varying degrees.
- The length of the stalks pose a physical challenge. 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.

Where and how can this IFES be replicated?

This IFES can be replicated anywhere where millet and sorghum grow. This IFES is naturally emerging in the study communities and its adoption is linked to the degree of firewood shortage. Some of the drivers of replicability include access to and cost of firewood, availability of land, and access to production inputs, especially labour. With capacity building and extension services to farmers the uptake can be increased.

Outlook

The stalks of the late maturing millet provide the best firewood and are not eaten by animals other than donkeys, while stalks of early varieties have competitive uses as fodder for animals. This is something to consider in efforts to upscale the IFES. Fuel-efficient appropriate cookstoves can further leverage the savings of fuel and forest resources and the reduction of greenhouse gas emissions.

4.1.3. Palm oil processing utilizing oil palm residues for thermal energy generation

IFES Case: Use of residues from palm oil processing for thermal energy generation

Location: Cape Coast Municipality, Central Region, Ghana

Main actors

- **Industrial processors:** Twifo Oil Palm Plantation (TOPP) partly owned by Unilever and linked with more than 1,500 outgrower and independent smallholder farmers who supply fresh fruit bunches.
- **Artisanal crude palm oil processes:** Small scale processing plant owners, smallholder oil palm farmer and crude palm oil processors

The IFES concern farmers who have been farming oil palm for many years, and therefore not recently –established plantations. Therefore, the IFES do not concern recent land use changes to establish the oil palm plantations

Key element of IFES

By-products from crude palm oil processing (fibre and palm kernel shells) are used as fuel to generate thermal energy for those processing activities where heat is required. The IFES is observed from two levels of aggregation – industrial and artisanal processing levels.

- 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 uses to run all the machinery in the factory for the processing activities and the offices.
- Artisanal processors utilize only fibre or fibre-kernel pastes as fuel for all boiling activities during processing.

IFES – BAU comparison

At each level of the IFES, different 'business-as-usual (BAU)' scenarios apply:

Industrial level of the IFES: Processing factory relies on fossil fuel (diesel) or main grid electricity and discards fibre and kernel shells.

Artisanal level of the IFES: Processors rely on fossil fuel (diesel) or firewood for boiling activities and dispose of fibre and kernel shells.

Social criteria:

- Energy Access: At both levels of aggregation, the IFES provides processors with a readily available, easily accessible fuel and cheaper fuel source. The TWIFO compound is energy-self-sufficient for both electricity and process heat generation from own resources.

Environmental criteria:

What are major benefits that make this IFES likely to be sustainable?

- Climate change mitigation: The bioenergy in the IFES generates less CO_2 emissions compared to use of fossil fuels. It can even be carbon neutral. At the artisanal processing level, it substitutes firewood and mitigates the pressure on the forest.
- Soil health: As part of the IFES, at the industrial processing level, empty fruit bunches are returned to the oil palm farms to serve as mulch, thereby improving soil fertility for smallholder and outgrower farmers.

Economic criteria:

- Profitability: At both levels of aggregation, the IFES saves cost on fuel use and improves the likelihood of profitability of the processing business.
- Resource use efficiency: The IFES improves resource use efficiency. Processors utilise their own generated residues as fuel which also reduces their waste. This makes waste management more cost-efficient as they save the extra cost of disposing of the by-products.

Challenges

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.

Where and how can this IFES be replicated?

Industrial level of the IFES: The use of fibre and kernel shells to generate steam and electricity can be applied by medium to large scale oil palm processors who find it profitable to use bioenergy furnaces.

Artisanal level of the IFES: At the artisanal level, the IFES can be scaled up across the oil palm belt in Ghana.

Outlook

- At the artisanal level, there is a potential to improve the aspects of the IFES, while passing on additional benefits to households involved in processing. The ASA Initiative, an NGO, is testing a new large stove to utilize empty palm bunches for boiling activities in the oil processing chain. This stove saves the charred residue from burning of the oil palm biomass for further use as bio-fertilizer.
- Again, there is potential for processors to take advantage of an emerging IFES which uses palm kernel shells in a top-lit up-draft (TLUD) micro gasifier stove for home cooking.

4.1.4. Pelletized Maize Cobs as household cooking fuel in biochar-creating gasifier stoves

IFES Case	PELLETIZED MAIZE COBS AS HOUSEHOLD COOKING FUEL AND BIOCHAR-FROM GAS STOVES
Location	Cape Coast Municipality, Central Region, Ghana
Main actors	ASA Initiative, a non-governmental organization which closely collaborates with members of the ASA Initiative Farmer Group, the main end-users of the IFES

Key element of IFES	Maize cobs, which would have ended up being dumped, are compressed into pellets. The pellets are used as a fuel source for household cooking in a char-creating top-lit up-draft (TLUD) micro gasifier stove.
IFES – BAU comparison	The IFES was compared to a 'business-as-usual (BAU)' scenario where the maize cobs are either dumped to rot or burnt to ashes as cooking fuel in open fires.
What are major benefits that make this IFES likely to be sustainable?	**Social criteria:** ➢ Food security: This IFES reduces household costs of preparing meals, especially when compared to charcoal that has to be purchased: it saves households at least GH¢1.3 (US$0.33) for an average meal. Additionally the improved stoves allow for a faster preparation of meals than conventional charcoal stoves. ➢ Energy Access: Households using pellets benefit from access to additional sources of cooking fuels. For short cooking times the cooks enjoy that they don't have to supervise and permanently stoke the fire, unlike with firewood. ➢ Health implications: The IFES also reduces health risks as the pelletized maize cobs in the gasifier stove generate less smoke than entire cobs in an open fire. **Environmental criteria:** ➢ Climate change mitigation: This IFES generates less GHG emissions compared to the BAU scenario due to the cleaner burning of the pellets and the substitution of unsustainably harvested firewood. ➢ Soil health: The IFES can improve soil characteristics, if the charred pellets resulting from the cooking process are used to prepare organic manure to improve soil fertility and hence farm yields. **Economic criteria:** ➢ Profitability: The IFES creates an additional stream of income, from sale of stoves and maize cob pellets, for ASA Initiative and the Farmer Group. ➢ Ease of use and maintenance: Although the TLUD stove costs more than the traditional charcoal stove (BAU), the IFES is still an economically feasible option for users. This is because of the additional benefits derived from its use.
Challenges	There are certain features of the TLUD stove which discourage the use of the IFES, e.g. some users complained of the inability to regulate the fire generated by the stove. It is also difficult to extend the cooking times, as fuel cannot be added during cooking. The stove is a batch feeding stove and needs to be refilled completely once the fuel is consumed.
Where and how can this IFES be replicated?	This IFES is replicable across the country since maize is cultivated in all the regions in Ghana. In the short run, a NGO similar to the ASA Initiative is required to promote the IFES with the assistance of an external donor or funding source for the initial investment into pelletizing equipment.
Outlook	With continuous national or donor support, the IFES can be scaled up. This is because there is already an existing market for cookstoves, availability of the biomass (maize cobs) across the country and experienced NGOs which can promote its uptake.

4.2. MOZAMBIQUE CASE STUDIES

4.2.1. Intercropping pigeon pea with maize on the same field to produce food, fodder and fuel

IFES Case	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 entails **no drastic 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 percent 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.**

4.2.2. Production of heat energy by using rice husks to process rice

IFES Case	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 percent 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 affect 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.

4.2.3. Jatropha production to protect food crop and produce biodiesel and soap

IFES Case	JATROPHA AROUND SMALLHOLDER FOOD CROP FIELD
Location	Quirimba National Park QNP, Cabo Delgado
Actors	Smallholder farmers living within the boundaries of the national park, supported by NGOs, initially ADPP (Association for Development Assistance from People to People), later GSB (Grupo de Saneamento de Bilibiza), private sector JATfuel producer ADM (Agro-Negócio para o Desenvolvimento de Moçambique, Limitada)
Key element of IFES. IFES 1 before 2011, IFES 2 since 2012	IFES 1: As part of an intervention package by ADPP to increase food security, *Jatropha curcas* was primarily introduced as live fencing that is no eaten by animals to protect smallholder food crops on aggregated fields from wild animals in the park. Pressing of oil from Jatropha fruits came in at a later stage, originally with the intention to generate electricity for the teacher training center in Bilibiza before the national grid reached the town. IFES 2: Today ADM elaborates JATfuel, a blend of petroleum and Jatropha oil to power off-grid maize mills for higher quality maize flour production in remote areas.
BAU - IFES comparison	Before the introduction of Jatropha fences smallholder fields were dispersed in the park and crops raided by animals. Both IFES include Jatropha, IFES 1 only as fences, IFES 2 as well on company owned small monoculture fields. Farmers sell Jatropha seeds to an oil mill for pressing. The oil is either used for biofuel production by the company operating the mill or for soap-making through farmers, if they can buy back the oil from the press.
Benefits likely to make the IFES sustainable	Jatropha fits very well into the prevailing farming system and seasonal calendars. Planted as fencing it does not conflict with food production. In IFES 1 farmers received extension services, seeds and inputs from the ADPP project. Coupled with the Jatropha fences farmers increased yields of food crops. Farmers could take their Jatropha to the press and get better returns from the oil by making high-value soap.
Challenges: potential kill factor for replicability	For energy use the price for Jatropha oil is bound to world market prices of fossil oil. The current low prices offered for Jatropha seed to farmers is too low to be profitable for many farmers, who stopped harvesting and selling to ADM. Unless farmers can access the oil to make high-value soap there is little incentive to harvest Jatropha. With soap-making the benefits from the high value added stays with the farmers, while with oil for energy use they don't benefit and the meagre profits go to ADM.
Where and how can this IFES be replicated?	Jatropha fence planting around smallholder fields can in principle be replicated in any farming system, but viability depends under which aspect it can be profitable: ➢ **Jatropha for energy as diesel substitute is normally not profitable and has little chances of widespread uptake and replication**. It is only economically viable where access to diesel is

limited or expensive. 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 the seed, de-husk and sell the seed to an oil mill. 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.

- Non-energy related aspects like soap making, the protection of fields with animal repellent fencing, erosion control etc. are better motivations to grow Jatropha.
- 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.

Lessons learnt for replicability

- Production of Jatropha seems to be most viable on smallholder fields in association with food crops rather than as monoculture on large fields
- There is no competition for land, rather a synergy: Jatropha is not eaten by animals and the fences around the fields protect the food crops and increase yields.

Outlook

There is very big 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 can be used for own needs, it has a guaranteed local and a potential export market.

5. DISCUSSION

Safely integrating energy production in food systems has both potential benefits and risks. The context matters as the six IFES case studies from Ghana and Mozambique clearly demonstrate. This becomes especially clear when contemplating the sheer diversity of typologies of integrated food and bioenergy production in the two pilot countries, Ghana and Mozambique. The variety of different crops such as rice, maize, pigeon pea and jatropha, and energy technologies such as improved small-scale cooking stoves, large gasification furnaces and diesel generators demonstrate that there is no one-size fits all solution to sustainable bioenergy production. IFES can evolve organically as a way to produce sustainable food system with energy production being a co-benefit, or, they can evolve from a dedicated planned effort to produce sustainable food and energy together. In any case, it is imperative to assess its social, economic as well as environmental sustainability in order to ensure that the system is truly sustainable on all three fronts.

In Mozambique, for instance, while there was a dedicated effort to use by-product from rice production to produce in an industrial rice mill which was environmentally and socially sustainable, the challenge lies in ensuring its economic sustainability since the amount of rice produced may not be enough to make the commercial level mill economically viable. Given the volatility in the volumes of rice produced in the region is a direct consequence of frequent extreme weather events (floods and droughts), the government is thinking of changing from rainfed to irrigated rice.

On the other hand, the jatropha plantation as a hedges in smallholder production system in Northern Mozambique, did not initially evolve as a means to produce energy but to protect the various food crops with from animals. It was only later that the co-benefit of producing energy from Jatropha emerged.

The scale of the IFES also matters. Some IFES grow because of local fuel needs. The energy component of the system is mainly used in the domestic sector for cooking or heating, as is the case in the Gold Coast province of Ghana where pellets from maize cobs together with improved cooking stoves mean an improvement in the kitchen work for local women. In other cases, the energy component of an IFES originates from the processing of the food component at industrial scale as was the case in Mozambique, where rice husk from a rice processing company provides the fuel for the drying of the rice grain as such.

5.1. CAN IFES MAKE FOOD SYSTEMS MORE SUSTAINABLE AND EFFICIENT ON A MEANINGFUL SCALE?

IFES aim to make food production more sustainable and efficient, combined with better access to sustainable energy. The challenge lies in planning and implementing IFES, which requires an understanding of local specificities to identify and appraise local conditions, barriers, opportunities and dynamics of these factors over time. There are no 'miracle' solutions or 'magic' formulas. This is evident from the six IFES cases that were analysed and compared to the BAU scenarios.

Sustainability of IFES scenario should be assessed by comparing the IFES case to a BAU scenario, which does not combine food and energy production. Such an assessment is essential to identify the IFES that should be replicated and promoted. The analysis undertaken in this project shows that there can be trade-offs between the three pillars of sustainability within an IFES; which require informed decision making to be based on evidence and a complete knowledge of local context This is briefly illustrated hereafter:

5.1.1. Mozambique cases

- For instance, the rice husk IFES in Mozambique does indeed perform well on environmental and social sustainability but may face challenges in economic sustainability, not because of energy production from husks unfeasible, but due to the volatile supply of rice in the first place. No disadvantages of the rice husk IFES were reported or observed compared to the BAU scenario. The IFES does not affect the farming systems and farmers activities on their fields; it only concerns the operations at factory level. However, the rice mill, which has a capacity to process 2 500 tonnes of rice per year, has been functioning at much lower capacity than that which may affect the economic sustainability of the system. In 2013/2014 with favourable weather conditions, rice production peaked at 580 tonnes/year. However, in 2014/2015, heavy flooding destroyed crops and only 250 tonnes was harvested. In the 2015/2016, a severe drought again resulted in a dip in rice production and EOZ only received 100 tonnes to process. This means that due to extreme weather conditions there was not enough rice to process, and the factory operated at a mere 4 percent of it designed capacity. Therefore, in this case the focus should be on increasing rice production through more climate-resistant seeds or other agronomic practices that increase the resilience of rice farming in the first place. This could even lead to massive switching from rainfed to irrigated rice, a change that would require significant learning by the farmers, support to them in such an endeavour, and time to adjust to a new farming system.

- On the other hand, intercropping of pigeon pea with maize seems to present an opportunity to scale up and replicate due to various favourable factors that currently exists in Mozambique. The assessment shows that the integration of pigeon pea into existing maize fields is simple and social acceptance is high in general and even higher by farmers who have experienced the vulnerability of maize in drought situations. This is because the pigeon pea, protects' the maize crops against diseases, and improves soil properties, both through through nitrogen fixation and better soil water retention. These features in turn reduce the risk of crop losses and increases yields, hence improving farmers' resilience and livelihoods. In addition, this IFES system reduces the risks related to unsustainable gathering of woodfuel – hence of forest degradation. Finally the policy environment has never been so favourable and enabling for the replication of this IFES given the recent MoU signed between the Government of Mozambique and the Government of India in July 2016, which provides a stable demand for pigeon pea for export. The challenge in this case is to allow for expansion of the IFES system while keeping the positive features associated with the combination of a food and energy crop is smallholdings.
- The results from the Jatropha case in Mozambique points toward an interesting dynamic between external factors and an apparent successful IFES. Jatropha was introduced as a fence crop to protect the food crops on the fields, such as maize, cassava and groundnuts from wild animals. This was when the grid had not yet reached Bilibiza and there was no diesel pump in the park, consequently, diesel was only available from vendors at high prices. Jatropha was seen as a suitable feedstock to produce liquid fuels intended to substitute diesel. This was good for food production as well as the socio-economic wellbeing of the farmers who got paid 5 MZN per kg of Jatropha by the Jatropha processing company while additionally they were granted access to the Jatropha oil for profitable soap making. 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[3] for soap making. Additionally, 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. This made harvesting Jatropha economically unviable for the farmers and the system started underperforming. The lesson learned here is again the fact that IFES are not stand alone systems but influenced by external factors. In this case, the two simultaneous occurring event- 1. Low fossil fuel prices and 2. Expansion of electricity grid and diesel pump had a big impact on markets for local Jatropha-based biofuel and therefore on interest in producing Jatropha

[3] PPO: rate of flagrances and essential oils for soap making

for that purpose. Even though production of biodiesel from Jatropha stands environmentally sustainable, it performed poorly on social and economic sustainability over time due to external factors. Nevertheless, it was assessed that production of Jatropha seems to be most viable on smallholder fields in association with food crops rather than as monocultures on large fields. In the case study there is no competition for land, rather a synergy as Jatropha can increase food crop yield through protecting fencing of the food crops. Additionally, 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. Additionally, Jatropha may be more sustainable 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. On the other hand, soap has a guaranteed local market and can be used for own consumption and may find a niche market for export. This highlights the importance of having a feedstock that has multiple purposes, as a way to be able to adjust to changes in market dynamics.

5.1.2. Ghana cases

The cases from Ghana seem to be better poised for replication albeit with some challenges:

- One of the cases in Ghana 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 interconnected systems of value chains (biochar manure, vegetable production, oil palm kernel). It performs well in all three pillars of sustainability as it is socially acceptable, environmentally reliant and economically viable. This systems also fits well with the maize, energy and climate change policy, with potential to be adopted as a mechanism for improving agricultural production while addressing climate challenges. Finally, adequate human and technical capacity exists to provide the needed support wherever the IFES is replicated in Ghana. However, challenges exist and pertain to the social adoption of ELSA stoves.
- The design of the ELSA stove presents some technological challenges 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 then lit at the top. Some challenges with TLUD gasifiers comprise the ignition and the regulation of heat output. Due to the way the fuel is filled into the stove, the top surface of the entire fuel should be ignited as evenly as possible, yet pellets are hard to ignite so some fire starter and a good technique is needed.
  - The biggest technological 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.
- There are also some social acceptance challenges:
  - Certain ELSA stove features do not meet the cooking specification of women. For example, some 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 maintain the original height. 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.
  - Furthermore, several women complained that after a couple of years of use, the stove begins to deteriorate, yet, they do not have contacts with any of the artisans that repair

the stoves. This challenge can be overcome by training more artisans and over time develop a properly functioning market for the ELSA stoves with appropriate after-sales services.

These challenges, although significant, do not stem from the IFES as such, but are adoption challenges and can be solved as the learning curve of the stakeholders develop. The need is to adapt the stove to local preferences and ensure that maintenance capacity is developed. However, further economic analysis would be needed to ensure that the system is economically viable for the both the producer and consumer involved in the system.

- The case of utilising stalks from sorghum and millet farms to substitute firewood as cooking fuel to varying degrees in northern Ghana is more intricate, and points out another important dimension of IFES that is significant when assessing the sustainability of the systems – i.e. - the impact of IFES system on other uses of available energy feedstock. The users of stalks are classified into two types–(1) those who partially depend on sorghum-millet residue and substitute 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, compared with the BAU scenario, where no stalks are utilized. The production practices of sorghum and millet grains are not different for the IFES and BAU scenario. The main difference between the two systems however, lies in the end-use of the residue (stalk). While in the BAU scenario, the residue is either sold or used as fodder, they are at least partially used for fuel in the IFES. Therefore, while this IFES definitely has a positive impact on household expenditure on cooking fuels[4] and may reduce the pressure on forest resources, it may have impact on the livestock sectors in cases where stalks are diverted from livestock feed to cooking fuels. Managing such trade-offs is key to developing and scaling up IFES. Nevertheless, this IFES seems replicable provided some of the trade-offs and challenges are managed well. Another important challenge of this IFES lies in the fact that the stalks do not burn cleanly in the 3-stone-fires and often require cumbersome adjustments when in use. Nevertheless, this challenge also creates the opportunity to develop and promote efficient appropriate cook stoves that can use less stalk to generate more heat for cooking, thereby prolonging the availability of the stalks.
- The oil palm IFES in Ghana distinguishes between artisanal and industrial processors. The IFES involves long-established cultivation of oil palm (food component) and the use of its biomass (fibre and kernel shells as energy component) as fuel in the processing of Crude Palm Oil (CPO) and Palm Kernel Oil (PKO). The use of residues for energy purposes seems to have emerged naturally among artisanal processors in response to the need for cheaper energy and as a means to manage waste. Whereas the idea of the IFES is not new to the industrial processors, new technologies have to be procured before the IFES can be fully utilized. Hence, at this level, it is partly indigenous (idea) and introduced (technology). The IFES potentially improves rural farm household food security through savings on energy expenditure which can be used to buy food. Additionally, when (CPO) is produced, the gross margins after sale can be up to 60 percent more than when it is produced under the BAU system and 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. It also improves resource use efficiency since the processors utilize their own generated residues as fuel which also reduces their waste. Furthermore, 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.

[4] *Estimated savings on cooking fuel by households in northern Ghana by up to 66 percent*

5.2. MEASURING SUSTAINABILITY OF BIOMASS PRODUCTION AND USE ACROSS THE FOOD SYSTEM

The assessment of IFES sustainability is challenging, for different reasons:

- The sheer diversity of different types of biomass, IFES typologies, and contexts where they occur makes the search for common indicators to inform decision-making a difficult undertaking;
- Furthermore, indicators need to be tailored to inform a particular question within a given context – not the other way round. Trying to find the right data to fit a previously designed indicator without knowing the reality on the ground––often does not fit with local realities. Cookstoves illustrate this point. While the World Health Organization (WHO) and the Global Alliance for Clean Cookstoves (GACC) put much emphasis on low-emission cookstoves to protect human health, local users are often more concerned that a stove is appropriate for the local cooking habits, that it cooks fast and is convenient to use with the available fuels;
- Another challenge lies in the often significant requirements in terms of time, knowledge and budget to carry out assessment as prescribed by many monitoring and evaluation systems.

Given the above, a pragmatic approach to address the above-mentioned challenges seems of order, based on answering the following questions:

- How realistic is the selection and implementation of often required SMART (Specific, Measurable, Accepted, Realistic; Time bound) indicators?
- To what extent should one not combine such resource-demanding and often far from perfect impact assessments with indications on the quality of implementation based on proxy but more affordable, as a means to define "no-regret" pathways while waiting for detailed impact assessments.

Based on the experience gained though this project, the authors of this study argue that using performance indicators concerning the quality of implementation of good practice promoting good practices for biomass production and use could be a complementary, cost effective yet technically robust way to select such 'no-regret' pathways in the assessment of IFES sustainability. Indeed the experience has shown that this type of indicator is not only easier to measure, but also more cost- and time efficient, and yet scientifically sound.

Some experts argue that indicators which focus on management practices are critical, but dangerous because there is only limited knowledge about which practices are truly sustainable (Dale et al, 2015). However, our own assessment points to the fact that there is already considerable knowledge and work on good practices regarding important aspects of IFES sustainability. Examples include the WOCAT compilation of good land management practices (Liniger et al, 2011) and the FAO compilation of good bioenergy practices (FAO, 2012a; FAO, 2012b).

6. CONCLUSIONS

6.1. THE SUSTAINABILITY, REPLICABILITY AND POTENTIALS OF IFES

It is clear from the analysis of the six cases that IFES is a promising approach towards sustainable socio-economic development. However, it is also clear that in order to develop a successful IFES that guarantees environmental and agricultural sustainability, an understanding the local context is essential. This points towards the need for IFES to be developed ground up; adequately involving all stakeholders, including farmers.

Similar to biomass-based energy, bio-based plastics and other bio-based materials have found large interest in the industry because they lead to the reduction of greenhouse gas emissions and reduce the dependence on crude oil, however the concern for the use of raw materials competing with food have increased (Shankar, 2016). Critics who fear that the large amount of biomass needed for the steadily growing sector can by no means be sourced sustainably increasingly scrutinize Bioeconomy. And indeed, while the concept of sustainability is an integral part of current bioeconomy strategies throughout the world, very few specify what sustainability actually means.

The impact of changing climate and rising global average temperature are increasingly being felt across the word. The increase in frequency of occurrence of climate induced events like droughts, heavy storms and flood are a significant challenge faced by the agricultural systems and has the potential to severely impact food security. At the same time, agricultural systems also contribute to climate change and account for around 24 percent of global GHG emissions[5]. Therefore, reducing fossil fuel use in food production, increasing resource use efficiency and reducing deforestation are key to mitigate climate change. The developing and upscaling of successful IFES can play a significant part in efforts to both mitigate and adapt to climate change – hence to NDCs, and this was confirmed by discussions during the final workshops of the project in Mozambique and Ghana.

The signing of the Paris agreement put NDCs at the centre of the global strategy to tackle climate change by ensuring that economies move on towards a low-emission resilient development pathway. The implementation of the Agreement now relies on countries meeting their own 'contributions', which will require the implementation of relevant national policy frameworks, as well as the mobilization of financial resources from a wide variety of sources, instruments and channels. The challenge lies in converting NDCs into policies, measures and financeable investment strategies that are based on sound evidence. Countries now need to move from defining high level goals and translate them into specific policies and measures that can be implemented in a transparent and measurable manner. One concrete way of doing this is to develop bankable Nationally Appropriate Mitigation Actions (NAMAs) that will contribute to achieving some of the targets out lined in the NDCs. IFES can contribute to the agricultural aspects of NAMAs, as is currently the case in FAO projects in Viet Nam and Ivory Coast: in these countries, the assessment of GHG emissions and other sustainability aspects is being evaluated regarding rice value chains where climate smart practices are being implemented regarding on the one hand farming practices; on the other hand, the use of rice husks to produce energy.

NAMAs continue to be important for developing countries. The identification and replication of successful IFES offers a viable and bankable way to achieve this. The GHG mitigation impact of IFES stems from its ability to either displacing fossil fuel by providing alternative sustainably produced fuels to produce energy, to reducing deforestation or both. In some cases it may also increase soil carbon sequestration through improving the status of soil organic matter.

Developing bankable NAMAs requires considering three important dimensions in order to be implementable and attract the necessary financing for their achievement. All three need to be

[5] This includes agriculture, forestry and other land use.

addressed in a balanced manner for the NAMA to be solid and create favourable conditions for low-carbon investment (Surratt et al, 2016). A bankable NAMA should aim to:

- Improve policy and institutional frameworks, including through policy mandates, regulations that level the playing field for low-carbon investment, and/or the development or strengthening of institutional arrangements for policy planning and implementation;
- Address financial risks and returns, including through financial mechanisms and interventions that lower real and perceived risks and/or improve returns sufficiently to mobilize low-carbon investment; and,
- Identify projects and demonstrating feasibility, including the development of an initial project or set of projects, and the identification of a larger project pipeline."

The methodology to assess IFES can provide useful indications regarding these aspects.

On the other hand, sustainable IFES can also contribute to climate change adaptation, in two ways:

- By increasing local self-sufficiency in both energy and food supply,
- In some cases by allowing for income diversification of rural households through the sale of energy produced through the IFES.

The above means that IFES also have the potential to strengthen the implementation of country's 'National Adaptation Plans (NAPs).

The possible role of IFES in both NAMAs and NAPs is worth pointing out, as it means that replication and upscaling of sustainable IFES can strengthen the implementation of NDCs.

More broadly, sustainable IFES deployment can support the implementation of several SDGs in an integrated manner, given the key role of biomass in that respect mentioned in the introduction of this report and highlighted in IASS (2015).

6.2. THE METHODOLOGY TO ASSESS THE SUSTAINABILITY AND REPLICABILITY OF IFES

In this project we used both impact and performance indicators – and in some case qualitative descriptions and cross referencing with available literature– to reflect previously chosen criteria. Due to the short timeframe of the project and the limited financial resources, the most important requirement was the practicality of the indicators used; while not jeopardising the quality of the results: Indeed, timely and cost-effective measurement were imperative for this assessment. The results indeed show that the combination of impact and good-practice-based performance indicators can produce results that give a sufficient and solid indication on the quality and potential for replication of IFES. Based on this experience, we would argue that such conclusions are worth exploring beyond IFES, i.e. in all areas concerned with the measurement of the sustainability and potential for replication of biomass production and use. These include the conventional biomass sectors such as agriculture, forestry and fisheries, but also the production of non-food/feed goods such as bioenergy and bio-based products in the context of bioeconomy, NDC implementation, and, more broadly, SDGs.

7. RECOMMENDATIONS AND PROPOSED WAYS FORWARD

Interesting lessons have been drawn from the analysis of the IFES cases in Ghana and Mozambique. However, as mentioned earlier in this report, there are no 'miracle' solutions or 'magic' formulas. On that basis, the following recommendations can be made regarding the implementation and/or scaling up of IFES:

- If the raw energy feedstock is produced in the field, one should choose raw material that have multiple uses (as in the case of pigeon pea and jatropha), as a way to limit risks by allowing for adaptation to different local circumstances, and offer more income opportunities for the raw material producers;
- Favour the use of renewable biomass (crops and residues) instead of non-renewable biomass (standing forest);
- Proceed with great caution in the expansion of IFES; justified by great market opportunities as was the case with jatropha, and possibly pigeon pea in Mozambique. When such opportunities appear, one should:
    - Start from what exists, is known and proven, and keep the proven advantages that such systems have on a small scale (for example those of the pigeon pea- maize mixed cropping system);
    - Guarantee the flexibility of the IFES system to allow for adaptation to changes in local conditions (market, needs, policies, etc);
    - Scale up incrementally, through "learning by doing';
    - Take into account not only the requirements of the new markets, but also local needs and experience (e. g in the selection of varieties of pigeon pea for the Indian market in Mozambique);
- Keep in mind that IFES systems grow organically and overtime. Especially those systems that involve perennial crops are likely to take time and resources to grow and flourish. The initial hurdle until the first harvest as seen in agroforestry systems for instance often needs financial support;
- Capacity building is key to the establishment of IFES as seen in the case of maize-pigeon pea in Mozambique or the improved cook stove programs in Ghana. Institutions or "champions" that can fulfil this task are therefore an important requirement to the upscaling of IFES;
- The application of the IFES concept should not be seen as an additional task to others or a stand-alone project. Instead, IFES should be 'mainstreamed' and integrated into the tasks of relevant programs (agriculture, energy, rural development and the environment) that already exist to improve the performance of these programs by ensuring better integration and to providing opportunities to take advantage of possible synergies. Given the nature of IFES systems, their implementation requires a holistic approach and cross-sectoral coordination. This is a major challenge because in most cases it is not institutionalized.

Table 1 presents some of the implementation challenges, and proposes ways to overcome them.

Table 1: Main challenges to promote IFES and proposals on how to address them

Challenges	Proposals to address them
Coordination at National level Provincial level	Use existing mechanisms regarding relevant cross –sectoral topics that also offer good support possibilities - for example, climate change issues (Climate Financing through NAMA, INDCs and The Adaptation Strategy, Rural Development). These issues are often part of the mandate of the Ministry of Environment. If they already exist, use the coordination mechanisms related to the implementation of rural development plans and contributions to the country's commitments on climate change. If such mechanisms do not exist, create an IFES task force /working group, starting in provinces where there is interest in and experience on IFES.
Achieve scale and commercial viability of IFES	Policy measures on incentives (fiscal, training, preferential markets, etc.) Specific credit systems (through the involvement of the banking sector) Favour adding value in the country – e.g. regarding the manufacture of equipment (e.g. improved stoves) and food processing- if you have local market (e.g. food products from pigeon pea) Capacity building on management, business plans, sustainable biomass production (e.g. shift from rainfall to irrigated rice, etc.)
Mobilize financial support	Climate Funds linked to INDCs / NAMAs, Adaptation). This requires a detailed analysis of the situation with and without IFES regarding greenhouse gas emissions as well as on how to improve adaptation – as these are the priorities of such funds. This should be coordinated by the respective Ministry in charge of Environment as it is part of their formal mandate. Another possibility is the Low Carbon Agriculture Programme; which is coordinated by the Ministry of Agriculture) Finally, the implementation of the bioenergy program; which is part of the remit of the Ministry of Energy. In the case of climate funds, it is important to show how all this contributes to the implementation of INDCs as an inclusive commitment and IFES covers all these aspects. Another possibility, though less promising, would have to do with the issue of rural development In addition to climate funds:

	• Explore possibilities with bilateral donors (e.g. USAID, DFID, BMZ – in this case explore their Zero Hunger cum Green Technology Centre Programmes), • Need to develop public-private sector partnerships; • There are few and small possibilities of financial support to with FAO. But the FAO could also help regarding the other financial mechanisms and sources.
Mobilize non-financial support	Being an implementing agency and not a donor, FAO mainly provides technical support. However, FAO can also facilitate linkages with other partners, including financial ones. Other partners may also provide technical assistance (e.g. GIZ)

Given the possible contribution of sustainable and replicable IFES to both food and energy security as well as climate change adaptation and mitigation, the deployment of sustainable IFES is quite relevant to many NDCs, especially those that have identified both agriculture and bioenergy as major measures to implement these commitments the case in most African countries. FAO's Analytical Framework (IFES AF) is a tool to identify successful cases of IFES, analyse their sustainability and finally assess their replicability, which would then make that particular IFES case a potential candidate for a successful NDC. The intercropping of pigeon pea with maize in Mozambique, for instance, has shown significant replicability potential, and therefore, is well suited to develop into a NAMA and a NAP. The same is true for the IFES in Ghana that aims to use dry maize cob for the production of clean-burning pellets. Through active collaboration between the respective National Governments, FAO, civil society and other key stakeholders, successful IFES cases have the potential to mobilize resources to be replicated and scaled as important contributions to the implementations of countries' NDC and SDG commitments.

The conclusions and recommendations point out the value of promoting sustainable IFES. The following ways forward in that direction are proposed:

- Draw the attention of decision makers at all levels on the importance of biomass in achieving both the SDGs and the Paris Agreement on Climate Change;
- In parallel, highlight the positive role sustainable IFES can play in that respect; this should stem primarily from countries where successful IFES have been implemented and assessed;
- Linked to the above point, support more testing on the sustainability and replicability of IFES in different countries. The cost effective yet robust methodology used in this project can be of use, and perhaps complemented by other tools if need be;
- The above proposals should start from a dialog between national stakeholders groups, including country delegations of possible bilateral and/or international partners, concerned and involved in the implementation of national commitments as regards NDCs and SDGs.

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ANNEX – TYPE OF IMPACT AND PERFORMANCE INDICATORS USED IN THE SUSTAINABILITY ASSESSMENT

	Criterion	Impact indicator	Performance indicator concerning recognised good practices
Social	Food security	1) Yield of crop(s) and/or crop residues (kg/ha/season) In combination with Farm land size (ha) (2) Rural household income (USD/kg) a. Income from food component and/ or reduced expenditures/or wage b. Income from energy component or reduced expenditures/or wage c. Other income from farming system (e.g. biochar, bioslurry) or reduced expenditures or wage	1) Share of food expenditures in total household expenditures (percent)
	Energy access		
	Adaptive capacity to climate change and variability	1) Percentage of years without crop failure due to drought or floods	1) Share of cropland under good adaptation practices (percent) And 2) Income diversification expressed in number of sources of income
	Health	Changes in mortality and burden of disease attributable to indoor smoke	Health impacts from the furnace - significant generation of smoke (yes/no)
	Employment	Number of full time equivalent jobs	N/A
Environmental	Soil health	Soil organic matter (carbon) content (tons of carbon per hectare)	1) Share of cropland under soil conservation practices (percent) or 2) Months of soil cover (months)

	Pollution (nutrients)	Fertilizer applied per unit of arable land (tons of nutrients per hectare of arable land)	Share of agricultural land under good nutrient management practices (percent)[6]
	Pollution (pesticides)	Pesticide use per unit of cropland (tons of active ingredient applied per hectare)	Share of cropland under chemical pest management (percent)
	Pollution (air)	N/A	Share of cropland with residue burning (percent)
	Greenhouse gas emissions and carbon sequestration	Food production per unit of GHG emissions (tons of food produced per year per ton of CO2 equivalent)	Share of farm area with agricultural GHG emissions mitigation practices (percent)
	Agrobiodiversity	Total number of species in the system. Included are total number of species of crops, trees and domestic animals; excluded are soil biota, spontaneous vegetation or other plants and animals	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)
Economic	Profitability	Output – input costs/ha/year	N/A
	Resource use efficiency (Water)	(1) Crop/biomass production per drop of water withdrawn (kilograms of crop produced per cubic meter of water per year) in combination with (2) Water stress ratio (water demand/ water supply in cubic meters)	Share of irrigated cropland area with efficient irrigation practices in place (percent)
	Resource use efficiency (Biomass)	Biomass used per plant (grams of plant used per plant produced)	Share of used biomass (percent) (as opposed to biomass burnt or left to decay)
	Resource use efficiency (Land)	Crops/biomass produced per hectare of cultivated area (kilograms of crop produced per hectare of land per year)	Share of land area used for biomass production (percent)

[6] Need to distinguish between artificial fertilizer, manure, and green manure (e.g. leguminous crops etc)

Resource use efficiency (Energy)	Crops/biomass produced per energy invested Or Crops/biomass processed per energy invested	Share of crop land areas with energy efficient crop farming practices in place (percent) Or Share of processing equipment with energy efficient technologies in place (percent)

ISBN 978-92-5-130350-4

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I8627EN/1/02.18