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EVIDENCE-BASED ASSESSMENT OF THE SUSTAINABILITY AND REPLICABILITY OF INTEGRATED FOOD-ENERGY SYSTEMS

A GUIDANCE DOCUMENT

ENVIRONMENT AND NATURAL RESOURCES MANAGEMENT WORKING PAPER

ENVIRONMENT CLIMATE CHANGE [ENERGY] MONITORING AND ASSESSMENT

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SUMMARY

Bioenergy when *managed sustainably* and *efficiently* can be a source of energy to reduce energy access problems. When bioenergy feedstock is produced based on the principles of sustainable production intensification and energy efficiency improvements are made by applying agro-ecological practices and locally adapted technologies, both rural and urban communities are likely to benefit from increased access to energy, and as a direct consequence, improved food security.

However, at the same time, there has also been a lot of debate on whether producing bioenergy could actually threaten food security. This has particularly been raised in the context of producing crops and other biomass for liquid transport fuels and bioelectricity.

FAO argues that to mitigate such risks and to harness the potential benefits of bioenergy production, one is well advised to apply good practices of bioenergy production in the first place. The production of bioenergy in Integrated Food-Energy Systems (IFES) is one of such good practices as IFES by their very nature allow one to meet both food and energy demand.

An IFES is defined as a diversified farming system that incorporates agrobiodiversity and builds on the principles of sustainable production intensification, which aims to maximize primary production per unit area without compromising the ability of the system to sustain its productive capacity. More particularly, the concept of IFES combines the sustainable production of food and other biomass across different ecological, spatial, and temporal scales, through multiple-cropping systems, or systems mixing annual crop species with perennial plants, i.e. agroforestry systems. These systems can be combined with livestock or fish production to maximize benefits.

Furthermore, to increase synergies between food crops, livestock, fish production and forestry, it allows for maximum utilization of all by-products, and encourages recycling and economic utilization of residues for the health and well-functioning of the farming system, for instance as soil amendments and animal feed. Surplus residues may be used for the production of renewable energy (RE) through gasification, anaerobic digestion, combustion or other RE processes.

In many situations, the production of renewable energy can feasibly go well beyond bioenergy alone and other locally available (non-biological) renewables can be incorporated such as solar thermal, photovoltaics, geothermal, wind and water power. Last but not least, end-use devices such as improved cooking stoves or efficient irrigation devices increase the energy-use efficiency of IFES.

While the concept of IFES builds on the principles of sustainable intensification and the ecosystem approach, it stresses the fact that the diversification of crop and livestock species can lead to a sustainable production of *both* food and energy feedstock, as long as relevant practices and technologies are *locally devised and adapted*. It further emphasises that energy efficiency can be reached in these systems when applying sound agro-ecological practices and locally adapted technologies. This can be observed in many smallholder farming systems around the world, for example, agroforestry or intercropping systems

that provide food, on the one hand, and generate crop residues and woody biomass for cooking or heating, on the other.

However, far less common are those IFES that build on a sustainable production of food and energy feedstock *and* combine it with renewable energy technologies, that eases access to *modern* energy. Many pilot studies, research projects and business innovations suggest that food and energy for fuel, heat and electricity can be sustainably produced in such food-energy systems. Yet the supporting evidence to bring these types of IFES to scale is still scarce and projects often remain single islands of success.

It is well known that evidence is a critical element in successful decision-making. However, evidence is often inadequate or does not exist when decisions are made. This is the case in the emerging bioenergy sector and the growing bioeconomy, particularly due to a lack of understanding of the links between bioenergy and food security. Unsurprisingly, this also concerns the potential to soundly integrate food and bioenergy production: IFES provide many advantages compared to conventional farming systems, *yet al*so raise considerable challenges.

Given the heterogeneity of global agriculture, there is no one-size-fits-all solution. In fact, there are many different types of existing IFES. Some are adopted widely, such as certain types of agroforestry systems that provide households with food and fuelwood at the same time. Others are more innovative and less common, for instance, those systems that use agricultural residues from food crops and livestock to produce biogas, or intercropping schemes that provide both feedstock for food and bioethanol production at the same time. An **analytical framework** is needed to be able to screen IFES options systematically and to be able to define which IFES systems are sustainable and replicable.

FAO, with the financial support of the Dutch NL Agency, has therefore set out to develop such an analytical framework (AF). The AF is envisioned to be **a guidance document** that will allow its user to assess which factors make an IFES truly sustainable and which factors need to be considered when replicating such a system - be it a pilot project, a business innovation or a research experiment.

Furthermore, it will help to systematically describe the potential contribution of IFES to **sustainable agriculture** and the **growing bioeconomy**, and raise awareness among decision-makers about which factors can facilitate the replication of such innovative projects. This will include strengths and weaknesses as well as opportunities and risks.

The first part of the AF includes a set of criteria, indicators and measures to help screen IFES projects based on their environmental, social and economic sustainability. The second part of the AF contains a set of leading questions and related features that will help to analyse which factors need to be built into new IFES cases to make them replicable and bring them to scale. This is particularly important, as in the growing bioenergy sector and the developing bioeconomy, many questions related to how to implement sustainable bioenergy and solutions and bring them to scale still remain unanswered. The analytical framework will help decision-makers to pose the relevant questions and obtain information that is instrumental in shaping the enabling environment for sustainable bioenergy.

In other words, the IFES AF is a tool that helps to identify barriers to adoption of IFES and to understand how these barriers can be addressed. The IFES AF seeks to analyse which policies and measures need to be in place to create an enabling environment for IFES. Additionally, the IFES AF will support the identification of relevant stakeholders, appropriate institutions, and the available human, technical and financial capacity to further the adoption and replication of IFES.

While the **key audience** for this guidance document is primarily policy and decision-makers, it could also be useful for practitioners who wish to get a preliminary indication of whether their project has the potential to be brought to scale.

The IFES AF will be pilot tested in interested FAO member countries. Furthermore, a range of dissemination and outreach activities have been and continue to take place aiming both at the public and private sector, civil society organizations as well as the scientific community. The emphasis is on informing these and other stakeholders about the concept of IFES, as well as raising awareness about the need for implementing the AF to strengthen the evidence base of such systems. Moreover, FAO proposes concrete action to strengthen global and national knowledge and capacities related to developing sustainable and inclusive bioenergy systems that foster energy access and food security.

ABBREVIATIONS AND ACRONYMS

AF	Analytical Framework
BEFS	Bioenergy and Food Security
C	Carbon
FAO	Food and Agriculture Organization of the United Nations
GBEP	Global Bioenergy Partnership
IFES	Integrated Food-Energy Systems
PRA	Participatory Rural Appraisal
RE	Renewable Energy
SOC	Soil organic carbon

CONTENTS

CHAPTER 1

INTRODUCTION

Energy is vital for food security and resilient livelihoods; nevertheless, the linkages between energy and food security and the importance of energy for food security are often overlooked. The globally accepted definition of food security states that 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). In this context, energy is a crucial requirement for cooking food and boiling drinking water and therefore for the provision of safe and nutritious food. A significant segment of the world's poorest population that are *food* insecure[1] rely on traditional bioenergy[2] – often the only option to meet their energy needs for cooking or heating, because, at the same time, these people are *energy* insecure.

While this strong link between food insecurity and energy insecurity is most apparent in rural and remote areas, this problem not only concerns rural livelihoods as such, but also the management of agricultural systems and the food production value chain in general. Modern agriculture is highly dependent on energy from fossil fuel burning for many processes, from on-farm mechanization, to fertilizer production, to food and feed processing and transportation. For instance, the price of oil is closely correlated with the price of fertilizer. This means that higher energy prices could raise production costs leading to higher food prices in both rural and urban areas.

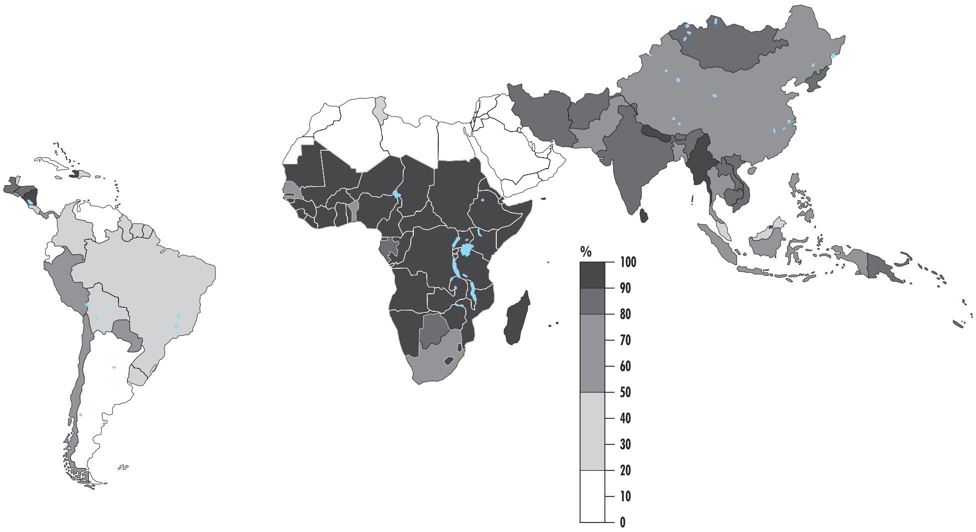
Despite the vital importance of energy for food security and agriculture, lack of energy access is still problematic around the world. In 2009, the number of people without access to electricity was 1.3 billion or almost 20 percent of the world's population. Furthermore, almost 40 percent of the world's population still depend on bioenergy sources, such as fuelwood, charcoal and animal dung, i.e. bioenergy, for cooking and space heating (Legros *et al.*, 2009) (see figure 1 on Share of Traditional Biomass in Residential Consumption by Developing Country).

1 According to FAO, Food insecurity is a situation that exists when people lack secure access to sufficient amounts of safe and nutritious food for normal growth and development and an active and healthy life. It may be caused by the unavailability of food, insufficient purchasing power, inappropriate distribution or inadequate use of food at the household level. Food insecurity, poor conditions of health and sanitation and inappropriate care and feeding practices are the major causes of poor nutritional status. Food insecurity may be chronic, seasonal or transitory (FAO, no date).

2 Bioenergy is energy generated from biofuels, which are fuels derived from biomass (FAO, 2004). Biofuels can be further subdivided by type (solid, liquid and gas) and by origin (forest, agriculture and municipal waste). Biofuels from forests and agriculture come from a wide range of sources, including forests, farms, specially grown energy crops, and residues and waste after harvesting or processing of wood, food crops and fish. *Traditional* bioenergy refers to the use of bioenergy that is "still widely practiced in developing countries and is a non-commercial way to fulfil people's energy needs. In some parts of the world it is still the only energy available for cooking or heating" (Reegle, no date).

FIGURE 1.

Share of Traditional Biomass in Residential Consumption by Developing Country.



Source: IEA, 2006.

The use of biomass is not in itself a cause for concern. However, when resources are harvested unsustainably and agronomic practices and energy conversion technologies are inefficient, there are serious adverse consequences for the health of people, the environment and economic development:

- Almost two million deaths result annually from pneumonia, chronic lung disease, and lung cancer associated with exposure to indoor air pollution resulting from cooking with biomass on inefficient stoves.
- When bioenergy is sourced unsustainably, it has negative impacts on soils and forests leading to soil and forest degradation, and last but not least on agricultural and forest productivity.
- Emissions from burning solid fuels in open fires and inefficient stoves also have significant global warming effects contributing to climate change.

Bioenergy when managed sustainably and efficiently, however, can be a source of energy to reduce energy access problems. When bioenergy feedstock is produced based on the principles of sustainable production intensification, and energy efficiency improvements are made by applying agro-ecological practices and locally adapted technologies, both rural and urban communities are likely to benefit from increased energy, and concomitantly food security.

Due to the complexity of this topic area, and moreover, the perceived risk related to bioenergy development, there has also been a lot of debate on whether producing bioenergy, particularly feedstock for liquid transport fuels and bioelectricity, could threaten food security. However, experience has shown that energy produced from biomass can actually contribute to food security as long as it is sustainably produced and managed. One good practice to do so is the production of bioenergy in Integrated Food-Energy Systems (IFES). Such IFES are farming systems that by their very nature allow one to meet both food and energy needs.

An IFES is defined as a diversified farming system (also see Box 1) that incorporates agrobiodiversity and builds on the principles of sustainable production intensification[3]. More particularly, the concept of IFES combines the sustainable production of food and other biomass across different ecological, spatial, and temporal scales, through multiple-cropping systems, or systems mixing annual crop species with perennial plants, i.e. agroforestry systems. These systems can be combined with livestock or fish production to maximize benefits.

Furthermore, to maximize synergies between food crops, livestock, fish production and forestry, IFES allows for maximum utilization of all by-products, and encourages recycling and economic utilization of residues for the health and well-functioning of the farming system, for instance as soil amendments and animal feed. Surplus residues may be used for the production of renewable energy (RE) through gasification, anaerobic digestion, combustion or other RE processes.

In many situations, the production of renewable energy can feasibly go well beyond bioenergy alone and other locally available (non-biological) renewables can be incorporated such as solar thermal, photovoltaics, geothermal, wind and water power. In addition, end-use devices such as improved cooking stoves or efficient irrigation devices increase the energy-use efficiency of IFES.

While the concept of IFES builds on the principles of sustainable production intensification and the ecosystem approach, it stresses the fact that the diversification of crop and livestock species can lead to a sustainable production of both food and energy feedstock, as long as relevant practices and technologies are *locally devised and adapted*. This can be observed in many smallholder farming systems around the world, for example, agroforestry or intercropping systems that provide food, on the one hand, and generate crop residues and woody biomass for cooking or heating, on the other.

However, far less common are those IFES that build on a sustainable production of food and energy feedstock[4] and combine it with renewable energy technologies, that allow access to modern energy[5]. Many pilot studies, research projects and business innovations suggest that food and energy for fuel, heat and electricity can be sustainably produced in such integrated food-energy systems (Bogdanski, 2012). Yet the supporting evidence to bring these types of IFES to scale is still scarce and projects often remain single islands of success.

3 There is no globally accepted definition of sustainable production intensification. In the context of the document, it refers to the ecological intensification of agriculture, which is "understood as a means of increasing agricultural outputs while reducing the use and the need for external inputs, capitalizing on ecological processes that support and regulate primary productivity in agroecosystems" (Titonell &Giller, 2013). Godfrey *et al.* (2009), in other, but similar terms, define it as "producing more from the same area of land while reducing negative environmental impacts and increasing contributions to natural capital and the flow of environmental services". The FAO glossary on organic agriculture (2009c) refers to "[m]aximization of primary production per unit area without compromising the ability of the system to sustain its productive capacity. This entails management practices that optimize nutrient and energy flows and use local resources, including: horizontal combinations (such as multiple cropping systems or polycultures); vertical combinations (such as agroforestry); spatial integration (such as crop-livestock or crop-fish systems); and temporal combinations (rotations)".

4 Food and energy feedstock as used in the document refers to crops, trees, livestock and their waste and by-products such as manure, primary crop and forest residues from the field, and secondary residues from the agroprocessing and wood processing sites.

5 There is no internationally agreed definition of modern energy. In this document, we therefore build on a definition provided by the global Sustainable Energy for All Initiative and the International Energy Agency which define access to modern energy as "a household having reliable and affordable access to clean cooking facilities, a first connection to electricity and then an increasing level of electricity consumption over time to reach the regional average." [Sustainable Energy for All, no date]

BOX 1.

WHAT IS A FARMING SYSTEM?

Farming systems can be small subsistence units or large corporations. They are structurally complex and form various interrelationships between their numerous components (Dixon *et al.*, 2001): different types of land, water sources and access to common property resources such as grazing lands, fish ponds and forests as well as other natural, human, social and financial capital. All these components, including the household, its resources, and the resource flows and interactions at the farm level are referred to as a farming system (Dixon *et al.*, 2001).

It is important to note that a farming system does not stop at the physical boundaries of the farm itself. The enabling environment is a determinant factor of the functioning of a farm system. This includes policies, institutions, markets and access to information (Dixon *et al.*, 2001). Income from off-farm activities is also considered as part of the farming system, as it is often fundamental to maintain the farmers' livelihood and the farm itself.

The term "Integrated" farming system concentrates one's attention on the diversification of plant and/or animal species across ecological, spatial, and temporal scales within a farming system. Such diversification provides a mechanism for maintaining and regenerating biotic interactions and corresponding ecosystem services that provide a large set of essential provisioning, supporting, regulating and cultural services to humankind in general, and agriculture in particular (e.g. Kremen, 2012; Shennan, 2008). Three of the most obvious services are the provision of nutritious food, clean water and energy. Other services such as pest and disease control, pollination, soil quality and climate regulation form the basis of these and are essential for the functioning of healthy agro-ecosystems, and last but not least, achieving food security.

CHAPTER 2

OBJECTIVE: SUPPORTING THE DECISION-MAKING PROCESS FOR THE SUCCESSFUL IMPLEMENTATION OF IFES

Evidence is a critical element in successful decision-making. However, evidence is often inadequate or does not exist when decisions are made. This is the case in the emerging bioenergy sector and the growing bioeconomy, particularly due to a lack of understanding of the links between bioenergy and food security. Unsurprisingly, this also concerns the potential to soundly integrate food and bioenergy production: IFES provide many advantages compared to conventional farming systems, *yet al*so raise considerable challenges (Bogdanski *et al.*, 2010).

These challenges, which are primarily related to capacity building, knowledge transfer and finance, need solid policy support to be addressed appropriately. Nonetheless, there is still limited evidence of which IFES are successful - IFES that are sustainable and replicable; in other words: IFES that have the potential to be widely adopted by the farming community in different parts of the world. **The evidence base** to support decision-making and policy processes for the wider uptake of IFES by the farming community is simply missing, and without such evidence, decision and policy-making remains difficult.

Given the heterogeneity of global agriculture, there is no one-size-fits-all solution. In fact, there are many different types of existing IFES. Some are adopted widely, such as certain types of agroforestry systems that provide households with food and fuelwood at the same time. Others are more innovative and less common, for instance, those systems that use agricultural residues from food crops and livestock to produce biogas, or intercropping schemes that provide both feedstock for food and bioethanol production at the same time. An **analytical framework** is needed to be able to screen IFES options systematically and to be able to define which IFES systems are sustainable and replicable.

FAO, with the financial support of the Dutch NL Agency, has therefore developed such an analytical framework (AF). The AF is envisioned to be **a guidance document** that will allow its user to assess which factors make an IFES truly sustainable and which factors need to be considered when assessing the replication potential/replicability of such a system – be it a pilot project, a business innovation or a research experiment. Furthermore, it will help to systematically describe the potential contribution of IFES to **sustainable agriculture** and the **growing bioeconomy**, and raise awareness among decision-makers about which factors can facilitate the replication of such innovative projects. This will include strengths and weaknesses as well as opportunities and risks.

The first part of the AF includes a set of criteria, indicators and measures to help screen IFES projects based on their environmental, social and economic sustainability as further discussed in section 2.1. The second part of the AF contains a set of leading questions and related features that will help to analyse which factors need to be built into new IFES cases to make them replicable as discussed in section 2.2.

The **key audience** for this guidance document is primarily policy and decision-makers, but it could also be useful for practitioners who wish to get a preliminary indication of whether their project is sustainable and has the potential to be replicated elsewhere.

The AF will be first pilot tested in several countries where some promising cases of integrated food-energy production have been implemented. After the pilot testing the AF will be finalized taking into account the feedback from the pilot testing phase.

2.1 ASSESSING THE SUSTAINABILITY OF IFES

The first part of the IFES analytical framework (AF) is designed to systematically describe and assess different IFES cases according to a set of different sustainability indicators. Based on the results, countries might opt to invest further resources to replicate a project that has been identified as sustainable (as described in section 2.2).

Sustainable development has been a key concept in the development arena for the past decades, at the very latest since the publication of the Brundtland report in 1987. It defined the term *Sustainable Development* as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (The World Commission on Environment and Development, 1987).

In the context of integrated farming systems, sustainability refers to sustained agricultural productivity in the long term while, at the same time, maintaining or increasing the underpinning ecosystem services that provision, support or regulate such productivity. Sustainable farming systems are to assure food and nutrition security, generate employment, or provide income among other aspects.

Sustainability relies on three pillars – environmental soundness, economic viability and social acceptance. Institutional capacity is increasingly considered as a fourth pillar of sustainability. Furthermore, sustainability of farming systems can be characterized by a set of underlying attributes inherent in each system. Lopez-Ridaura *et al* (2005) point to five core attributes, which refer to the functioning of a farming system itself – productivity and stability – and three related to the behaviour of the system when exposed to internal and external impacts – reliability, resilience and adaptability. Productivity describes the efficiency of a system, while stability relates to the conservation of the resource base. Resilience, reliability and adaptability describe the capability of a system to face perturbations in its own functioning and within the environment.

As this description of the various facets of sustainability suggests, assessing all dimensions of sustainability is a complex undertaking, and it poses a significant challenge to both scientists and policy-makers alike. One therefore needs to be aware of the fact that:

1. Sustainability is relative and therefore often lies in the eye of the observer: what is sustainable, and what is not, depends on what one defines it to be - according to a pre-defined set of goals or objectives.
2. These goals and objectives are then defined by a selected set of criteria and indicators that can describe these goals in the best possible way. Yet while criteria and

indicators for the assessment of integrated systems need to be comprehensive, it is crucial to keep the measurement of indicators as simple as possible. Furthermore, they need to be: easily understandable and transparent; policy relevant; theoretically well founded from a solid scientific basis; sensitive to (human-induced) changes; show changes in time; technically measurable; and appropriate to scale (temporally as well as geographically and/or spatially) (Malkina-Pykh, 2002). Last, but not least, indicators need to be realistic, that is the appropriate data sets need to be available or must be easily collectable. Defining such a comprehensive set of indicators with easily measurable and appropriate thresholds or reference values for sustainable agriculture is therefore a challenge that has yet to be successfully tackled. Simplifying a holistic assessment for the sake of policy-making is crucial, yet it always bears the risk of losing important details and weight.

3. Assessing sustainability is also a question of resource availability. The availability of data, time, financial or human resources is likely to determine whether the analysis needs to be kept relatively simple or can be more detailed. Where appropriate, this AF will therefore suggest both, a rapid assessment based on relatively rough methodologies for an initial screening, and a more comprehensive methodology for a more concise outcome, as discussed in section 3 and in the Annex.

2.2 ASSESSING THE REPLICABILITY OF IFES

Pilot projects, business innovations or case studies often lead to remarkable results, and are advertized as successful models for upscaling. Yet this does not necessarily mean that they will be widely adopted or replicated. Many projects remain single islands of success. It is seldom possible to exactly reproduce them in a different context and location. This is also the case for IFES, even if they have proven to be sustainable. The second part of the AF is therefore intended to assess the replicability of an IFES project.

We define replicability as the potential of a project, innovation or pilot test to be replicated, scaled up, expanded, or adapted. Terms which are often used interchangeably are scalability, potential for replication or scaling up. Replication can be regarded as an intentional and planned type of scaling up.

Testing the replicability of a project will help determine 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.

One needs to note however, that a replicability assessment of IFES is a complex undertaking because:

1. First, IFES are established for different purposes and objectives. For instance, some might be designed to diversify agricultural production and household income while others, in contrast, might build on a business idea to bring renewable energy entrepreneurs together with small agribusinesses.
2. Furthermore, some IFES work as well as they do because of the individual skills or

character of those who run them, a factor that is often impossible to reproduce.

3. In addition, communities where IFES are located are different in size, character, and culture, and all of these factors might affect the implementation and operation of a particular IFES project.

Despite these variables, there are usually some common features related to the nature of the IFES project itself and its enabling environment which can help determine whether it is replicable or not. For example, this could be the way the project is structured and managed as well as how institutions and policies support its implementation and functioning. While there is no established theory on replicating successful projects, there are more and more studies that propose guidelines for analyzing and planning for replication (Holocombe, 2012). This will be further explored in section 3.2.

CHAPTER 3

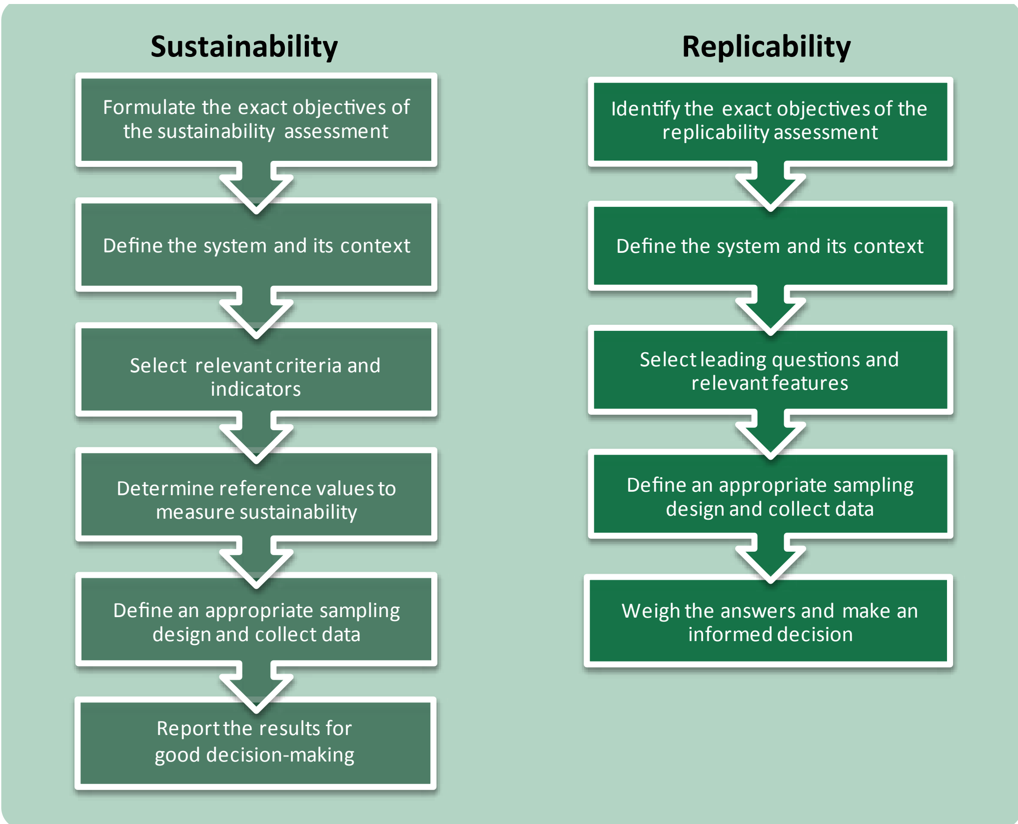
THE ANALYTICAL FRAMEWORK

This section gives guidance on which steps to follow when assessing both the sustainability (section 3.1) and the replicability (section 3.2) of a particular IFES project. The main text which follows hereafter describes the various stages of each assessment. It can be used as a manual to guide the user from one step to the other as illustrated in figure 2. For purposes of clarity, the following section is restricted to describing the assessment process as such and the main issues addressed, while the specific methodologies and tools chosen for an IFES assessment are dealt with in the Annex.

As each project is unique, the following analytical framework will need to be adapted and contextualized to each specific IFES case. The guidance given hereafter is therefore general, and will require further refinements once the pilot studies are chosen.

FIGURE 2.

Step by step: Guidance on assessing the sustainability and replicability of IFES



3.1. GUIDANCE ON ASSESSING THE SUSTAINABILITY OF IFES

The purpose of this section is to support those who wish to assess the sustainability of a specific IFES case through an indicator-based framework. At the core of this objective lies the need to improve decision-making for adoption and replication of sustainable IFES. The underlying assumption is that good decision-making on IFES needs to be based on a critical mass of evidence to inform decision-makers, at local, but also at national and global scales (see also Bogdanski *et al.*, 2010, p. 105).

As outlined in figure 2 above, the following subsections will explain the necessary steps to conduct a sustainability assessment of IFES at the local scale, tailored towards the needs of local contexts and actors in order to improve decision-making at local, but also at national and global scales.

3.1.1. Formulate the exact objectives of the sustainability assessment

The objectives of a planned sustainability assessment need to be carefully identified, clearly formulated, and tailored towards each specific case and its context. The main questions to be asked are "Why is such a sustainability assessment necessary?" and "What kind of results do I expect from the assessments?". The answers might vary widely, which in turn, impacts the design and the following steps of the assessment process.

For instance, if IFES managers want to know how their operations impact the livelihoods of the surrounding communities and their immediate environment in social, economic and environmental terms, this guidance will help them to improve those operations that require further attention, and replicate others that have proven to be very sustainable, and therefore successful. Furthermore, they might seek to communicate the sustainability performance of their operations to the wider public to demonstrate their corporate responsibility. For this to happen, they need evidence-based data, which can be obtained from applying such a sustainability assessment.

Alternatively, government decision-makers seeking to develop or improve policies may recognize that the sustainable management of natural resources can improve both food and the energy security, in a specific locality or region of the country, contributing to better livelihoods and rural development. However, they may also be aware of the risks that bad management of natural resources can cause. Hence, they wish to see evidence of IFES practices, operations or systems that increase opportunities and reduce risks, for a better understanding of their potentials and eventually, for shaping decision-making processes and policy development. By assessing the sustainability of different pilot projects implemented in different parts of the country, be it by companies, NGOs or the government itself, they will be able to obtain such information.

As these two examples show, the motivation and ultimate objectives of applying such assessments can vary widely. Precise communication between those that commission the assessment ("the decision-makers") and those that design and implement the assessment ("the scientists") is therefore essential. Within this communication process, scientists should help decision-makers formulate their questions clearly and identify adequate indicator values and measurements to generate the necessary data for improved evidence.

3.1.2. Define the system, the local context and its actors

As a first step, the **specific components** of the IFES project that is to be assessed need to be identified and characterized. This includes inputs and outputs and the interactions between the different components (see figures 3a and 3b below showing two sample IFES typologies).

Second, the **geographical and biophysical** context of the IFES needs to be recorded. This includes data on the localization of the farming system, the total surface area, and the climate, crop and animal production of the farm. Such a description of the geographical and biophysical context is likely to explain why the implementation of a specific IFES was possible in the first place.

Third, the **stakeholders** involved in the IFES should be identified and mapped out. At a later stage, their characteristics and interactions will be analysed in more detail (see 3.2.3, Question 2).

Annex A gives some examples of how such a characterization of an IFES could be carried out.

FIGURE 3.

Examples of IFES typologies

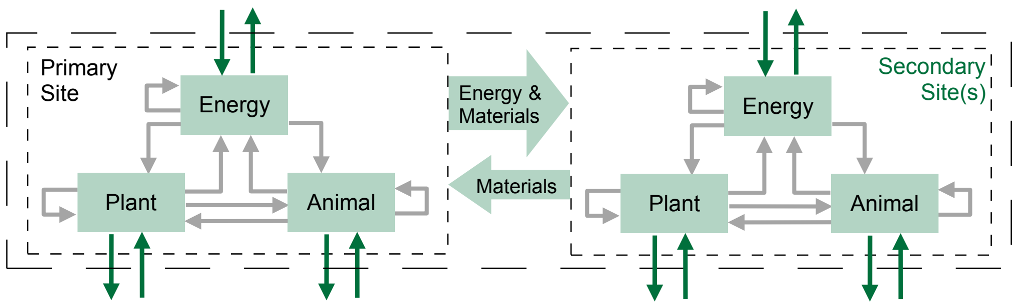


Figure 3a. General schematic of the potential flows among IFES plant, animal, and energy subsystems and primary and secondary sites. Dashed box indicates the IFES boundary. Dotted boxes delineate sites within IFES. If more than one site exists, then the primary site takes in materials from the secondary site and possibly returns energy and materials. Solid arrows represent material and energy flows, where black arrows are products sold off-site and gray arrows are on-site exchanges (Gerst *et al.*, no date).

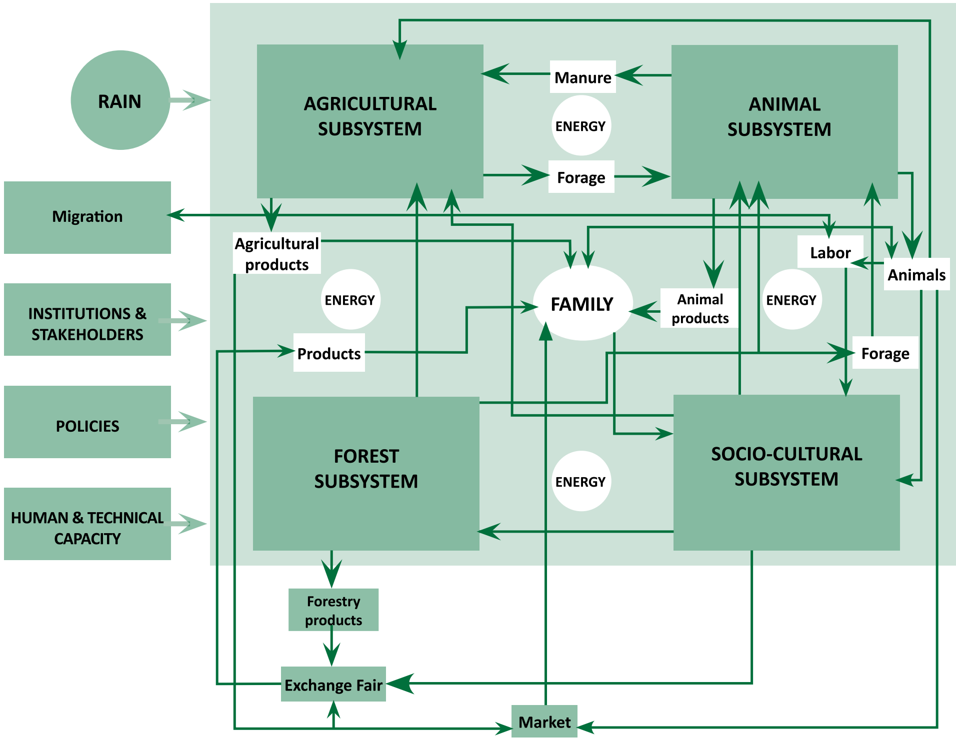


Figure 3b. A specific schematic of an agropastoral IFES from Bolivia (adopted from Astier *et al.*, 2012), composed of the IFES nucleus, i.e. the family, and the various subsystems, which interact with this nucleus. Dotted lines between the subsystems and the nucleus indicate material and energy flows. The solid box marks the boundaries of the IFES. Arrows beyond this box point to crucial components which stand in interaction with the system, i.e. the enabling environment.

3.1.3. Select relevant criteria and indicators

Criteria and indicators are the "tools" that help assess the selected IFES. This section will give an overview of relevant criteria (Figure 4) for assessing an IFES project. 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.

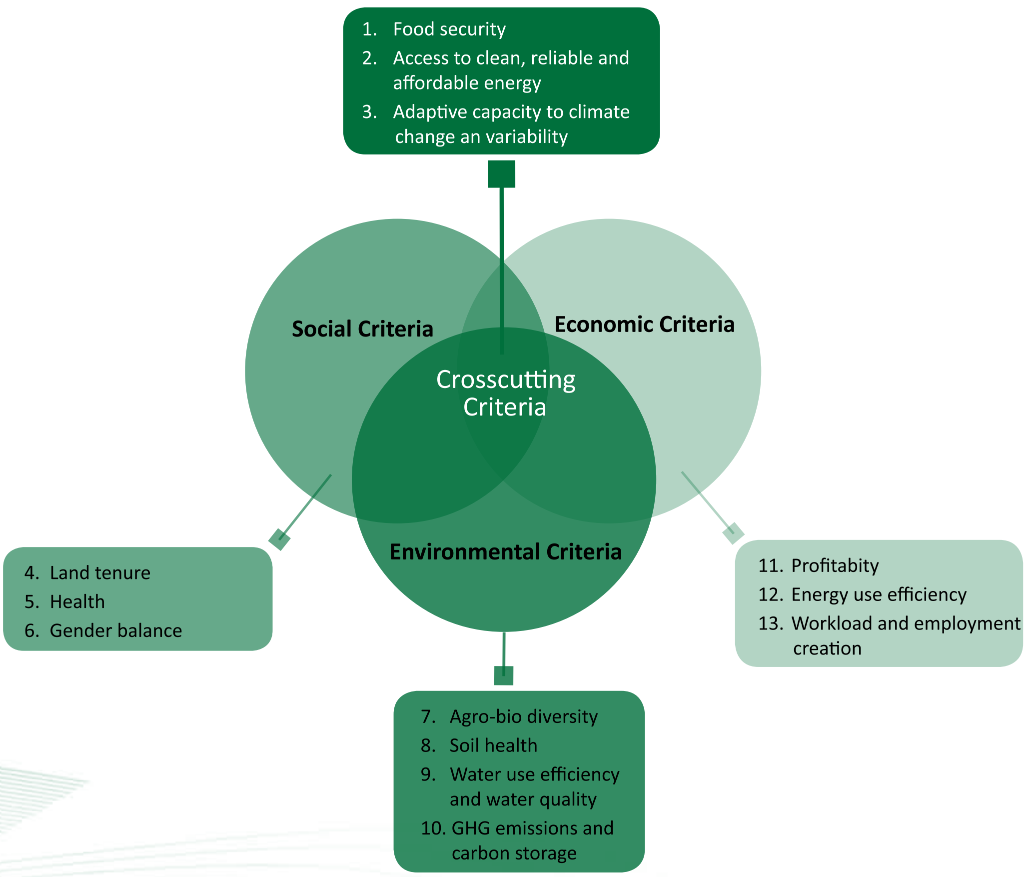
Since each farming system is unique, and is shaped by its context and the system as such (see 3.1.2.), not all potential criteria and indicators listed below are relevant to assess a specific situation. The selection of criteria and indicators can therefore only be understood as a list of suggestions, some of which might be applicable in a specific context and some of which might not be suitable at all. The final set of criteria and indicators can therefore only be selected once a specific case study has been chosen, and the objectives of the planned sustainability assessment have been identified (3.1.1.).

The criteria provided below have been carefully chosen according to the general requirements of IFES. However, they should only be understood as a potential starting-point helping to identify issues of relevance to a particular IFES. It needs to be understood that this selection is not exhaustive and might have to be complemented with other relevant criteria and indicators related to a specific IFES case.

The criteria and indicators presented in this document have been adapted from a large variety of different sources such as sustainability frameworks, guidelines and freestanding indexes related to sustainable agriculture and the sustainable production of bioenergy. These include the Compilation of Bioenergy Sustainability Initiatives and the Operator Level Tool of the FAO Bioenergy and Food Security Projects (BEFS), the Sustainability Indicators for Bioenergy of the Global Bioenergy Partnership (GBEP), the Indicator-based assessment framework of ecosystem change and human well-being of the United Nations University, the Total Energy Access index of Practical Action, and the Agro-Ecological Indicators for Dairy and Mixed Farming Systems Classification of the Cuban "Estación Experimental de Pastos y Forrajes Indio Hatuey", among others. The relevant sources are referenced in the subsequent description of each criterion.

The indicators and methodologies to assess the following criteria (listed in Annex B) will be revisited after the first testing of the analytical framework, as these tests will help assess their robustness and cost-effectiveness. Additional to being robust and cost-effective, it will also be very important to involve the main stakeholders, especially the farmers, during the sustainability assessment, and build on their experience.

FIGURE 4.
Sustainability criteria for assessing IFES



3.1.3.1.Criterion 1: Food security

As the name suggests, one expects that Integrated Food-Energy Systems safeguard food security while producing energy (for self-sufficiency or sale), at the same time. However, this might not always be the case, and this therefore needs to be analysed in more detail.

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:

I. Physical availability of food: "Food availability addresses the "supply side" of food security and is determined by the level of food production, stock levels and net trade" (EC - FAO Food Security Programme, 2008, p.1). In concrete terms, this pillar helps explain how IFES can – or cannot – contribute to an increase in the supply of food.

This pillar of food security directly links to the criteria on agrobiodiversity, soil health, water use efficiency and water quality, and greenhouse gas emissions and carbon storage.

II. Economic and physical access to food: "An adequate supply of food at the national or international level does not in itself guarantee household level food security. Concerns about insufficient food access have resulted in a greater policy focus on incomes, expenditure, markets and prices in achieving food security objectives" (EC - FAO Food Security Programme, 2008, p.1). In the context of IFES, this pillar describes whether the extra income generated through the sale of surplus food and bioenergy will contribute to food security. Beyond this economic dimension, this pillar also relates to the physical access to food. Land tenure security is therefore an important issue to consider.

This pillar of food security directly links to land tenure, energy use efficiency, profitability, and workload and employment generation.

III. Food utilization: "Utilization is commonly understood as the way the body makes the most of various nutrients in the food. Sufficient energy and nutrient intake by individuals is the result of good care and feeding practices, food preparation, diversity of the diet and intra-household distribution of food. Combined with good biological utilization of food consumed, this determines the nutritional status of individuals" (EC - FAO Food Security Programme, 2008, p.1). This pillar of food security is expected to be affected by IFES in two different ways:

i. The diversification of crop and animal species may lead to higher diversity of the diet.
ii. The provision of safe and nutritious food requires energy as one crucial input to prepare/cook the food and boil drinking water. A number of key staple food crops are only palatable and fully digestible after cooking. Furthermore, if the cooking time is reduced because of lack of fuel, protein intake is often lowered. In many areas, families can eat only one cooked meal a day instead of two, simply because they lack fuel. Hence, without access to energy, food security is significantly reduced.

This pillar of food security directly links to the criteria on access to energy health, and agrobiodiversity.

IV. Stability of the other three dimensions over time: Even if one's food intake is adequate today, a person is still considered to be food insecure if he/she has inadequate access to food on a periodic basis, risking a deterioration of his/her nutritional status. Adverse weather conditions, political instability, or economic factors such as unemployment or rising food prices may therefore have an impact on a person's food security status (EC - FAO Food Security Programme, 2008). As is apparent, farming systems have little means to respond to political instability. However, depending on the design of the system, they can be more or less resilient to adverse weather conditions. Diverse farming systems, and their inherent agrobiodiversity, is used by many rural communities directly as an insurance and coping mechanism to increase flexibility and spread or reduce risk in the face of increasing uncertainty, shocks, and surprises (Millennium Ecosystem Assessment, 2005).

This pillar therefore directly links to the criteria on adaptive capacity to climate change and variability and on agrobiodiversity.

3.1.3.2. Criterion 2: Energy access

Providing access to energy is widely acknowledged as the "Missing Development Goal". Access to electricity and other modern[6] energy sources is a basic requirement to achieve and sustain higher living standards. Lightning, heating and cooking, as well as education, modern health treatment and productive activities all depend on energy. Yet half of the world's population, almost three billion people still rely on unsustainable biomass-based energy sources (UNDP/WHO 2009), to meet their basic energy needs for cooking and heating, and 1.4 billion people lack access to electricity (IEA 2010). The lack of modern energy services impedes income-generating activities and hampers the provision of basic services such as health care and education.

Renewable energy (RE) could help to accelerate access to energy for those who are still using traditional biomass, and who do not have access to electricity. Access to electricity is particularly restricted in rural areas, where remote villages and settlements are not connected to the grid. People are using wood-based fuels such as firewood, and charcoal or agricultural residues and animal dung to fulfil the most basic cooking and heating needs, which is neither efficient, nor healthy. Many health, social and environmental issues are related to the use of such traditional bioenergy sources, which is particularly true for women and children. Most fuels are burned indoors and cause severe lung diseases. Two million people die every year due to indoor air pollution from cooking. Of those deaths, 44 percent are children, and among adult deaths, 60 percent are women (UNDP/WHO 2009) (*see also the criterion on health*). The time that needs to be invested by women or children to gather fuel is immense, and so is the household income that is spent on charcoal or kerosene (*see also the criterion on profitability and the criterion on workload and employment*). Extensive firewood collection can lead to forest degradation, and the use of agricultural residues or animal dung for energy purposes diverts a crucial source of soil

6 There is no internationally agreed definition of modern energy. In this document, we therefore build on the global Sustainable Energy for All Initiative and the International Energy Agency which define access to modern energy as "a household having reliable and affordable access to clean cooking facilities, a first connection to electricity and then an increasing level of electricity consumption over time to reach the regional average" [Sustainable Energy for All].

nutrients away from agricultural production (*see also the criterion soil health*).

Beyond cooking and heating, access to energy services is needed to facilitate economic activities and improved livelihoods. A large share of the population in developing countries live in households depending primarily on agriculture and the food-based economy for their livelihoods. Improved agricultural practices in agricultural production, agro-processing, post-harvest and storage facilities, and distribution and retail can contribute to poverty alleviation (Sims, 2011). For instance, energy generated on-farm from IFES may be used to dry surplus fruit and vegetables to reduce food losses in the post-harvest stages (*see also the criterion on energy use efficiency*).

The employment of RE could be part of the solution to address these issues. Lloyd and Visagle (2007) suggest that liquid or gaseous RE fuels, for instance ethanol gels, could replace solid biomass for cooking. In addition, an FAO working paper on small-scale bioenergy initiatives highlights several cases of how different sources of bioenergy can help to increase energy access for smallholders (FAO 2009), for example, by using animal waste for biogas production. The Intergovernmental Panel on Climate Change states that "the low levels of rural electrification offer significant opportunities for RE-based mini-grid systems" (IPCC 2011a) and, that in many instances RE "can provide the lowest cost option for energy access" (IPCC, 2011b). However, IPCC (2011a) also states that "apart from the specific relevance of RE for electrification in remote areas, it is not well understood how contributions from RE sources can make a specific difference with regard to providing energy access in a more sustainable manner than other energy sources."

Indeed, while many research projects and single examples prove the feasibility of small RE systems to provide energy access, large-scale implementation remains limited to few cases (e.g. Bogdanski *et al.*, 2010), and many constraints still need to be addressed before small RE systems will truly change the situation of the poor. One of these challenges is related to the technologies as such (i.e. quality and affordability), however many other constraints go far beyond this. They relate to the availability of knowledge (how to use and maintain a certain technology) and financing, particularly upfront investment costs. Constraints can also be found on the institutional or policy level where the lack of technical support, for instance, might impede the implementation of certain technologies, or where policies counteract the employment of RE, e.g. through subsidies for fossil fuels which make RE a less attractive option (e.g. Sovacool 2008) or where policies for sustainable development do not consider the importance of energy access.

This will be further discussed in the replicability section of this analytical framework.

3.1.3.3. Criterion 3: Adaptive capacity to climate change and variability

Smallholder 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. The adaptive capacity inherent in a human system represents the set of resources available for adaptation (information, technology, economic resources, institutions and so on), as well as the ability or capacity of that system to use the resources effectively in pursuit of adaptation" (Kuriakose *et al.*, 2009, p. 9) – a crucial prerequisite to become more resilient. Considering the important role of energy in food production and consumption, energy is one of such crucial prerequisites.

While there are currently no *direct* ways to measure adaptive capacity, studies often refer to the asset base as one key indicator for adaptive capacity to describe the human dimension of adaptive capacity; that is, the availability of key assets that allow the system to respond to evolving circumstances (Jones *et al.*, 2010). Energy forms a vital part of such key assets, as the lack of availability and access to energy can considerably limit the ability of the farmer/farming system to cope with the effects of climate change and wider development. *This criterion is therefore closely related to criteria on food security and energy access,* when food and energy are produced for self-sufficiency *and/or to criterion 12 on profitability,* when food and energy feedstock are sold as cash crops.

To capture the natural dimension of how IFES contribute to climate change, one has to focus on the agronomic characteristics of IFES. Integrated and diversified farming systems have shown to exhibit resilience and robustness to cope with such disturbance and change (i.e. climate change or pest outbreaks) minimizing the risk of crop loss: by planting several species and varieties of crops, yields are stabilized over the long term and returns are maximized, even with low levels of technology and limited resources (Altieri *et al.*, 2012).

This criterion is therefore also closely related to the criterion on agrobiodiversity.

3.1.3.4. Criterion 4: Land tenure security

Land tenure security is an essential component of making IFES work in the long run, and hence in a sustainable manner. The farmer or entrepreneur behind an IFES is not likely to make any large or long-term investment decisions without the security over his land and resources. A crucial factor to ensure this, is that the State or the community be able to guarantee, in practice, the rights accorded to all land users by law. Only then can investors – large and small, entrepreneurs and communities – make financial and longer-term plans with the confidence that the parameters shaping their long-term vision are relatively stable. Smallholders and entrepreneurs hence require land tenure security as a guarantee to adequate and long-term access to, and use of, land and other natural resources such as trees and water.

Therefore, a country's land tenure policies and legislation should clarify property rights, in the recognition of customary and traditional rights of indigenous and other local people, establish public land allocation procedures following participatory and other due process, including free, prior and informed consent and due compensation, and provide effective access to fair adjudication, including the court systems or other dispute resolution processes (e.g. FAO, 2009b; FAO, 2012). Furthermore, land rental and sales contracts, including contracts for temporary use agreements, should be accessible to all. In the absence of such a system, competition for land for any reason (including production of food and bioenergy) is more likely to result in adverse social consequences.

There are ways to address this challenge, and these have been developed and discussed in recent major international initiatives such as the Voluntary Guidelines on the Responsible Governance of Tenure of Land, Fisheries and Forests in the Context of National Food Security developed by FAO and partners (FAO, 2012). Their implementation is highly relevant for the safe and lasting implementation of IFES.

This criterion is closely linked to the criterion on food security.

3.1.3.5. Criterion 5: Health

Cooking with biomass such as woodfuels or charcoal on traditional fireplaces often comes at the expense of health. Four million premature deaths occur every year due to smoke exposure from traditional cookstoves or open fires (Global Alliance, 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 indoor smoke are three times more likely to suffer from chronic obstructive pulmonary disease, such as chronic bronchitis or emphysema, than women who cook with electricity, gas or other cleaner fuels. And coal use doubles 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.

However, also other types of biomass might come with health risks. The handling of manure for biogas production, for instance, might be very risky when certain hygienic standards are not followed. The same applies for the use of biogas slurry, the residual of biogas production, which in some cases is incautiously used carrying health risks (Groot & Bogdanski, 2013).

The criterion on Health is closely related to the criterion on Food security and the criterion on Energy Access.

3.1.3.6. Criterion 6: Gender balance

Both women and men play a vital role in agriculture, and hence in IFES. Yet often, relative to men, women have less access to land and services such as finance and extension. For instance, it is often – but not always – men who represent the family in agricultural cooperatives, and in general, women tend to lack a political voice (World Bank, 2009). For FAO, a gender balance, or gender equality is equal participation of women and men in decision-making, equal ability to exercise their human rights, equal access to and control of resources and the benefits of development, and equal opportunities in employment and in all other aspects of their livelihoods (FAO, 2009). Such gender imbalances in families and communities, especially those that have lost or are losing their traditional coherence and roles, often result in less food being grown, less income being earned, and higher levels of poverty and food insecurity (World Bank, 2009).

Beyond these inequalities in access to assets, services and political involvement, men and women often have a different knowledge base. Women are generally knowledgeable about food and health aspects and, last but not least, on how to source energy for cooking and heating. Men, on the other hand, are most often responsible for securing household income and dealing with business-related aspects of the farm.

This means that, depending on the type of IFES, the participation and roles of women or men in the implementation and operation of IFES need to be carefully adapted to local social and cultural conditions. IFES that contribute to subsistence agriculture and income are most likely better driven by women, whereas larger scale commercial IFES might more likely fall within the responsibility of men. However, such generalizations do not always hold true, particularly when local cultures are changing under external influences and thus each case needs to be carefully assessed.

3.1.3.7. Criterion 7: Agrobiodiversity

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" (Millenium 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.

3.1.3.8. Criterion 8: Soil Health

Healthy soils are fundamental for food and bioenergy production. "Soil health can be 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, p. 10). Furthermore, healthy soils do not pollute the environment but contribute to mitigating climate change by maintaining or increasing its carbon content (FAO, 2010).

Today, many soil management practices are unsustainable. Two of the most common problems are related to excessive or 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 corn 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.

This criterion is directly linked to the criterion on food security.

3.1.3.9. Criterion 9: Water use efficiency and quality

Depending on the system, the production of food and energy feedstock may require considerable amounts of water. In water scarce areas this can present a significant challenge for IFES. Furthermore, where IFES compete for water with other types of agricultural production, this competition could lead to negative impacts on food security. For instance, water might be used to produce additional energy feedstock rather than to ensure food production as yields might decrease when scarce water is allocated to different uses. However, where enough water is available, this might not be an issue at all. It is therefore important to assess how efficiently IFES use water in a specific context, and to identify and address potential trade-offs in regard to water use and risks in view of climate uncertainties.

This criterion is directly linked to the criterion on energy use efficiency.

In terms of water quality, 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.

This criterion is directly linked to the criterion on food security.

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.

3.1.3.10. Criterion 10: 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 biosolid management through the process of anaerobic digestion and through more efficient use of manure and biosolids as nutrient sources.

This criterion is closely linked to the criteria of Food security, Soil Health, and Agrobiodiversity.

3.1.3.11. Criterion 11: 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 its practices to be adopted by small-scale farmers and other stakeholders. Financial and resource availability as well as use efficiencies should be balanced to consider the real value, both environmentally and economically, from any IFES practice.

IFES can increase the farmers' net income from the sale, barter and/or own consumption of the products from IFES. The increase of income for rural dwellers is a central motivation for supporting bioenergy production in many developing countries. It can increase the standard of living, particularly through the improvement of consumption levels (Madlener and Myles, 2000). The International Labour Organization (ILO, no date, p. 2) defines household income as "all receipts whether monetary or in kind (goods and services) that are received by the household or by individual members of the household at annual or more frequent intervals, but excludes windfall gains and other such irregular and typically one time receipts."

Household income may be defined to cover: (i) income from employment (both paid and self-employment); (ii) property income; (iii) income from the production of household services for own consumption; and (iv) current transfers received."

Relevant for this assessment are: (i) income from employment (both paid and self-employment) and (ii) income from the production of household services for own consumption. Following GBEP (2011), we measure the change of income through the implementation of IFES:

1. either through wages paid in the case of a commercial IFES operation which employs rural labour;
2. or through net income from the sale, barter and/or own consumption of the products from IFES.

By consuming your own produce, be it food or energy, one can save on household expenditures. For instance, with IFES that produce biogas, farmers can potentially save money because they can replace some of their fossil fuels with gas for their domestic energy needs. They can also save on chemical fertilizer if they use the slurry from biogas production (Groot & Bogdanski, 2013). However, the biogas technology requires up-front investment costs. It therefore needs to be seen whether the gain in resources savings can make the investment profitable.

This criterion is closely linked to the criteria on food security, employment creation and workload.

3.1.3.12. Criterion 12: Energy efficiency

Energy efficiency can be used to describe the productivity of an IFES. It describes the output from a production process per unit of input. More particularly, the efficient use of energy, or energy efficiency, are terms that describe measures that help to reduce the amount of energy required to provide products and services. Using energy efficiently has two benefits: it can lead to significant cost savings and to emission reductions.

Energy is widely used during crop, livestock and fish production (i) in the form of direct energy, i.e. for irrigation, or indirect energy, that is in fertilizer production. For instance, in irrigation, one needs to ask oneself: how much energy is being used for pumping, lifting and recycling of water? There may be trade-offs between water and energy. High energy costs and uses may be incurred for more water-efficient irrigation, i.e. when shifting from surface to pressurized systems. It is also important to assess whether it is it cost-effective to produce certain crops in certain areas compared to costs for water and energy. Energy also forms a crucial part of processing and packaging (ii), distribution and transportation (iii) and consumption (iv).

Depending on the type of product and its origin, these steps of the food chain show different energy intensities, i.e. the amount of energy used per unit of commodity. The more energy intense, the less energy efficient a given process is.

Schneider and Smith (2009) found that global agricultural energy intensities increased until the 1980s and slightly decreased thereafter. However, they note that this is the combined global trend, which does not account for the large differences that exist between countries, particularly in agricultural management, i.e. the production stage of the food chain.

While developed countries show decreasing energy requirements per calorie output, energy intensities in developing and newly-industrializing countries have been steadily rising (Schneider and Smith 2009). The study attributes this to an increase of energy intensity in fertilizer consumption and machinery use, especially in China and India. Meanwhile, developed countries have adopted precision agriculture and low or zero tillage techniques (FAO 2011), which considerably reduce energy inputs, e.g. through improved crop varieties, more efficient machineries, irrigation systems and improved input management. These measures require significant capital investment, however, and are therefore often out of reach for many farmers in developing or newly industrializing nations.

Nonetheless, there are other ways that allow one to achieve higher energy efficiency without costly high-tech options. These options, often referred to as integrated farming systems, require higher manual labour, full integration of the use of resources (e.g. crops and livestock or crop rotations), and replacement of fossil fuel dependent external inputs with agricultural residues or green manures. There are several examples of such farming systems all over the world (Pretty *et al.,* 2006), and IFES seem to be good candidates to achieve resource use efficiency, and particularly energy use efficiency in agriculture (Bogdanski *et al.*, 2010). For example, Funes-Monzote (2009), in an experiment which compared IFES with conventional/specialized systems, showed that IFES realized much higher energy use efficiencies and lower energy costs of protein production than specialized dairy systems. The researcher found that this was strongly associated with the significantly higher energy outputs and also lower total energy input in the mixed farming systems related to a more intensive use of internal resources.

This criterion is directly linked to the criteria on food security, energy access, water use efficiency and profitability.

3.1.3.13. Criterion 13: Workload and employment creation

IFES are often labour intensive. Where multiple crops are grown on one piece of land, or where there is a diverse array of interconnected crops and livestock, there tends to be less scope for specialization and mechanization, and therefore IFES often require significant manual input. IFES also require considerable capacity development, and therefore, next to manual input, also a good understanding of the nature and the management of such systems.

The aforementioned could be a good opportunity to create employment in deprived rural areas. Employment creation is an important building block for sustainability. It is crucial for fighting poverty, income inequalities and slow job growth, all of which are critical constraints on economic and social progress. Agriculture can be a strong vehicle to create employment.

Any IFES operation requires labour by employees or family members. As a proxy for labour, we chose indicators for employment creation. They provide information of how many jobs have been created through an IFES operation. This includes employment on farms that hire seasonal labour, and large-scale commercial IFES developments that depend on a large workforce or IFES based on outgrower schemes. Nevertheless, also family members who are not paid with a salary but rather in kind should be considered.

Employment creation does not ensure sustainability as such, but can have a significant impact on sustainable development, when the four fundamental labour rights are respected (ILO, no date):

- Freedom of association and the effective recognition of the right to collective bargaining
- Elimination of all forms of forced or compulsory labour
- Effective abolition of child labour
- Elimination of discrimination in respect of employment and occupation.

However, despite these potentials for employment, in reality, such capacities and labour are not always readily available. More and more healthy, young people who would traditionally farm are seeking employment in cities where opportunities are seemingly vast instead and manual labour in the countryside is seen as less appealing (Jamieson, 2008).

The high labour requirements might therefore be a big barrier to IFES adoption. IFES may be profitable in the long term but not in the short term. Hence if the workload is too heavy people might not invest.

One needs to consider, however, that one of the major cooking and heating fuels used in developing countries to date is fuelwood. Collecting fuelwood is often a very time consuming activity that might make IFES, by comparison, a more attractive option. To give an idea of how much time is spent on average on fuelwood collection, one can consult the World Health Organization (WHO) review of fuel-collection time and biomass energy use among 14 countries in Sub-Saharan Africa (WHO, 2006). The review found a wide range of estimates for the number of hours spent collecting biomass energy, from a low of 0.33 hours up to 4 hours per day. In some cases, these figures were even higher. For instance in Nigeria, where the collection of wood can take up to 6 hours for one person to gather enough wood for the day's meals (Kersten, 1998).

This criterion is closely linked to the criteria on food security, and profitability.

3.1.4. Define reference values to measure sustainability

Determining sustainability is a matter of perspective. "Sustainable compared to what" is therefore a legitimate 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; Acosta-Alba and van der Werf, 2011). Policy-based values refer to targets or limits set by policy, while science-based values relate to scientifically founded targets or limits.

Science-based values can be further subdivided into *target values* and *environmental limits (*Acosta-Alba and van der Werf, 2011). Target values identify desirable conditions, and environmental limits indicate minimum or maximum levels or ranges of acceptable values that should not be exceeded.

If such *normative* reference values do not exist, it might be necessary to do an experimental comparison with a similar system and derive *relative* reference values from this system. In the case of IFES, this could be a comparison between a monoculture bioenergy farming system with an IFES. For instance, one might compare an intercropped corn-leguminous farming system with a neighboring monoculture corn plantation to to obtain a general (understanding. However, in the ideal case, one would set up an experimental design to assure the same conditions for both comparators.

The kind of reference values that will ultimately be selected, will depend on the case studies chosen, data availability and the financial resources available for the project. A typology of reference values, and their pros and cons are discussed in table 1.

3.1.5. Define an appropriate sampling design and collect data

The sampling design is an essential part of data collection for evidence-based decision-making. A well-developed sampling design plays an important role in ensuring that data are sufficient to draw the conclusions needed.

This step also involves the measurement of the indicators, i.e. the collection of data, as specified further in the Annex within the description of each criterion (see Annex X). Measurements include the collection of biophysical, agronomic and socio-economic data. For the biophysical and agronomic data collection, we suggest a set of different tools for field sampling and some social research methods. For most of the social and economic indicators, a mixed methods approach of quantitative and qualitative methods will need to be conducted.

There is a wide variety of specific sampling designs that can be used to improve the quality of environmental and socio-economic data collection. However, for practical reasons, one needs to compromise between data collection costs and the need to be as concise as possible and necessary. Such costs can increase, either due to the number of samples required to achieve the desired reliability or because sampling and analytical equipment is expensive. Therefore, an important step of the indicator selection process is to reject those indicators that do not match the available budget, and choose more cost effective options instead. Yet awareness of the resulting limitations in accuracy and reliability needs to be mentioned.

The results of the measurements will be compared to the reference values identified in the previous step 3.1.4.

TABLE 1.

TYPOLOGY OF REFERENCE VALUES

TYPE OF REFERENCE VALUE	SUB-TYPE	DESCRIPTION	ADVANTAGES	DISADVANTAGES
Historic		Historic values refer to data collected in the past	Exact	Hardly ever exist; in rare cases, such data exist for long-term scientific studies
Normative policy-based		Policy-based values refer to targets or limits set by policy		Might not be scientifically sound
Normative science-based		Science-based values relate to technically founded targets or limits	Technically well founded and reliable values	Might be costly to collect
	Target values	Target values identify desirable conditions	If based on good science, a very reliable reference value type	Costly. Might have to depend on potentially unreliable expert judgement
	Environ-mental limits	Environmental limits indicate minimum or maximum levels or ranges of acceptable values that should not be exceeded	If based on good science, a very reliable reference value type	Costly. Might have to rely on untrustworthy expert judgement
Relative		Relative values are derived from experimental comparisons	A very reliable reference value type	Costly, often time intensive and not possible to set up an experimental design

Source: own elaboration with information of Wattenbach and Friedrich, 1997; Van der Werf and Petit, 2002; Acosta-Alba and van der Werf, 2011.

3.1.6. Report the results for good decision-making

For the sake of good communication and good mutual understanding, it is essential that the technicians engaged in this process should communicate their results to the decision-makers in a precise, but simple way. This is essential to allow for a good decision-making process. There is a variety of different ways to express the results of such a sustainability assessment (Acosta-Alba and van der Werf, 2011) (for an overview, see table 2):

- Many studies give the *ratio* of the indicator value over the reference value.
- Others give the *difference* between the indicator and the reference value, the "sustainability gap".
- Yet other studies express the results more graphically, for instance as *colour "flags"*, sometimes called a *Scorecard* or *Traffic Light* system (see for instance the IDB Bioenergy Scorecard (IDB, n.d) or the Sustainability Assessment of Development Scenarios (Nijkamp and Vreeker, 2000). Green typically indicates good performance; yellow indicates medium performance; red indicates bad or risky performance.
- Another example is the *radar graph*, used within the *Framework for Assessing the Sustainability of Natural Resource Management Systems* (abbreviated as *MESMIS*, with the capital letters of the original Spanish title), which was developed by Masera *et al.* (1999). It builds on the often used radar chart system, a graphical method of displaying three or more quantitative variables in the form of a two-dimensional chart starting from the same point.

The scorecard system combined with a rapid assessment methodology is often favoured by project developers, banks or international institutions such as the UN who wish to evaluate the performance of a project within a relatively short timeframe and a limited budget (FAO, 2013; IDB, n.d.). However wherever this initial screening shows red, additional, more detailed project evaluation is often recommended.

TABLE 2.

EXAMPLES FOR REPORTING OF THE RESULTS

REPORTING TYPE		DESCRIPTION
Numeric	Ratio	*Ratio* displays the indicator value over the reference value.
	Difference	*Difference* refers to the gap between the indicator and the reference value, the so-called "sustainability gap".
Graphic	Colour flag	Colour flags are sometimes also called *Scorecard* or *Traffic Light* system, is a graphical method of displaying the results in three categories: green typically indicates good performance; yellow indicates medium performance; red indicates unacceptable or risky performance.
	Radar graph	The radar graph is also known as *radar chart or web chart*, a graphical method of displaying three or more quantitative variables in the form of a two-dimensional chart starting from the same point.

3.2. GUIDANCE ON ASSESSING THE REPLICABILITY OF IFES

This section will give guidance on how to assess the replicability of a specific IFES case. According to the dictionary, 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 guidance given below builds on the basics of social scientific research and literature relevant to the replicability of IFES. The central method used is a SWOT analysis which stands for **S**trengths, **W**eaknesses, **O**pportunities and **T**hreats. It is one of the most known methods to identify and categorize significant internal and external factors that a project and its environment is exposed to.

The assessment framework benefits from related work such as from Holocombe (2012) who developed a general description of how to assess the potential for replication of pilot projects, which we have adjusted to the particular needs of this analytical framework. Other guiding frameworks and publications that we used have been developed by Dubois (1998), and applied by Practical Action (2009) who presented a methodology to draw lessons from small-scale bioenergy initiatives, by the Global Village Energy Partnership (2010) who focused on energy business financing, and by Wilson *et al* (2012) who showed how to bridge the gap between poor rural communities and modern energy services. We further build on Bogdanski *et al.* (2010) who produced a review of IFES good practices. These and additional resources are referred to in each respective section.

3.2.1. Identify the exact objectives of the replicability assessment

The ultimate objectives and the motivation behind doing a replicability assessment have to be carefully identified, clearly formulated, and tailored towards each specific case and its context. The main questions to be asked are “Why is such a replicability assessment necessary?” and “What kind of results do I expect from the assessment?”.

Similar to the assessment of sustainability, the answers are likely to vary widely between different IFES projects, which in turn, impacts the design and the following steps of the analytical process. Precise communication between those that commission the assessment ("the decision-makers") and those that design and implement the assessment ("the scientists") is therefore essential. Within this communication process, scientists should help decision-makers formulate their questions clearly and identify adequate lead questions and relevant features to generate the necessary data and improve the evidence-base of IFES.

3.2.2. Define the system, its context and involved actors

This second step of the replicability assessment is the same as suggested for the sustainability, and therefore does not have to be repeated if already undertaken. To briefly summarize: first, the **single components** of the IFES project that is to be assessed need to be identified and characterized. This includes inputs and outputs and the interactions between the different components (see figure 3 on typology in section 3.1.2).

Second, the geographical and biophysical **context** of the IFES needs to be recorded. This includes data on the localization of the farming system, the total surface area, and the climate, crop and animal production of the farm.

Third, the **stakeholders** involved in the IFES should be identified and listed through a stakeholder mapping exercise. This will help to indentify all relevant stakeholders – a crucial prerequisite in order to rightly address the following lead questions and features. At a later stage, their characteristics and interactions will be looked at in more detail (see section 3.2.3, Question 2).

Annex A shows some examples of how to carry out such a characterization of an IFES.

3.2.3. Identify leading questions and features

Guidelines that help to assess the replicability of IFES could be structured around several **leading questions** that highlight the different areas of interest to a replicability assessment. These should be further broken down into several **features** further detailing each question. Doing so, one obtains a systematic structure under which to describe the **strengths and weaknesses** and **opportunities and threats** of each IFES innovation and its enabling environment:

- Replicability strengths will point to IFES internal issues that are favourable for the replication of an IFES project. One should therefore ensure that these aspects are kept and built in the replication process.
- Replicability weaknesses will point to IFES internal issues that need to be improved before the replication of an IFES can take place. One should therefore ensure that these aspects are kept out and not built in the replication process.
- Replicability opportunities will point to external possibilities that exist to support the implementation and replication of the IFES project. One should therefore ensure that these aspects are present or can be created where the project is to be replicated.
- Replicability threats will point to external obstacles that may hinder the

implementation and replication of the IFES project. One should therefore ensure that these aspects are not present or can be removed where the project is to be replicated.

Based on Bogdanski *et al.* (2010) and two expert consultations on IFES held at FAO in Rome, Italy, in 2010 and 2013, we developed a set of relevant questions shown in table 3. A detailed description of each question and their features are listed below. Related methodologies are listed in Annex C.

TABLE 3.

LEAD QUESTIONS TO ASSESS THE REPLICABILITY OF IFES

1. What are the enabling or constraining project features that simplify or complicate the replication of IFES?
2. What is the role of stakeholders and institutions in the replication of IFES?
3. How does the policy environment enable or disable the replication of IFES?
4. How does human and technical capacity shape the replication of IFES?

Question 1: What are the enabling or constraining project features that simplify or complicate the replication of an IFES?

Starting with a question about the project itself, it is assumed that simplicity makes the upscaling of a project easier and simple features are therefore considered strengths in terms of replicability. On the other hand, complex features are considered weaknesses. The same logic applies for opportunities and threats related to IFES project features. This assumption has been proven to hold true for many IFES projects that were screened for FAO's recent overview publication *Making Integrated Food-Energy Systems Work for People and Climate* (Bogdanski *et al.,* 2010). It showed that the simpler the design of projects, the higher the rate of their uptake, i.e. the adoption rate and acceptability by local beneficiaries. For instance, while relatively simple integrated crop-livestock systems with a biogas digester showed a relatively high rate of uptake in many Asian countries, the more complex yet very efficient Tosoly farm in Colombia, which counted a large number of different plant and animal species as well as different energy technologies has not been replicated. The major factors identified that complicated the upscaling of more complex systems were related to the knowledge intensity inherent in such systems, the financial hurdles and the increased workload.

Table 4 lists a range of issues that help to determine whether the characteristics of a certain project will simplify or complicate its replication. The table adapting suggestions by Holocombe (2012), is followed by a detailed explanation of each issue.

'Clarity and Credibility' refers to the implemented model and the implementing entity. Is there scientific evidence that this project type will succeed? Is the person or entity implementing the IFES respected and trusted. Does he/she/it have a record of success in the energy and food sectors (see also question 2)?

'Legitimacy' refers to the ownership of the project. Who owns it? A farmer, a foreign investor, an international agency or a local NGO? Does the foreign investor cooperate with national partners? Has the project been initiated by the farmer himself or herself? Or does the project idea originate from the local community, the government, any other stakeholder? Or have outsiders imposed the project idea, without prior consultation with the target group, e.g. the farmers or entrepreneurs?

TABLE 4.

STRENGTHS AND WEAKNESSES OF IFES PROJECT FEATURES

	STRENGTHS	WEAKNESSES	OPPORTUNITIES	THREATS
Clarity and Credibility				
Legitimacy				
Ease in assessing results				
Business Model, incl. funding				
Alignment and Linkage				
Complexity, Coordination and Behaviour Changes				
Acceptability in local knowledge systems and culture				

'Ease in assessing IFES results' makes reference to how easy it is to assess project results. It relates primarily to the time required for tangible results to be measurable. Some interventions might take years until they show their full impact, for instance, when trees are planted for agroforestry systems or soil fertility is gradually enhanced through green manuring over a certain period of time. The easier positive impacts are perceived, the more likely the replication of a project will be, triggering the uptake from neighbour to neighbour, for example.

If the project is commercially motivated, the **'Business model'** is key to determine whether a project will take off and is replicable. Is there a business model in place, and if so, does it contain all the necessary information? This most importantly includes the issue of **'Funding'**: does the project itself generate resources? Or is the project only viable with donor or government support?

'Alignment and Linkage' refers to an alignment with national and local policies as well as the priorities of the main stakeholders (farmers, poor communities etc). This feature is important to mention here, yet it is also closely related to and covered in more detail in question 3 on *How does the policy environment enable or disable the scaling up of projects.*

'Complexity, Coordination and Behaviour Changes' makes reference to the technological and organizational complexity of the project. Does the implementation and running of the project involve many different actors, and decision-makers (see also question 2)? Are the technologies used easy to maintain, or does it require a regular check-up and maintenance by foreign specialists (see also question 4)? Is the new project a completely new activity for the main stakeholders or does it build on old, and well-known practices (see also question 4)?

'Acceptability in local knowledge systems and culture' refers to the cultural acceptance of an IFES project. Can it be integrated into the local culture? Does it build on local knowledge of the community?

Question 2: What is the role of stakeholders and institutions in the replication of IFES?
The second question to ask is about stakeholder's characteristics, the status of stakeholder interaction, and the involvement of institutions, as these can significantly influence the scaling up potential of projects.

While it is usually the farmer or entrepreneur him-or herself – hence referred to as the 'main actor' – who is central to the success or failure of an IFES project, there are often many other stakeholders involved who may strongly influence the process. Is there a champion, an influential stakeholder, an organization, who advocates for the scaling up of this particular project? As experience with IFES projects has shown, these drivers are instrumental for the replication of a project. Be it the Dutch SNV advocating for biogas projects, or the Kenya-based World Agroforestry Centre implementing agroforestry projects – these stakeholders clearly play a strong role in promoting IFES.

Beyond the mere analysis of stakeholder and institutional roles, it is crucial to also assess their interactions. Bioenergy, in general, and IFES, in particular, belong to a highly interdisciplinary subject area, and are, by their very nature, a meeting ground for various stakeholders with different types of expertise and interests. It is therefore not surprising that this calls for multidisciplinary, inter-stakeholder and inter-institutional participation. This experience has been gained within FAO's Bioenergy and Food Security (BEFS) country projects, for instance, where FAO has supported government authorities to establish inter-ministerial working groups (from national or regional governments and other stakeholders), with the aim of stimulating dialogue among members and to discuss the concerns, needs and challenges they foresee in terms of bioenergy.

Table 5 below gives guidance of how to structure those factors that can facilitate or weaken the replication of IFES. The table adapted from Dubois (1998) and Holocombe (2012) is followed by a detailed explanation of each feature.

TABLE 5.
STAKEHOLDER FEATURES IN RELATION TO REPLICABILITY

FACTOR	STRENGTHS	WEAKNESSES	OPPORTUNITIES	THREATS
Main actor (Farmer/ Entrepreneur)				
Implementing organization				
Supporting organization				
Champions				
Quality of stakeholder interaction				

The **'main actor'** of the intervention describes the people that drive the project or that are directly addressed by the intervention. Rural dwellers, be it farmers, local entrepreneurs or farmer cooperatives, usually make choices in order to improve their well-being, and therefore tend to pursue activities that improve their income, mitigate their financial and physical risks, reduce labour requirements, and if possible, choose work that they enjoy doing. However, at the same time, they are faced with a range of constraints that might not allow them to follow their first choice of actions. This might prevent them from implementing promising IFES as there could be biophysical and geographical constraints, financial hurdles, inadequate institutional support such as no access to training and capacity building, or no access to necessary technologies, and hindering policies and regulations. It is therefore important to ask whether they are convinced of the benefits that the project will bring along, whether they feel ownership of the proposed activities and whether they are driving the process proactively.

When we deal with an IFES that has been proposed by a donor or another organization different from the 'main actor, we refer to the '**Implementing organization'**. In this case, it is important to ask whether the organization is professional and credible with demonstrated capacity. Whether the organization that implemented the (pilot) project in the first place would be able to facilitate the replications as well. Whether it has the mandate to do so/ or if not, whether it has good links with key actors like government or community officials.

The **'supporting organization'** gives financial support (e.g. a bank), undertakes capacity building (e.g. an NGO) or provides technical advice (e.g. an extension service or local university). For instance, up-front financing costs may be high and need initial support. Knowledge intensive IFES will most likely require capacity building and technical advice – factors that are crucial for upscaling IFES (they will be dealt with separately in question 4).

'Champions' can help to advocate for the upscaling of a promising project. An influential NGO, a strong lobby group, or even an influential individual on the local or global level – such as Hillary Clinton and Julia Roberts who are spokespersons for the Global Alliance for Clean Cookstoves, for instance – can take a lead role here.

'Quality of stakeholder interaction' refers to how the different stakeholder groups interact and stand to each other. It relates to clarity and agreement of stakeholder roles in a way that also gives an indication of power differences between IFES stakeholders, as this feature is often crucial in ensuring continuity of replicability of a project. This can be achieved through the use of the '4Rs' approach; which considers on the one hand stakeholders' balance of rights, responsibilities and returns, and, on the other hand the type of relationships they have. The '4Rs'approach is briefly described in Annex 2.

Question 3: How does the policy and legal environment enable or disable the replication of projects?

What does the enabling (or disabling) environment look like? What are the policies and legal frameworks and their related policy instruments that incentivize or disincentivize the scaling up of an IFES project? Policies and legal frameworks refer to policy decisions or legislations that act in favour of or create barriers for the project. Such policies and legal frameworks require policy instruments to support their implementation.

IFES, for example agroforestry, often faces significant challenges such as unfavourable policy incentives, inadequate knowledge dissemination, legal constraints and poor coordination among the multiple sectors to which it contributes, nor is it sufficiently addressed in national policy-making, land-use planning and rural development programmes (FAO, 2013b). One of these challenges, for instance, is the national support of food, feed or biomass production in monocultures, and the often subsidized mechanized farming, which discourages the integration of trees into farmland. Table 3 helps to elucidate these and other issues. The table is followed by a detailed explanation of potential policy instruments and areas where they are applied.

Policies relevant to IFES may originate from a variety of sectors reflecting the diversified and integrated nature of IFES. Sectors that play a significant role in the upscaling of IFES, or those, that to the contrary hinder their uptake, are the agricultural and the renewable energy (RE) sector, but also other production sectors such as forestry and fisheries, and the environmental sector, including climate change and waste management policies.

Policy instruments can be categorized as Mitchell *et al* (2012, p. 11) suggest in:

- Fiscal incentives: actors are allowed a reduction of their contribution to the public treasury via income or other taxes or are provided payments from the public treasury in the form of rebates or grants.
- Public finance: public support for which a financial return is expected (loans, equity) or financial liability is incurred (guarantee).
- Regulation: rule to guide or control conduct of those to whom it applies.

The policy instruments can be applied to a variety of areas that support the uptake of IFES. They include but are not limited to the following polices (Mitchell *et al.,* 2012; Hardaker, 1997) (see also table 6):

Research and development (R&D): public support can enhance the performance of nascent agricultural and renewable energy practices and technologies until full adoption, or improve existing ones that are already widely deployed. R&D comprises fiscal incentives such as academic R&D funding, grants incubation support or private-public partnerships, and public finance such as venture capital or soft loans. Findings have shown that R&D investments are most cost effective when complemented by deployment policies that enhance the demand for RE technologies, for instance.

Technology deployment: financial incentives can reduce the costs and risks of investing in RE or agricultural technologies by lowering the upfront investment costs, reducing the cost of production or increasing the payment received for energy generated with RE sources or for agricultural goods produced with sustainable agricultural practices. Public finance provided by the World bank or other development banks can further help to mobilize or leverage commercial investment in IFES. Furthermore, government development agencies and international programmes can disseminate best practices, support strategy and policy development and strengthen institutions.

Building of human capacity: This includes the training of agricultural extensionists or private entrepreneurs that know how to deploy and maintain IFES practices and technologies. Policies might also provide capital for training facilities or facilitate the uptake of a farmer field school programme developed by FAO. Also the potential role of media to promote and inform about sustainable agricultural practices such as IFES should not be underestimated.

Communication networks, abilities, and strategies: For any long-term success of any IFES policies or projects, there is a need for proper communication networks to be built (also whole knowledge system webs or chains), people to be trained in communicating better (exchange, media, negotiation skills), technologies and approaches to be established (mobiles, radio with internet, etc) and plans, policies, finances, ideas at different levels stimulated, sown, and initiated.

Resource and property rights: The degree of recognition, enabling implementation of secure customary and diverse tenure rights is a determining factor for effective investment in IFES. This includes also the enabling of local governance of territories and commonly held land, water and other natural resources. For instance, when land tenure is secure, people are more likely to engage in more sustainable forms of agriculture that often require time to be established, but also add value to the land. Without secure tenure rights, farmers have less incentive to implement IFES because they have no guarantee that they will be able the see the long-term gains of their investments materialize.

Encouragement of good and discouragement of bad environmental behaviour: There is a wide variety of policy instruments that could be applied in the context of IFES. For example, farmers may be penalized for undertaking certain practices thought to be environmentally damaging, such as burning of crop residues. Other instruments may, to contrary, incentivize good environmental behaviour through economic incentives. A well known example is tradable carbon emission permits.

Policies are often linked with **national or regional targets**. For example, in the European Union (EU) the energy sector aims to provide 20 percent of renewable energy to all energy used in the EU by 2020. As a response, many European countries introduced biofuel blending mandates. However, also in the food production sector, targets have been set, for example, in Switzerland, where the Swiss Federal Agricultural Law and the Agricultural Act 2002 target subsidies towards ecological practices. Policy differentiates between three different levels of public support depending on the sustainability of agriculture (FAO, 2002b): Farmers receive payments for integrated production if they comply with some minimum conditions such as the use of diverse crop rotations and the reduction of pesticides to established risk levels.

Other areas that require public support in the agriculture, or energy sectors are related to the building of infrastructure, to the increase of agricultural produce prices or the supply of agricultural inputs. These are often only indirectly related to the replication of IFES, yet can in some instances become a serious barrier. For example, when subsidies for agricultural inputs are very high, there is less or no incentive to practice integrated pest management, which would reduce the need to use synthetic pesticides and save costs.

TABLE 6.

POLICY AREAS RELEVANT FOR THE REPLICABILITY OF IFES

	STRENGTHS	WEAKNESSES	OPPORTUNITIES	THREATS
Research and development (R&D)				
Technology deployment				
Building of human capacity				
Communication networks, abilities and strategies				
Resource and property rights, incl. secure land and resource tenure				
Encouragement of good and discouragement of bad environmental behaviour				
National or regional production targets				

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

The availability of human and technical capacity as well as the sustainable use of natural resources are prerequisites for replicating IFES. *Human capacity* refers to the human know-how developed through education, training and knowledge dissemination, while *technical capacity* describes a country's potential to manufacture and supply the necessary technologies and infrastructure. While human know-how and especially technologies can also be imported, it is often preferable to train local manufacturers or entrepreneurs and create domestic industries. This way, one supports local growth and job creation, which is likely to increase the acceptability and adoption of IFES.

Regarding *technical capacity,* many countries have put forward domestic content rules (DCR) and requirements to stimulate more domestic renewable energy production. DRC are policies that treat imported products less favorably than domestic products. In Spain, for instance, such DRCs have been instrumental for the success of the domestic wind energy sector (Lewis *et al.*, 2007).

While one might automatically relate the technical capacity to the energy part of IFES, the biomass component should not be underestimated. Plant materials such as seeds and seedlings are often not available, or the quality of available material is not sufficient. For instance, researchers from Malawi have reported that many of the trees planted in Malawi's agroforestry programmes do not reach their yield potential because of the poor quality of seed germplasm, which severely affects their country wide adoption (Nyoka *et al.*, 2011). Tree germplasm quality control systems such as certification schemes have proven to successfully address this problem.

Human capacity refers *to* education, training and knowledge transfer. Experience in the renewable energy sector shows that, even if a government offers generous incentives and low-cost capital, people will not invest in renewable energies if they lack information about them. For the case of IFES this means that education, training and knowledge transfer related to renewable energy technologies, farming and, most importantly, the combination of both, must be in place. It can include everything from resource studies and education about IFES, to training and information about available government incentives and support systems (see also question 3).

Last but not least, human capacity is not only linked to individual capacities, but also to human know-how in institutions. For instance, to design and implement policies necessary to promote IFES, government officials need to be aware of the related opportunities and constraints in the first place, and need to take the right management decisions.

Table 7 gives an overview of the features related to human and technical capacity. The table is followed by a detailed explanation of each issue.

TABLE 7.

FEATURES RELATED TO HUMAN AND TECHNICAL CAPACITY

	STRENGTHS	WEAKNESSES	OPPORTUNITIES	THREATS
Technical capacity				
Institutional know-how and management capacities				
Education, training and knowledge transfer				

'Technical capacity' refers to existence of manufactures, industries and infrastructure related to producing and providing technologies and services needed to develop an IFES. Which bioenergy processing technologies are viable in the country? Is there industry or infrastructure that can provide the necessary technologies and services? Are there policies in place which support domestic industry and provide important infrastructure? The latter is directly linked to question 3.

'Institutional know-how and management capacities' describes a set of factors important for the institutional back-up that the upscaling of a project will need. Are there leadership capacities within the organization? Is monitoring and evaluation a given practice of this particular institution? Does it maintain good contacts with other stakeholders? Are these institutions sufficiently financed to fulfil their mission and objectives? These issues are directly linked to question 2.

'Education, training and knowledge transfer' refers to the knowledge intensity of IFES schemes. Are there university or technical institutes that build human capacity in this field? Are extension services or farmer field schools in place that transfer the knowledge to the farmers? Alternatively, are there private service providers that offer their technical help in exchange for pay? In general, how well developed are the different elements of the local knowledge systems, including participatory experiences?

3.2.4. Define the sampling design and collect data

As described before, the sampling design is an essential part of data collection for evidence-based decision-making. A well-developed sampling design plays an important role in ensuring that data are sufficient to draw the conclusions needed. This is not only important for the assessment of sustainability, but also of replicability. To this end, we suggest a mixed methods approach to social research, which is specified in more detail in the Annex.

Following the sampling design, this step also involves the collection of data. Similar to the sustainability assessment, there is wide variety of specific sampling designs that can be used to improve the quality of socio-economic data collection needed for this assessment. However, for practical reasons, one needs to compromise between data collection costs and the need to be as concise as possible. Such costs can increase, either due to the number of samples required to achieve the desired effectiveness or because sampling and analytical equipment is expensive, for instance. Therefore, it is important to formulate questions and features in a way that can be sampled within the calculated budget, and reject those that go beyond.

3.2.5. Weigh the answers and make an informed decision

Once the data has been collected, it has to be carefully analysed in a way that helps to answer whether the assessed project has the potential to be replicated. One needs to note however, that the assessment won't provide a yes or no as an answer. It can help weigh the strengths and weaknesses as well and opportunities and threats of an innovation and thereby guide its users to an informed decision.

The success of the SWOT method is mainly owed to its simplicity and its flexibility, which is important for the sake of assessing complex and diverse IFES projects. It is therefore an advantage that the implementation of a SWOT analysis does not require technical knowledge and skills.

However, it does pose challenges when one needs to weigh the answers to derive an informed decision. There is no way to prioritize the different factors, because being as simple as it is, there are no requirements for their classification and evaluation. The SWOT method does also not include any suggestions of how to solve potential disagreements between the different stakeholders, and most importantly, the decision-makers involved in the replicability assessment. All that being said, there is the risk that the final decision is based on subjective conclusions and personal interpretation of the SWOT analysis – something to keep to keep in mind when applying such a simple and flexible method.

CHAPTER 4

THE WAY FORWARD

4.1 Pilot testing of the analytical framework

The IFES AF will be first pilot tested in several countries where some promising cases of integrated food-energy production have been implemented. After the pilot testing the AF will be finalized taking into account the feedback from this pilot testing phase.

4.2. Dissemination and outreach activities

A range of dissemination and outreach activities have been and continue to take place throughout the project aiming both at the public and private sector, civil society organizations as well as the scientific community. The emphasis is on informing these and other stakeholders about the concept of IFES, as well as raising awareness for the need of implementing the AF and strengthening the evidence base of IFES.

To this end, Dartmouth College, in collaboration with FAO, creates an international forum for open knowledge exchange, collaborative research and communication about co-production of food and energy in agricultural systems. There is only scant published information on opportunities of and barriers to good practice and technology adoption, and no mechanism for sharing this knowledge among farmers, developers, policy-makers, researchers and funding agencies. As such, FAO recognizes that there is a critical need for a bridging organization to create a compendium of IFES cases, gather data about these systems and the emerging technologies they employ, and serve as a clearinghouse and catalyst for research, assessment, outreach and technology transfer.

4.3. Capacity building

Furthermore, FAO has reached out to interested UN member countries such as Côte d'Ivoire, Malawi, and Mozambique in Africa as well as Viet Nam, Indonesia and China in Asia and Brazil in Latin America with the overall objective to contribute toward achieving both sustainable energy for all and food security in these countries. In particular, the proposed action aims to strengthen global and national knowledge and capacities related to developing sustainable and inclusive bioenergy systems that foster energy access and food security, while improving farming systems in general. The participatory assessment of the sustainability and replicability of IFES suggested in this document is an important step to reach this objective. In some countries, this might be combined with a rapid participatory appraisal of the domestic sustainable bioenergy potential and the development of a national bioenergy roadmap which is currently being developed by FAO (FAO, n.d.). More particularly, FAO suggests to:

- Involve a broad group of concerned actors through participatory approaches that allow to frame the specific needs and concerns of all relevant stakeholders regarding bioenergy, energy access and food security and ensure the issues are addressed in an integral manner.
- Identify appropriate technologies, which could be effectively deployed within the context of local needs and resources through the use of the IFES framework and the Bioenergy and Food Security Rapid Appraisal (BEFS RA).
- Strengthen the country's own knowledge generation capacities through in country participatory scientific and local knowledge assessments using the IFES Framework and the BEFS RA.
- Build in country capacity to absorb and use existing technologies for sustainable production of food and bioenergy through integrated food and energy systems.
- Prepare a national bioenergy roadmap through the participatory application of the BEFS RA and IFES in consultation with relevant stakeholders.

REFERENCES

Acosta-Alba, I., & Van der Werf, H. 2011 . The Use of Reference Values in Indicator-Based Methods for the Environmental Assessment of Agricultural Systems. *Sustainability*, 3 12 , 424–442. doi:10.3390/su3020424

Altieri, M. A., Funes-Monzote, F. R., & Petersen, P. 2012 . Agroecologically efficient agricultural systems for smallholder farmers: contributions to food sovereignty. *Agronomy for Sustainable Development*, *32* 1 , 1–13. doi:10.1007/s13593-011-0065-6

Astier, M., L. García-Barrios, Y. Galván-Miyoshi, C. E. González-Esquivel, and O. R. Masera. 2012 . Assessing the sustainability of small farmer natural resource management systems. A critical analysis of the MESMIS program 1995-2010 . *Ecology and Society* 17 3 : 25.

Bailey, A. P., Basford, W. D., Penlington, N., Parka, J. R. , Keatinge, J. D. H., Rehman, T., Tranter, R. B. and Yates, C. M. 2003. A comparison of energy use in conventional and integrated arable farming systems in the UK Agriculture. *Ecosystems & Environment* 97 1-3 : 241-253.

Bockel, L & Touchemoullin, O. 2011 . *The Low Carbon Agricultural Support Project LCASP in Vietnam*. Rome, Italy: Food and Agriculture Organization of the United Nations.

Bogdanski, A., Dubois, O., Jaimieson, C., & Krell, R. 2010. *Making Integrated Food-Energy Systems work for People and Climate*. Rome, Italy: FAO.

Bogdanski, A. 2012 . Integrated food–energy systems for climate-smart agriculture. *Agriculture & Food Security*, 1 1 , 9. doi:10.1186/2048-7010-1-9

Bogdanski, A. & Roth, C. 2012 . Integrated Food-Energy Systems: Growing fuel wood on farm in Malawi. *Nature & Faune*, 26 2 , 52–61.

Bruce JP, Frome M, Haites E *et al.* 1999 . Carbon sequestration in soils. *Journal of Soil and Water Conservation*, 54, 382–389.

Business Dictionairy n.d. . Replicability. Retrieved Sep 1st 2013 from http://www.businessdictionary.com/definition/replicability.html#ixzz2fzU2IS6c

Colomb, V., Bernoux, M., Bockel, L., Chotte, J.-L., Martin, S., Martin-Phipps, C., Mousset, J., Tinlot, M. and Touchemoulin, O. 2012 . *Review of GHG Calculators in Agriculture and Forestry Sectors: A Guideline for Appropriate Choice and Use of Landscape Based Tools, Version 2.0 ADEME, IRD, FAO* p 43. Rome, Italy: Food and Agriculture Organization, Rome. Retrieved July 20th 2013 from www.fao.org/tc/exact/exact-publications/papers-mentioning-ex-act/en/

Convention on Biological Diversity CBD. 2008 . The potential impacts of biofuels on biodiversity - matters arising from SBSTTA recommendation XII/7; Note by the Executive Secretary; UNEP/CBD/COP/9/26

Chambers, R. 2008 . *Revolutions in development inquiry*. London: Earthscan.

Chambers, R., & Gujit, R. 1995, April . PRA - five years later. where are we now? *Forests, Trees and People Newsletter, 26/27*, 4-14.

Chambers, R. 1994 . The origins and practice of participatory rural appraisal. *World Development*, 22 7, 953–969.

Crawford, I. M. 1997 . Chapter 8: Rapid Rural Appraisal. In *Marketing Research and Information Systems*. Rome, Italy: Food and Agriculture Organization, Rome. Retrieved from http://www.fao.org/docrep/W3241E/w3241e09.htm

Denef, K., Paustian, K., Archibeque, S., Biggar, S., and Pape, D. 2012. *Report of Greenhouse Gas Accounting Tools for Agriculture and Forestry Sectors*. Interim project technical report to USDA under Contract No. GS23F8182H. Retrieved July 2nd 2013, from http://www.usda.gov/oce/climate_change/techguide/Denef_et_al_2012_GHG_Accounting_Tools_v1.pdf

Dixon, J. A., Gibbon, D. P., & Gulliver, A. 2001. *Farming systems and poverty: improving farmers' livelihoods in a changing world*. Rome, Italy: FAO.

Dubois, O. 1998. Capacity to manage Role Changes in Forestry: Introducing the 'four Rs' Framework. *Forest Participation Series* No. 11, International Institute for Environment and Development, London.

European Commission (EC) - Food and Agriculture Organization (FAO) Food Security Programme. 2008 . *An Introduction to the Basic Concepts of Food Security Practical Guides* p. 3. Rome, Italy: FAO.

Food and Agriculture Organization (FAO). 1999. Agricultural Biodiversity, Multifunctional Character of Agriculture and Land Conference, Background Paper 1. FAO/Netherlands Conference on the Multifunctional Character of Agriculture and Land. Retrieved 5 May 2013 from http://www.fao.org/mfcal/pdf/bp_1_agb.pdf

Food and Agriculture Organization (FAO). 2002a. What is land tenure. Land Tenure and Rural Development. FAO Land tenure studies 3. Retrieved 5 May 2013 from http://www.fao.org/docrep/005/y4307e/y4307e05.htm

Food and Agriculture Organization (FAO). 2002b. *Challenges and perspectives for the World Summit on Sustainable Development Johannesburg 2002. Land and Agriculture*. From UNCED, Rio de Janeiro 1992 to WSSD, Johannesburg 2002. A compendium of recent sustainable development initiatives in the field of agriculture and land management. FAO, Rome, Italy.

Food and Agriculture Organization (FAO). 2004. *Unified Bioenergy Terminology*. UBET. Rome, Italy: FAO.

Food and Agriculture Organization (FAO). 2008. *Visual Soil Assessment. Field Guides*. Rome, Italy: FAO.

Food and Agriculture Organization (FAO). 2009a. *Small Scale Bioenergy Initiatives*. Environment and Natural Resources Management Working Paper 31. Food and Agriculture Organization of the United Nations, Rome, Italy.

Food and Agriculture Organization (FAO). 2009b. *Dialogue, Consensus and Vision – Participatory and Negotiated Territorial Development - more than a methodology*. Land Tenure Working Paper 12. Food and Agriculture Organization of the United Nations, Rome, Italy.

Food and Agriculture Organization (FAO). 2009c. *Glossary on organic agriculture. Version 1.0* 15.10.09 EFS. 173.

Food and Agriculture Organization (FAO). 2010. *Climate-smart agriculture: Policies, practices and financing for food security, adaptation and mitigation.* FAO, Rome, Italy.

Food and Agriculture Organization (FAO). 2012a. *The Voluntary Guidelines on the Responsible Governance of Tenure of Land, Fisheries and Forests in the Context of National Food Security*. Retrieved August 8th 2013 from http://www.fao.org/nr/tenure/voluntary-guidelines/en/

Food and Agriculture Organization (FAO /IIASA/ISRIC/ISSCAS/JRC). 2012b. *Harmonized World Soil Database version 1.2*. FAO, Rome, Italy and IIASA, Laxenburg, Austria.

Food and Agriculture Organization (FAO). 2013a. BEFS Investment Screening. Retrieved August 8th 2013 from http://www.fao.org/energy/befs/78918/en/

Food and Agriculture Organization (FAO). 2013b. *Advancing Agroforestry on the Policy Agenda: A guide for decision-makers*, by G. Buttoud, in collaboration with O. Ajayi, G. Detlefsen, F. Place & E. Torquebiau. Agroforestry Working Paper no. 1. Food and Agriculture Organization of the United Nations. FAO, Rome. 37 pp.

Food and Agriculture Organization (FAO). n. d. *BEFS Rapid Appraisal.* Retrieved Oct. 21st 2013 from http://www.fao.org/energy/befs/rapid-appraisal/en/

Food and Agriculture Organization (FAO). n. d.. *Hunger Portal.* Retrieved Oct. 21st 2013 from http://www.fao.org/hunger/en/

Funes-Monzote, F.R. 2009a. *Eficiencia energética en sistemas agropecuarios. Elementos teóricos y prácticos para el cálculo y análisis integrado*. Estación Experimental Indio Hatuy, Universidad de Matanzas.

Funes-Monzote, F. R., Monzote, M., Lantinga, E. A., Ter Braak, C. J. F., Sánchez, J. E., & Van Keulen, H. 2009b. Agro-Ecological Indicators AEIs for Dairy and Mixed Farming Systems Classification: Identifying Alternatives for the Cuban Livestock Sector. *Journal of Sustainable Agriculture*, 33 4 , 435–460.

Global Alliance for Clean Cookstoves. 2013. Retrieved November 7, 2013, from http://www.cleancookstoves.org/

Godfray, C., Beddington, J.R., Crute, I.R., Haddad, L., Lawrence, D., Muir, J.F., Pretty, J., Robinson, S., Thomas, S.M. & Toulmin, C. 2010 . Food security: The challenge of feeding 9 billion people. *Science,* 327, 812- 818

Gradl, C. & C. Knobloch. 2011. *Energize the BoP. Energy Business Model Generator for Low-Income Markets* p. 52 . Germany: Endeva. Retrieved from http://www.energize-the-bop.net/report/

GBEP. 2011. *The Global Bioenergy Partnership Sustainability Indicators of Bioenergy*. First Edition. Rome, Italy: GBEP.

Gerst, M.D., Cox, M.E., Laser, M., Locke, K., & Kapuscinski, A. n.d. . A taxonomy of integrated food-energy systems. Working paper.

Gliessman, S.R. 2001. *Agroecology: Ecological processes in sustainable agriculture*.CRC Lewis Publishers, Boca Raton. 408 pp.

Gollany, H. T., J. M. Novak, Y. Liang, S. L. Albrecht, R. W. Rickman, R. F. Follett, W. W. Wilhelm, and P. G. Hunt. 2010. Simulating soil organic carbon dynamics with residue removal using the CQESTR Model. *Soil Science Society of America Journal* 74:372&150;383.

Grandin, B. 1988. *Wealth ranking in smallholder communities. A field manual.* London: Intermediate Technology Publications

Groot, L. de & Bogdanski, A. 2013. Bioslurry = *Brown Gold? A review of scientific literature on the co-product of biogas production* No. 54 p. 41 . Rome, Italy: FAO

Gugino, B.K., Idowu, O.J., Schindelbeck, R.R., van Es, H.M., Wolfe, D.W., Moebius-Clune, B.N., Thies, J.E. and Abawi, G.S. 2009. *Cornell Soil Health Assessment Training Manual*, Edition 2.0, Cornell University, Geneva, NY.

GVEP 2010. *Training Manual For Micro, Small, And Medium Entrepreneurs*. In Energy Business Financing, GVEP International, Nairobi, Kenya.

Hardaker, B. 1997. *Guidelines for the integration of sustainable agriculture and rural development into agricultural policies*. Rome, Italy: Food and Agriculture Organisation.

Holocombe, S. 2012. *Lessons from practice: Assessing Scalability.* Washington DC, United States: World Bank. Retrieved January 5th 2013 from http://siteresources.worldbank.org/INTARD/Resources/Scalabilityfinal.pdf

Hailu, Y. G. 2012. Measuring and monitoring energy access: Decision-support tools for policymakers in Africa. *Energy Policy*, 47, Supplement 1, 56–63. doi:10.1016/j.enpol.2012.03.065

IDB. n. d. *IDB Biofuels Sustainability Scorecard*. Retrieved 23 July 2013, from http://www.iadb.org/biofuelsscorecard/

IEA. 2010. *World Energy Outlook 2010. The Electricity Access Database*. Retrieved Oct. 4th 2011 from http://www.iea.org/weo/database_electricity10/electricity_database_web_2010.htm

ILO no date. *Resolution concerning household income and expenditure statistics*. Retrieved 23 July 2013 from http://www.ilo.org/wcmsp5/groups/public/---dgreports/---stat/documents/normativeinstrument/wcms_087503.pdf

International Finance Cooperation IFC. 2012. *From Gap to Opportunity: Business Models for Scaling Up Energy Access* p. 172. Washington DC, United States: IFC. Retrieved 23 July 2013 from http://www1.ifc.org/wps/wcm/connect/ca9c22004b5d0f098d82cfbbd578891b/energyaccessreport.pdf?MOD=AJPERES

IPCC. 2011a. Special report on renewable energy and climate change mitigation, Chapter 9, Policy, Financing and Implementation, Working Group III, Intergovernmental Panel on Climate Change. Retrieved Oct. 4th 2011 from http://srren.ipcc-wg3.de/report/IPCC_SRREN_Ch9

IPCC. 2011b. Special report on renewable energy and climate change mitigation, Chapter 11, Policy, Financing and Implementation, Working Group III, Intergovernmental Panel on Climate Change. Retrieved Oct. 4th 2011 from http://srren.ipcc-wg3.de/report/IPCC_SRREN_Ch11

Jamieson, C. 2008. *An Innovative System for Zero Carbon Fuel and Food Production*. Low Carbon Vehicle Partnership.

Jianbo, L., 2006. Energy balance and economic benefits of two agroforestry systems in northern and southern China. *Agriculture, Ecosystems and Environment* 116: 255-262.

Jones L., Ludi E., & Levine S. 2010. *Towards a characterization of Adaptive Capacity: A Framework for Analysing Adaptive Capacity at the Local Level*. London, UK: Overseas Development Institute.

Kelly, S. 2012. *Smallholder business models for agribusiness-led development. Good practice and* *policy guidance* p. 28. Rome, Italy: Food and Agriculture Organisation. Retrieved Oct. 4th 2013 from http://www.fao.org/docrep/015/md923e/md923e00.pdf

Kersten, I., Baumbach, G., Oluwole, A., Obioh, I., & Ogunsola, O. 1998. Urban and rural fuelwood situation in the tropical rain-forest area of south-west Nigeria. *Energy*, 23 10 , 887–898.

Koga, N., T. Sawamoto, & Tsuruta, H. 2006: Life cycle inventory-based analysis of greenhouse gas emissions from arable land farming systems in Hokkaido, northern Japan. *Soil Science and Plant Nutrition,* 52, pp. 564-574.

Kremen, C., & Miles, A. 2012. Ecology and Society: Ecosystem Services in Biologically Diversified versus Conventional Farming Systems: Benefits, Externalities, and Trade-Offs. *Ecology and Society*, 17 4 , 40.

Kuriakose A.T., Bizikova L. & Bachofen C.A. 2009. *Assessing Sustainability and Adaptive Capacity to Climate Risks*. Washington, DC: World Bank.

Legros, G., Havet, I., Bruce, N., & Bonjour, S. 2009. *The energy access situation in developing countries. A review focusing on the least developed countries in sub-Saharan Africa* p. 142 . New York, USA: UNDP/WHO. Oct. 4th 2013 from http://content.undp.org/go/cms-service/stream/asset/?asset_id=2205620

Lewins, A., & Silver, C. 2007. *Using software in qualitative research. A step-by-step guide* 1st ed. . London: Sage Publications.

Lewis, J. I., & Wiser, R. H. 2007. Fostering a renewable energy technology industry: An international comparison of wind industry policy support mechanisms. *Energy Policy*, 35 3 .

López-Ridaura, S., Keulen, H. V., Ittersum, M. K. van, & Leffelaar, P. A. 2005. Multiscale Methodological Framework to Derive Criteria and Indicators for Sustainability Evaluation of Peasant Natural Resource Management Systems. *Environment, Development and Sustainability*, 7 1 , 51–69.

Lloyd, P.J.D., & Visagle, E.M. 2007. A comparison of gel fuels with alternate cooking fuels. *Journal of Energy in Southern Africa*, 18 3 , pp. 26-31.

Madlener R. & Myles, H. 2000. *Modeling Socio-Economic Aspects of Bioenergy Systems: A survey prepared for IEA Bioenergy Task 29*, September. Paris, France: IEA.

Malkina-Pykh IG. 2002. Integrated assessment models and response function models: pros and cons for sustainable development indices design. *Ecol Indicators* 2:93–108.

Manuel-Navarrete, D., S. Slocombe, & Mitchell, B. 2006 . Science for place-based socioecological management: lessons from the Maya forest Chiapas and Petén . Ecology and Society 11 1 : 8. Retrieved September 5th 2013 from http://www.ecologyandsociety.org/vol11/iss1/art8/

Martine, G. & Villarreal, M. 1997. Gender and Sustainability: Re-assessing Linkages and Issues. Retrieved September 14th 2013 from http://www.fao.org/sd/wpdirect/wpan0020.htm

Masera, O., Astier, M. & López-Ridaura, S. 1999. *Sustentabilidad y manejo de recursos naturales: El marco de evaluación MESMIS*. México, Mundi-Prensa.

Mather, R., de Boer, M., Gurung, M. & Roche, N. 1998. *Aerial Photographs and 'Photo-maps' for Community Forestry. ODI Rural Development Forestry Network* RDFN. Paper 23e. 13-22.

Mikkelsen, B. 2005. *Methods for development work and research* 2nd ed. . London: Sage Publications.

Millennium Ecosystem Assessment. 2005. *Ecosystems and Human Well-Being: Synthesis*. Island Press, Washington. 155pp.

Mitchell, C., J. L. Sawin, G. R. Pokharel, D. Kammen, Z. Wang, S. Fifi ta, M. Jaccard, O. Langniss, H. Lucas, A. Nadai, R. Trujillo Blanco, E. Usher, A. Verbruggen, R. Wüstenhagen, & Yamaguchi, K. 2011. Policy, Financing and Implementation. In *IPCC Special Report on Renewable Energy Sources and Climate Change Mitigation* [O. Edenhofer, R. Pichs-Madruga, Y. Sokona, K. Seyboth, P. Matschoss, S. Kadner, T. Zwickel, P. Eickemeier, G. Hansen, S. Schlömer, C. von Stechow eds], Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Moreno, M.M., Lacasta, C., Meco, R. and Moreno, C. 2011. Rainfed crop energy balance of different farming systems and crop rotations in a semi-arid environment: Results of a long-term trial . *Soil and Tillage Research* 114 1 : 18-27.

Orr, A., Kambombo, B., Roth, C., Harris, D., & Doyle, V. 2013. Testing Integrated Food-Energy Systems: Improved cookstoves and pigeonpea in southern Malawi. Manuscript submitted for publication.

Practical Action Consulting. 2009. *Small-Scale Bioenergy Initiatives: Brief description and preliminary lessons on livelihood impacts from case studies in Asia, Latin America and Africa* Final report . Rome, Italy: FAO/PISCES.

Paul, R. 2006. *Participatory Rural Appraisal PRA Manual*. FAO, Rome, Italy. Retrieved May 10th 2013 from http://www.fao.org/alc/file/media/pubs/2006/pra_manual.pdf

Nijkamp P., & Vreeker R. 2000. Sustainability assessment of development scenarios: methodology and application to Thailand. *Ecological Economics*, 33 1 , 7–27.

Nyoka, B. I., Ajayi, O. C., Akinnifesi, F. K., Chanyenga, T., Mng'omba, S. A., Sileshi, G., … Madhibha, T. 2011. Certification of agroforestry tree germplasm in Southern Africa: opportunities and challenges. *Agroforestry Systems*, 83 1 , 75–87.

OECD. 2001. *Environmental indicators for agriculture. Methods and results*. Volume 3. Retrieved 29 April 2013 from http://www.oecd.org/tad/sustainable-agriculture/40680869.pdf

Pretty, J. N., Noble, A. D., Bossio, D., Dixon, J., Hine, R.E., Penning De Vries, P. W. T. and Morrisson, J. I. L. 2006. Resource-Conserving Agriculture Increases Yields in Developing Countries. *Environmental Science and Technology* 40 4 : 1114-1119.

Reegle. n.d. Retrieved Sep. 14th 2013 from www.reegle.info

Rosenstock, T. S., Rufino, M. C., Butterbach-Bahl, K., & Wollenberg, E. 2013. Toward a protocol for quantifying the greenhouse gas balance and identifying mitigation options in smallholder farming systems. *Environmental Research Letters*, 8 2 , 021003.

Saby, N. P. A., Bellamy, P. H., Morvan, X., Arrouays, D., Jones, R. J. A., Verheijen, F. G. A., … Simota, C. 2008. Will European soil-monitoring networks be able to detect changes in topsoil organic carbon content? *Global Change Biology*, 14 10 , 2432–2442.

Sattler, C., & Nagel, U. J. 2010. Factors affecting farmers' acceptance of conservation measures—A case study from north-eastern Germany. *Land Use Policy*, 27 1 , 70–77.

Saunders, C., Kaye-Blake, W., Hayes p., & Shadbolt, N. 2007. *Business Models and Performance Indicators for AgriBusinesses* p. 51 . Lincoln, New Zealand: Agribusiness and Economics Research Unit , Lincoln University. Retrieved April 5th 2013 from http://researcharchive.lincoln.ac.nz/dspace/bitstream/10182/3647/1/Business_models.pdfRetrieved from http://researcharchive.lincoln.ac.nz/dspace/bitstream/10182/3647/1/Business_models.pdf

Schneider, U. A. and Smith, P. 2009. Energy intensities and greenhouse gas emissions in global agriculture. *Energy Efficiency* 2: 195-2006.

Selener, D., Endara, N., & Carvajal, J. 1999. *Participatory rural appraisal and planning workbook.* Philippines: International Institute for Rural Reconstruction.

Shennan, C. 2008. Biotic interactions, ecological knowledge and agriculture. *Philosophical Transactions of the Royal Society B: Biological Sciences*, 363 1492 , 717–739.

Sims, R. 2011. '*Energy-Smart' Food for People and Climate Issue Paper* p. 78 . Rome, Italy: Food and Agriculture Organization of the United Nations. Retrieved 29 April 2013 from http://www.fao.org/docrep/014/i2454e/i2454e00.pdf

Smith, P., D. Martino, Z. Cai, D. Gwary, H. Janzen, P. Kumar, B. McCarl, S. Ogle, F. O'Mara, C. Rice, B. Scholes, O. Sirotenko, 2007 Agriculture. In *Climate Change 2007: Mitigation. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* [B. Metz, O.R. Davidson, P.R. Bosch, R. Dave, L.A. Meyer eds], Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Smith, R.D. & Maltby, E. 2003. *Using the Ecosystem Approach to Implement the Convention on Biological Diversity Key Issues and Case Studies* – IUCN. Oct. 4th 2013 from http://data.iucn.org/dbtw-wpd/edocs/CEM-002.pdf.

Standard Assessment of Mitigation Potential and Livelihoods in Smallholder Systems SAMPLES | World Agroforestry Centre. n.d. Retrieved 29 April 2013, from http://www.worldagroforestry.org/project/samples

Six, J., S.M. Ogle, F.J. Breidt, R.T. Conant, A.R. Mosier, & Paustian, K. 2004. The potential to mitigate global warming with no-tillage management is only realized when practiced in the long term. *Global Change Biology,* 10, pp.155-160.

Sovacool, B.K. 2008. Renewable Energy: Economically Sound, Politically Difficult. *The Electricity Journal*, 21 5 : 18-29.

Standard Assessment of Mitigation Potential and Livelihoods in Smallholder Systems SAMPLES | World Agroforestry Centre., n.d. Retrieved 15 October 2013, from http://worldagroforestry.org/project/samples

Sustainable Energy for All. n. d. Retrieved July 27, 2012, from http://www.sustainableenergyforall.org/about-us/faq

Total energy access standards |Practical Action. n.d. Retrieved December 11, 2012, from http://practicalaction.org/total-energy-access-standards

Thurston-Enriquez, J. A., Gilley, J. E., & Eghball, B. 2005. Microbial quality of runoff following land application of cattle manure and swine slurry. *Journal of water and health*, 3 2 , 157–171.

Tittonell, P., & Giller, K. E. 2013. When yield gaps are poverty traps: The paradigm of ecological intensification in African smallholder agriculture. *Field Crops Research*, 143, 76–90.

United Nations Development Programme UNDP and the World Health Organisation WHO. n.d. The Montréal Process. Retrieved January 22, 2013, from http://www.montrealprocess.org/

UNDP and WHO. 2009. The energy access situation in developing countries. A Review focusing on the Least Developed Countries and Sub-Saharan Africa. Retrieved Oct. 4th 2013 from http://www.who.int/indoorair/publications/energyaccesssituation/en/

UN General Assembly. 2011. Promotion of new and renewable sources of energy. Report of Secretary General, 22 August. Retrieved October 4th 2011 from http://www.un.org/esa/dsd/resources/res_pdfs/ga-66/SG%20report_Promotion_new_renewable_energy.pdf

Van der Werf, H. M., & Petit, J. 2002. Evaluation of the environmental impact of agriculture at the farm level: a comparison and analysis of 12 indicator-based methods. Agriculture, *Ecosystems & Environment*, 93 1–3 , 131–145.

Wattenbach, H., & Friedrich, T. 1997. *Farming systems indicators for sustainable natural resource management. In Land Quality Indicators and Their Use in Sustainable Agriculture and Rural Development*. Rome, Italy: Food and Agriculture Organization, Rome.

World Health Organisation (WHO). 2006. Fuel for Life. Geneva, Switzerland. Retrieved May 15th 2013 from http://www.who.int/indoorair/publications/fuelforlife.pdf

Wilson, E., Wood, R. G., & Garside, B. 2012. *Sustainable energy for all? Linking poor communities to modern energy services* p. 29 . London, UK: IIED.

WRI. 2013. GHG Protocol Agricultural Guidance A sector-specific supplement to the Corporate Standard for agriculture, horticulture and fisheries. Draft for open comment. Retrieved May 15th 2013 from http://www.ghgprotocol.org/feature/open-comment-period-agriculture-guidance

Wattenbach, H., & Friedrich, T. 1997. *Farming systems indicators for sustainable natural resource management. In Land Quality Indicators and Their Use in Sustainable Agriculture and Rural Development*. Rome, Italy: Food and Agriculture Organization.

World Bank. 2009. Gender in Agriculture Sourcebook Update # 2. Retrieved May 15th 2013 from http://siteresources.worldbank.org/INTGENAGRLIVSOUBOOK/Resources/Sourcebook_Update_2.pdf

World Bank. 2012. *Toolkit. Gender issues in monitoring and evaluation in agriculture*. Washington D.C., USA: The World Bank.

World Commission on Environment and Development. 1987. Report of the World Commission on Environment and Development: Our Common Future. Retrieved 16 May 2013 from http://www.un-documents.net/wced-ocf.htm

World Food Programme (WFP). 2012. WFP handbook on safe access to firewood and alternative energy SAFE. Rome, Italy: World Food Programme. Retrieved 16 May 2013 from http://documents.wfp.org/stellent/groups/public/documents/newsroom/wfp252989.pdf

World Food Summit (WFS). 1996. *Rome Declaration on World Food Security*. Rome, Italy: Food and Agriculture Organization.

ANNEX A: DEFINING AN IFES, THE LOCAL CONTEXT AND ITS ACTORS

The first step in assessing both the sustainability and replicability of an IFES is to identify and characterize the specific components that make up the IFES and how the various subsystems are interlinked. According to figure 3b (see figure in main text), an IFES may consist of five or more internal components. In the IFES typology in figure 3b, these subsystems include the family nucleus, the agricultural subsystem, the animal subsystem, the forest subsystem and the socio-cultural subsystem. These internal components are interlinked in various ways and are also linked to external components (the enabling environment) of IFES that include the following:

- Biophysical conditions such as the amount of rainfall
- Migration patterns
- Support institutions and organizations (CBOs, NGOs, agricultural extension stations, government agencies, etc.)
- Markets
- Local exchange/bartering fairs

The family/household is linked to the main subsystems through a range of flows which are needed to cover subsistence and energy needs and to provide income for the household. As indicated in Astier *et al.* (2012) these flows can include:

- Agricultural products
- Forest products
- Products from exchange fairs
- Animals and animal products
- Income from market sales
- Participation in socio-cultural interactions

The various subsystems which provide subsistence, energy and income flows to the household are also linked to each other. For example, forests can provide forage for animals and animals can provide manure for agricultural production.

The following field methods are useful in conducting an initial, exploratory assessment of the various subsystems and their internal linkages.

TRANSECT WALK

A transect walk can enable the researcher and members of a community or household to assess the distinct production characteristics of an IFES, how various subsystems are linked to each other as well as to the household and which problems and potentials are associated with the IFES. The following description is adapted from the methods proposed in Selener *et al.* (1999) and PFD (1999).

A transect walk is carried out in two major steps. Firstly, the facilitators and local inhabitants go on a walk through a section of the farm or community which encompasses the major features of the IFES. Along this route the most prominent characteristics of each subsystem (e.g. forest species, crops, animals, etc.) are noted and facilitators should carefully note and record what local people point out and comment on during the walk. Depending on the particular IFES, the following might be of particular interest to record:

1. Changes that have taken place during and after the implementation of the IFES
2. Problems and opportunities that people have experienced while implementing the IFES
3. How each component encountered on the walk is linked to other components
4. How each component is linked to household consumption and the household economy
5. How each component is linked to socio-cultural interactions within the community (e.g. communal cooking, rituals, celebrations)

It is important to keep the transect walk informal and allow local inhabitants to share the information they find most important. However, the process can be tailored and explained in such a way that inhabitants focus primarily on issues related to the interlinkages between components of the IFES.

After the transect walk, a transect diagram is made with local people based on what they remember and what the facilitators have written down. The transect and diagram will in most cases be at the level of a farm or single IFES but it can also be carried out at the community level. In the diagram, the terrain encountered on the route is mapped in the top part of a sheet of paper including topography, crops, grazing areas, forest plots, rivers, places of socio-cultural value and the location of homes. On the left-most side of the diagram, a column is made which lists in rows the most important characteristics to be analysed for the IFES. These characteristics may include problems, potential solutions, internal linkages with other components in the IFES and external linkages with markets, support institutions and migration patterns. These characteristics are then analysed in detail for each landscape in the next columns.

Sets of guiding questions can also be developed for the transect walk, which can be used for various components of the IFES (e.g. agricultural, forest and animal subsystems) (PFD 1999). Questions may also be formulated to assess other aspects of the IFES such as transport and community infrastructure, energy for cooking and heating and market access. A set of guiding questions for the agricultural subsystem may include the following questions:

- Which crops do you grow? For which purpose (e.g. subsistence, bioenergy, for the market)?
- How far are they located from your house?
- What percentage of your total land area does the area for cropping cover?
- Do you use the residues from your agricultural land? For which purposes?
- Where do you get water for your crops? Is there enough water to grow your crops?
- Are any of your crops sold? If yes, which crops? What percentage of the harvest is sold?

- Where do you get the seeds for agricultural and/or bioenergy production?
- Do you receive support from any organizations on what to grow and which techniques to use?

For a single farm or IFES it will take 1-2 hours for both the transect walk and diagram (Selener *et al.* 1999). A team of two researchers and four local inhabitants (two men and two women) can conduct the transect walk at the community level (PFD 1999). At the farm level the group can be reduced to 1 researcher and 1-2 local inhabitants. The materials needed for a transect walk are a notebook, pens or pencils.

SEASONAL CALENDARS

Drawing seasonal calendars can be a useful way to understand local patterns of labour, migration, food availability and health as well as other aspects of household and community livelihoods (PFD 1999). It is useful to conduct the seasonal calendar exercise in conjunction or in sequence with the transect walk. However, the seasonal calendar exercise is often carried out in larger focus groups disaggregated by gender or ethnicity depending on the social context.

A blank seasonal calendar is prepared and a suitable location for the session is selected in accordance with the socio-cultural context and norms. A group of local inhabitants are organized into groups, e.g. a representative group of women in a community who are engaged in an IFES. The researcher should explain carefully what the objective of the exercise is and ask if the group may have any questions.

The group is then asked to describe the work activities carried out during each month or seasonal period over the course of a year (PFD 1999). When discussing the various labour activities for each period the group should indicate whether the workload is low, medium or high. Combined with other methods this will allow the researcher to understand which activities pertain to specific subsystems of the IFES and what some of the enabling and constraining factors are.

The same procedure can be repeated with other topics such as migration, health, food availability, market conditions and energy access. In this way, it is possible to assess whether food availability, outmigration, energy access or health is low, medium and high during certain periods of the year and how these factors are aligned with specific livelihood activities.

An hourly schedule can be included at the bottom of the calendar to assess the daily activities carried out for various year-round activities.

Finally, the respondents should identify and discuss periods of particular difficulty and the relationships between the various patterns of community life (labour, health, energy access, etc.).

As with the transect walk sets of guiding questions should be prepared for some of the main topics that relate to the main patterns explored. These topics could include agricultural activities, forestry activities, animal husbandry, production of bioenergy feedstock and livelihoods. Questions concerning agricultural labour may include:

- What are the main agricultural activities carried out during each season?
- When do people cultivate [main crop]? How much time do they spend in the fields?
- What other activities take place during the dry season (or wet season)?
- When do people sell their crops at the market?

A seasonal calendar session should take about 1-2 hours to conduct with one group and the materials needed are a large, thick blank sheet of paper, coloured markers or pens and a notebook for recording important information. It is advised that two researches conduct the session – one who can facilitate and one who can take notes.

The seasonal calendar not only gives an indication of which subsystems make up an IFES and which activities are carried out; it also gives an indication of what particular conditions during a particular time of year enable or constrain a successful IFES.

VENN DIAGRAMS

The drawing or design of Venn diagrams are useful for conducting an institutional analysis of IFES. An institutional analysis is necessary to identify stakeholders who may strongly influence the process of implementing an IFES. With reference to figure 3b, these stakeholders constitute external components of the IFES and may include influential investors or organizations who advocate for the scaling up of a particular IFES. Experience with IFES projects has shown that external stakeholders can be instrumental for the replication of an IFES project.

The diagrams – also known as Chapatti diagrams in reference to the Indian bread – are used to depict and assess people's sense of how much external stakeholders are present in the community and how they relate to the community (Mikkelsen 2005, Selener *et al.* 1999). The Venn diagram shows which institutions are present, work with or are in some other way related to the community (Selener *et al.* 1999).

In order to carry out the Venn diagram, session community members or a focus group disaggregated by gender – facilitated by researchers – discuss the roles and importance of various organizations present in the area who were in some way involved in the implementation of the IFES. This initial exercise should result in a list of organizations or institutions who are prioritized in terms of their importance.

They are then placed – along with the community – in a diagram and all are designated by circles. The size of the circle symbolizes the power of the institution – its ability to enable change – while its location in the diagram vis-à-vis the community indicates the extent to which the institution is working in the interest of the community. The closer the institution is placed to the community, the more in line with the interests of the community it is (Selener *et al.* 1999). Lines should be drawn between the community and the specific institutions and text above the line should indicate the nature of the relationship (Selener *et al.* 1999). Lines can also be drawn between the various institutions with an indication of their relationship noted on the diagram. Institutions that work together may also be represented by overlapping circles (PFD 1999).

Community members may also want to add a smaller circle where community institutions are placed within a larger circle containing both internal and external institutions (PFD 1999). Depending on the size of the community and the population within it there may be significant and important internal institutions. These may have links to external institutions and may be of more or less importance to the average household that has implemented an IFES. If local institutions are included in the discussions it is most appropriate to start discussing and drawing these followed by a discussion of external institutions.

For the discussion, the following questions can be discussed:

1. Which organizations/groups/individuals within the community (but outside your households) were important in financially supporting you to implement an IFES?
2. Which organizations/groups/individuals within the community (but outside your households) were important in terms of offering technical support for you to implement an IFES?
3. Which organizations/groups/individuals within the community (but outside your households) created barriers for you to implement an IFES? (this question is of a sensitive nature and should be posed carefully or be omitted in some cases)
4. Which organizations/groups/individuals outside the community were important in financially supporting you to implement an IFES?
5. Which organizations/groups/individuals outside the community were important in terms of offering technical support for you to implement an IFES?
6. Which organizations/groups/individuals outside the community created barriers for you to implement an IFES?

The Venn diagram session requires about 1 hour to carry out and two people are required as facilitators (one to ask questions and one to take notes). Materials needed include a big paper and several coloured markers.

ANNEX B: INDICATORS FOR ASSESSING THE SUSTAINABILITY OF IFES

CRITERION 1: FOOD SECURITY

In order to rapidly assess food security impacts of IFES, we need to look at each of the four pillars of food security:

- Physical availability of food
- Economic and physical access to food
- Food utilization
- Stability of the other three dimensions over time

To measure the impact of IFES on *Physical availability of food and* on *Economic and physical access to food*, we suggest to use the Bioenergy and Food Security (BEFS) Operator Level Tool which is a web-based tool that can provide a preliminary indication of potential risks and benefits for food security from agricultural/bioenergy investments (FAO, 2013).

The BEFS Operator Level Tool consists of a set of indicators grouped in three parts: (i) Change in the supply of food to the domestic market; (ii) Resource availability and efficiency of use; and (iii) Physical displacement, change in access to resources, compensation and income generation. Each part includes indicators addressing key environmental and socio-economic dimensions relevant for food security. For each indicator, benchmarks and thresholds are provided. Based on these and on the information entered by the users of the tool, a score is then assigned to each indicator.

To measure the impact of IFES on *food utilization,* household surveys will be necessary. One of the standard indicators to measure food utilization is the *stunting rate* of under five year olds, comparing a baseline with the situation after an intervention a couple of years later. However, a stunting rate is not specific to the use of energy for cooking, but depends on a variety of factors such as food consumption or the susceptibility to disease. A simpler way of getting an indication of the links of IFES and food utilization could be the measurement of the *cooking frequency* for the main staple crops (personal communication with Christa Roth): This indicator is based on the assumption that fuel shortage leads to a decreased frequency of preparing energy intensive meals. It is also based on the hypothesis that the increased availability of fuel (such as fuelwood, crop residues or other forms of fuel) leads to an increased use of this fuel for cooking. A recent study that tested these assumptions could not provide any evidence of these links however (Orr *et al.,* 2013).

Other indicators such as *how many meals household members usually have each day, the supply of domestic energy, and the distance or time it takes to walk to collect firewood* could be other sample indicators for some types of IFES. However, it is important to be aware of the fact that it is difficult to attribute changes in these variables to a specific IFES.

Stability, in the context of IFES as explained above, can be expressed through the resilience and adaptability of a farming system. The more *diverse* a farming system is, and the more *diverse* the food products derived from the farm are, the more resilient the system will be to external shocks. We therefore suggest to apply the agrobiodiversity indicators (please refer to criterion 7 on agrobiodiversity) as a proxy – fully recognizing, however, that this indeed is only a very rough proxy indicator that can not reflect the entire extent of this criterion. Another proxy indicator for stability could be the *number of good practices* applied on farm that increase the resilience to extreme weather events such as droughts and heavy rainfall, and related occurrences such as disease and pest outbreaks. Methods to obtain this information could be a village timeline focusing on past shock events and how people responded.

When needed, as a complementary indicator for national or regional level assessments, we suggest to follow indicator 10 *Price and supply of a national food basket"* of the GBEP methodology (GBEP, 2011, p. 119 – 123). This assessment has been developed to assess *national* food security and not food security in the context of a *single farming system.* The methodology therefore needs to be modified accordingly. There are three ways to carry out the assessment and we recommend to follow approach 2 ("Tier II"), which is a causal-descriptive assessment of the role of bioenergy (in the context of other factors in the observed price increases and/or supply decreases). It is based on statistics and market surveys, and requires a multidisciplinary team of experts.

INDICATOR	DEFINITION	METHODOLOGY AND DATA REQUIREMENTS	MEASUREMENT UNITS
Change in the supply of food to the domestic market[a]	Change in the supply of food to the domestic market	Bioenergy and Food Security (BEFS) Operator Level Tool	N/A
Resource availability and efficiency of use[b]	Resource availability and efficiency of use	Bioenergy and Food Security (BEFS) Operator Level Tool	N/A
Physical displacement, change in access to resources, compensation and income generation[c]	Physical displacement, change in access to resources, compensation and income generation	Bioenergy and Food Security (BEFS) Operator Level Tool	N/A
Cooking frequency	The frequency of cooked meals per day	Survey	Numerical value
Meals consumed per day	Meals consumed per day	Household survey	Numerical value
Supply of domestic energy	Supply of domestic energy	Please refer to criterion on energy access	Numerical value out of 1 to 5
Distance or time it takes to walk to collect firewood	Distance or time it takes to walk to collect firewood	Household survey	Km or h
Agrobiodiversity	Agrobiodiversity	Please refer to criterion on agrobiodiversity	N/A
Good practices applied on farm to improve resilience	Number of good practices applied on farm to improve resilience	Focus group discussion to produce village timeline focusing on past shock events and how people responded; for further reference http://www.fao.org/docrep/w5830e/w5830e08.htm	Numerical value

a This indicator is a grouping of several issues as explained in more detail in FAO (2013).

b This indicator is a grouping of several issues as explained in more detail in FAO (2013).

c This indicator is a grouping of several issues as explained in more detail in FAO (2013).

CRITERION 2: ENERGY ACCESS

In order to measure energy access in IFES, we consider the energy access index developed by Practical Action (Total energy access standards |Practical Action, 2010) that determines the degree to which energy supply for household needs, electricity and mechanical power is assured. It assigns a numerical value to people's experience of accessing energy supplies, with 1 being the lowest and 5 the highest level of access.

The rapid assessment includes three indicators, namely:

- *Supply of domestic energy*, which describes the degree of access to cooking energy
  Level 1: Collecting wood or dung, using a three-stone fire
  Level 2: Collecting wood and using an improved stove
  Level 3: Buying wood and using an improved stove
  Level 4: Buying charcoal and using an improved stove
  Level 5: Using a modern, clean-burning fuel and stove combination
- *Supply of electricity*, which describes the degree of access to electricity
  Level 1: No access to electricity at all
  Level 2: Access to third party battery charging only
  Level 3: Own low-voltage DC access for home applications
  Level 4: 240 VAC connection but poor quality and supply
  Level 5: Reliable 240 V AC connection available for all uses
- *Supply of mechanical power*, which describes the degree of access to mechanical power
  Level 1: No access to mechanical power. Hand power only with basic tools
  Level 2: Mechanical devices available to magnify human/animal effort
  Level 3: Powered (renewable or fossil) mechanical devices
  Level 4: Powered (renewable or fossil) mechanical devices available for most tasks
  Level 5: Mainly purchasing mechanically

INDICATOR	DEFINITION	METHODOLOGY AND DATA REQUIREMENTS	MEASUREMENT UNITS
Energy supply household fuels	Energy access on the supply side for household fuels	Household surveys	Numerical value out of 1 to 5
Energy supply electricity	Energy access on the supply side for electricity	Household surveys	Numerical value out of 1 to 5
Energy supply mechanical power	Energy access on the supply side for mechanical power	Household surveys	Numerical value out of 1 to 5

CRITERION 3: ADAPTIVE CAPACITY TO CLIMATE CHANGE

Assessing the overall adaptive capacity of smallholders and their farming systems to climate change, is a very complex undertaking. Many different agronomic, environmental and socio-economic factors come into the equation – an exercise that goes beyond the scope of this analytical framework. This criterion therefore strictly refers to the contribution of IFES to the adaptive capacity of smallholders and their farming systems to climate change. Depending on the type of risk in a specific area (droughts, floods, frost) they need to be adjusted accordingly.

Two of the suggested indicators refer to risk of crop loss and the capacity of recover from such production loss:
- *Minimum, Maximum and average yield in driest years*
- *Time to recover from production loss*

Another indicator could be agrobiodiversity, as diverse systems have shown to increase the resilience of farming systems and therefore their adaptive capacity to climate change (see criterion 7 for more details):
- *Agrobiodiversity*

Another proxy indicator could be the number of good agronomic practices applied on farm to improve resilience:
- *Good practices applied on farm to improve resilience*

Last, but not least, a proxy indicator often used to assess the adaptive capacity to climate change is the income a farmer and his family have. This might depend on the products and income generated through IFES, but it could also come from other sources. This indicator therefore needs to be applied with caution. Income in this context relates to:
- *Income from wages through Integrated Food-Energy Systems*
- *Net income from the sale, barter and/or own consumption of the products from IFES*
- *Savings from reduced purchases of fossil fuels such as kerosene, LPG gas, or coal, and from charcoal*

This criterion is closely related to the criteria on food security, access to energy and agrobiodiversity.

INDICATOR	DEFINITION	METHODOLOGY AND DATA REQUIREMENTS	MEASUREMENT UNIT
Minimum, maximum and average yield in driest years	Minimum, maximum and average yield in driest years	Survey	t/ha
Time to recover from production loss (monetary or in terms of weight)	Time to recover from production loss from catastrophic events such as crop loss, forest fire or flooding in years	Survey	Years
Agrobiodiversity	Please see the criterion on agrobiodiversity.		
Good practices applied on farm to improve resilience	Number of good practices applied on farm to improve resilience	Focus group discussion to produce village timeline focusing on past shock events and how people responded; for further reference http://www.fao.org/docrep/w5830e/w5830e08.htm	Number
Income from IFES (wages)	Wages paid for employment in IFES operation	Data extracted from work contracts or through household surveys	Local currency unit per household/ individual per year
Income from IFES (sale, barter, own consumption)	Net income from the sale, barter and/or own consumption of the products from IFES	Household survey	Local currency units per household/ individual per year, and percentage (for share or change in total income)
Savings from reduced purchases of fossil fuels and/or charcoal	Savings from reduced purchases of fossil fuels such as kerosene, LPG gas, or coal, and from charcoal	Household survey	Local currency units per household/ individual per year

CRITERION 4: LAND TENURE SECURITY

According to FAO (2002), "**land tenure** is the relationship, whether legally or customarily defined, among people, as individuals or groups, with respect to land. (For convenience, "land" is used here to include other natural resources such as water and trees.) Land tenure is an institution, i.e., rules invented by societies to regulate behaviour. Rules of tenure define how property rights to land are to be allocated within societies. They define how access is granted to rights to use, control, and transfer land, as well as associated responsibilities and restraints. In simple terms, land tenure systems determine who can use what resources for how long, and under what conditions".

Tenure rights should eventually lead to **land tenure security** for people, guaranteeing legal protection against forced evictions that are inconsistent with States' existing obligations under national and international law, and against harassment and other threats (FAO, 2012). Hence, If IFES are to be sustainable, their owners need to hold certain land tenure security.

One can categorize different types of land tenure (FAO, 2002a):

- *Private*: the assignment of rights to a private party who may be an individual, a married couple, a group of people, or a corporate body such as a commercial entity or non-profit organization. For example, within a community, individual families may have exclusive rights to residential parcels, agricultural parcels and certain trees. Other members of the community can be excluded from using these resources without the consent of those who hold the rights.
- *Communal*: a right of commons may exist within a community where each member has a right to use independently the holdings of the community. For example, members of a community may have the right to graze cattle on a common pasture.
- *Open access*: specific rights are not assigned to anyone and no-one can be excluded. This typically includes marine tenure where access to the high seas is generally open to anyone; it may include rangelands, forests, etc, where there may be free access to the resources for all. (An important difference between open access and communal systems is that under a communal system non-members of the community are excluded from using the common areas.)

INDICATOR	DEFINITION	METHODOLOGY AND DATA REQUIREMENTS	MEASUREMENT UNIT
Security of private land rights	Existence of private land rights	Survey & content of national law and regulations pertaining to land and natural resource tenure	N/A
Security of communal land rights	Existence of communal land rights	Survey & content of national law and regulations pertaining to land and natural resource tenure	N/A
Security of open access rights	Existence of open access rights	Survey & content of national law and regulations pertaining to land and natural resource tenure	N/A

CRITERION 5: HEALTH
The indicator *Change in mortality and burden of disease attributable to indoor smoke* reflects the change from burning wood fuels, charcoal, animal dung or agricultural residues in traditional stoves or open fires to using woodfuels in improved stoves or modern bioenergy. The air pollution caused by excessive indoor smoke causes lung diseases, particularly for women and children who spent a lot of time indoors. Modern bioenergy, on the other hand, can reduce these risks and prevent almost 2 million deaths a year (UNDP and WHO, 2009). The indicator *Energy supply -household fuels* describes the type of energy households are using for cooking and heating. *This indicator has been described in more detail under criterion 2: Access to clean, reliable and affordable energy.*

INDICATOR	DEFINITION	METHODOLOGY AND DATA REQUIREMENTS	MEASUREMENT UNIT
Change in mortality and burden of disease attributable to indoor smoke	Change in mortality and burden of disease attributable to indoor smoke	Household survey which collects data on incidence of lung diseases	Number of sick household members, percentage
Energy supply - household fuels	Energy supply -household fuels	Energy access index as described above (see Criterion: Access to energy)	Numerical value out of 1 to 5

CRITERION 6: GENDER BALANCE

It is a challenge to disentangle the interactions between gender and sustainability and accordingly, finding appropriate indicators constitute a problem. For instance, in current literature, there is a "predominant focus on women rather than on gender relations and the tendency to take the category of "women" as a homogeneous entity, whose constituents are assumed to perform universal gender roles" (Martine & Villareal, 1997). However, keeping this in mind, one can choose from a wealth of suggestions of how to assess, monitor or evaluate the role of gender, and the gender balance of farming operations.

A recent World Bank publication on gender issues in monitoring and evaluation made several suggestions of how to assess the role of women in agricultural operations (World Bank, 2012). Some examples are listed below, recognizing that the role of gender and its indicators need to be tailored to each specific IFES case. Key to each gender indicator is the disaggregation of women and men during the measurement.

Alternatively to including a separate criterion on gender, one might opt to include gender considerations within each of the other criteria. This might be a more comprehensive, and at the same time, a more time and cost-effective way of considering gender in IFES sustainability assessments.

INDICATOR	DEFINITION	METHODOLOGY AND DATA REQUIREMENTS	MEASUREMENT UNIT
IFES managers/ farmers satisfied with agricultural services as a percentage of all IFES managers/farmers	Indicator related to knowledge systems and the role of extension services, which shows a percentage of IFES managers/ farmers satisfied with agricultural services as a percentage of all IFES managers/farmers, disaggregated by women and men	Survey	Percentage disaggregated by women and men
IFES managers/farmers who have adopted IFES	Indicator related to knowledge systems and the role of extension services, which shows the number of women and men IFES managers/ farmers who have adopted IFES	Survey	Number disaggregated by women and men
Day of training provided	Indicator related to knowledge systems and the role of extension services, which shows the number of days of training provided to women and men IFES farmers	Survey	Days disaggregated by women and men

CRITERION 7: AGROBIODIVERSITY
In order to measure agrobiodiversity, we suggest two indicators: • *Species Richness and* • *Diversity of Production.* As an indicator of *Species Richness,* we suggest the Margalef index as used by Funes-Monzote *et al.* (2009b), as a measure of species richness which combines the total number of species in the system and the total number of individuals. For the sake of this AF, species richness is calculated based on the total number of species of crops, trees and domestic animals; excluded, for this purpose, are soil biota, spontaneous vegetation or other plants and animals. The indicator *Diversity of Production* can be expressed in the Shannon index, which combines the number of products with the yield per product. Included are the yield of each separate farm output and that of the total system. The measures suggested for the rapid assessment based on proxy indicators are standard to calculate (agro)biodiversity. However, a comprehensive assessment usually includes ALL species found on farm, while the rapid assessment restricts itself to crops, trees and domestic animals. A comprehensive inventory of the entire farm is therefore needed, which would include not only crops and trees, but all plants on farm; and not only domestic animals, but also other mammals, birds, reptiles, amphibians and a variety of invertebrate groups such as different types of insects that are crucial for ecosystem functioning. This requires a team of specialized scientists, and accordingly, a relatively large amount of financial resources and time.

INDICATOR	DEFINITION	METHODOLOGY AND DATA REQUIREMENTS	MEASUREMENT UNIT
Species Richness	Species richness is calculated based on the total number of species of crops, trees and domestic animals; excluded, for this purpose, are soil biota, spontaneous vegetation or other plants and animals	Field sampling	Margalef index (according to Gliessmann, 2011)
Diversity of Production	Included are the yield of each separate farm output and that of the total system	Field sampling	Shannon index (according to Gliessmann, 2011)

CRITERION 8: SOIL HEALTH

When measuring soil health, soil organic carbon (SOC) is often used as a proxy. SOC can be an indicator of a soil's ability to hold water and to store and supply nutrients for plants. Carbon provides food for soil biological organisms and helps to maintain good soil structure. In addition, carbon stored in the soil is an ecosystem service that agricultural systems can provide to society, thereby reducing atmospheric carbon dioxide, a greenhouse gas. In some cases, one needs to go beyond this proxy where an assessment has identified significant risks, e.g. soil erosion, or soil compaction.

While SOC measurement is a relatively rapid and simple way of measuring soil health, it has to be noted, that soil characteristics need to be measured *over time* to give a meaningful result. Saby *et al.* (2008), for instance, assessed the feasibility of verifying the effects of changes in land use or management practice on SOC in some European countries, by comparing minimum detectable changes in SOC concentration. They came to the conclusion that only a time interval no shorter than *10 years* would enable the detection of some significant changes.

Using models can help to go round this dilemma. For instance, the CQESTR Model which is used to evaluate SOC stocks at field and farm scale, can perform long-term (up to 100 years) simulations. It is based on data inputs such as weather, above-ground and below ground biomass additions, soil properties and soil management factors (Gollany *et al.*, 2010).

One needs to be aware that one indicator as suggested below can only give a very rough idea of the real situation. Soil assessments are usually very comprehensive and require a significant amount of time and resources. There are plenty of protocols that explain how to conduct a comprehensive soil assessment. One example is the Cornell Soil Health Assessment Training Manual developed by the University of Cornell (Gugino *et al.,* 2009). It provides guidelines on how to conduct an in-field qualitative and quantitative soil health assessment based on 39 indicators.

INDICATOR	DEFINITION	METHODOLOGY AND DATA REQUIREMENTS	MEASUREMENT UNIT
Change of SOC content over time	1. Total land on which IFES is practised 2. Soil organic carbon content over time	*In-situ* measurements (see also GHG emission reduction protocol), together with a modelling exercise, i.e. with the CQESTR model	1. hectares or square metres 2. mg of organic carbon per g of soil sample

CRITERION 9: WATER USE EFFICIENCY AND QUALITY
As a proxy for water use efficiency, the indicator Water use technical efficiency is proposed as described by OECD (2001). It requires information on the physical mass of agricultural produce over the accounting period, and the volume of water diverted or extracted for irrigation, less storage and transmission losses and return flows, and excluding precipitation. To determine water quality, we choose three indicators as suggested by OECD (2001). The suggested indicators concern: • *Pollutant loadings to waterways and bodies of water attributable to mineral fertilizer and animal manure application.* Direct measurements of pesticides in surface or groundwater are not widely available, mainly because of the high costs of chemical analysis, and are therefore not covered here. The indicator, in the case of nitrate/phosphorous, is derived by taking sample concentrations of nitrate/phosphorous for groundwater and flow-weighted mean concentrations (mean concentrations per year) of nitrate (mg/l) for surface waters, in areas vulnerable to contamination from agriculture. The indicator reveals the share of the number of measurement points in vulnerable agriculture areas that are above national drinking (and/or environmental) water threshold values, as directly measured by national authorities. • *Microbial loads.* This indicator determines the bacterial contamination of water through animal waste and other products. It requires a bacterial analysis of water samples as described by Thurston-Enriquez *et al.* (2005). • *Pollutant loadings to waterways and bodies of water attributable to food and bioenergy processing.* The indicator measures the contamination with wastewater from food and bioenergy production facilities. A standard measure is the biochemical oxygen demand. It measures the amount of oxygen consumed by micro-organisms in decomposing organic matter in stream water, and is taken directly at the effluent discharge point.

INDICATOR	DEFINITION	METHODOLOGY AND DATA REQUIREMENTS	MEASUREMENT UNIT
Water use technical efficiency	For selected irrigated crops, the mass of agricultural production (tonnes) per unit volume of irrigation water utilized	The indicator requires information on the physical mass of agricultural produce over the accounting period, and the volume of water diverted or extracted for irrigation, less storage and transmission losses and return flows, and excluding precipitation.	t (produce)/l (irrigation water)
Pollutant loadings (fertilizer, manure)	Nitrate (or phosphorus) concentration in water: the proportion of surface water and groundwater above a national threshold value of nitrate concentration (NO3 mg/l) or phosphorus (P total mg/l)	The indicator, in the case of nitrate/phosphorous, is derived by taking sample concentrations of nitrate/phosphorous for groundwater and flow-weighted mean concentrations of nitrate (mg/l) for surface waters, in areas vulnerable to contamination from agriculture.	mg/l
Microbial loads	Microbial loads in water	Bacterial analysis of water samples	CFU/g
Pollutant loadings (biomass processing)	Pollutant loadings in food and bioenergy processing effluents	A standard measure is the biochemical oxygen demand.	mg/l

CRITERION 10: GHG EMISSIONS AND CARBON STORAGE

There are more than 100 different tools such as calculators, protocols and guidelines and process-based models which facilitate GHG accounting at a specific location, be it at farm or country level (Denef *et al.*, 2012): Calculators are automated web -, excel-, or other software-based calculation tools that can help to assess the GHG balance of a given farming system in a relatively easy and rapid way but they are usually tailored towards a specific situation. The multi-criteria GHG tool selector, an interactive website, can facilitate the choice of the right tool: http://www.fao.org/tc/exact/review-of-ghg-tools-in-agriculture/en/

Protocols can be understood as a description of different quantification methodologies for GHG accounting, which can be applied to any project, but require some expert knowledge to do so. The same is true for process-based models, which are process-based, empirical and mechanistic research models.

While many different tools for GHG assessments in agriculture exist, only few take the particularities of integrated farming systems into account. One of them is the Carbon Management Evaluation Tool for Voluntary Reporting of greenhouse gases (COMET-FARM). It serves as a calculator for farm level net emissions, and considers sustainable agricultural practices such as agroforestry and improved manure management. This automated web tool is tailored towards the context of the United States however, and therefore cannot be used in the context of IFES in *developing countries*. Nonetheless, it might serve to assess GHG fluxes from IFES in the US .

A more global approach has been taken by FAO who developed the Ex-Ante Carbon Balance Tool (EX-ACT), a land-based accounting system that is based on the Intergovernmental Panel on Climate Change methodology (IPCC). It estimates carbon stocks and stock changes per unit land and through time, and can be tailored to a particular farming system, including agroforestry, for instance (e.g. Bockel & Touchemoulin, 2011). EX-ACT offers the advantage of an integrated analysis of greenhouse gases, through its inclusion of a wide spectrum of activities concerning deforestation, afforestation and reforestation, land-use change and conservation, land degradation, annual crop production, agroforestry and production of perennial crops, irrigated rice as well as livestock production.

EX-ACT stimulates stakeholders to actively engage in scenario building exercises that compare different project and development options over time, possibly involving simulation and modelling. This engagement may lead to a clearer identification and reflection on the long-term goals and helps to adjust initial assumptions for their reasonability. We therefore suggest to apply the Ex-Act tool for a first assessment of the GHG balance in an IFES.

It needs to be noted however that while such tools are a relatively easy and rapid way of assessing a project's GHG balance, it is important to understand that to date, the IPCC does not provide emission factors and methodologies that account for integrated farming systems as a whole. In the case of an agroforestry system, for instance, most calculators consider one crop system next to a forestry system without taking the interactions between crops and trees into account (Colomb, 2012). This should be done within a more comprehensive assessment. For instance, a comprehensive guidance document to calculating emissions from agriculture has been developed by World Resources Institute. The *GHG Protocol Agricultural Guidance* includes guidance on accounting for the CO2 fluxes associated with the carbon stocks in agroforestry systems, short-rotation woody biomass plantations and forested conservation areas on farmland, including wood strips and riparian buffers. It looks at emissions sources upstream or downstream of primary production, CO2 fluxes to/from carbon stocks in soils as a result of agriculture or land-use change, CO2 fluxes to/from carbon stocks in biomass.

However, this protocol does not provide accounting methods for the CO2 emissions from the production and combustion of commercial biofuels. While the CH_4 and N_2O emissions from biofuel combustion should be reported in inventories, consensus on the accounting methodologies for CO_2 emissions has not yet materialized and requires the analysis of complex life cycle and indirect Land-Use Change. It does provide guidance on accounting for the combustion of biomass that is not sent beyond the farm boundary as biofuel stock, but, instead, is combusted on-site for energy production or other purposes. Chapter 9.3 of the GHG Protocol is particularly interesting for the sake of the IFES project as it provides guidance on accounting for the development of on-farm renewable energy projects.

Also, while this protocol is very comprehensive by nature, it does not account for the diversity and complexity of smallholder agriculture in developing countries (Rosenstock *et al.*, 2013). To tackle this complexity, the "Standard Assessment of Mitigation Potential and Livelihoods in Smallholder Systems" (SAMPLES) project has been developed by ILRI and ICRAF. The projects aims to develop a standard protocol for data collection, analysis, and interpretation of the greenhouse gas balance and livelihood indicators for smallholder systems at the whole-farm and landscapes scales (Standard Assessment of Mitigation Potential and Livelihoods in Smallholder Systems (SAMPLES) | World Agroforestry Centre., n.d.). and a first draft is expected to be published end of 2013.

INDICATOR	DEFINITION	METHODOLOGY AND DATA REQUIREMENTS	MEASUREMENT UNIT
C- stocks and stock changes per unit of land	C- stocks and stock changes per unit of land	The Ex-ACT tool requires data on land use, agricultural practices, areas in ha, and the amount of inputs.	tCO2e/ha

CRITERION 11: PROFITABILITY			
For this analytical framework, five indicators have been selected to measure the profitability of integrated food and bioenergy production: • Net revenue per hectare of utilizable land area • Net revenue per family work unit • Benefit/cost ratio • Income • Savings from reduced purchases of fossil fuels			
INDICATOR	**DEFINITION**	**METHODOLOGY AND DATA REQUIREMENTS**	**MEASUREMENT UNIT**
Net revenue per hectare	Net revenue per hectare of utilizable land area	Survey	Local currency/hectare
Net revenue per family work unit	Net revenue per family work unit	Survey	Local currency/family work unit
Benefit/cost ratio	Benefit/cost ratio	Survey	N/A
Income	Wages paid for employment in IFES operation	The average wage paid can either be extracted from current work contracts or through interviews with the employees.	Local currency unit per household/ individual per year
	Net income from the sale, barter and/or own consumption of the products from IFES	Data can be collected through household surveys and/or sales contracts of products. Additional costs such as fertilizer or labour need to be subtracted from gross income. The value of barter or own-consumption of IFES products may be obtained through specially designed household surveys as described in Carletto *et al.* (2007).	Local currency units per household/ individual per year, and percentage (for share or change in total income).
Savings from reduced purchases of fossil fuels or charcoal	Savings from reduced purchases of fossil fuels such as kerosene, LPG gas, or coal, and from charcoal	Survey	Local currency per household/individual per year

CRITERION 12: ENERGY USE EFFICIENCY
The energy efficiency of a productive system can be measured as net energy, energy output/input or energy productivity (Moreno *et al.,* 2011), although the majority of available literature describes an energy output/input ratio (Bogdanski, *unpublished manuscript*). The revised studies differ in the factors included and the units measured however. Energy inputs can be broadly subdivided into industrial inputs such as fossil fuels, electricity, and energy used to produce chemical fertilizer, pesticides and machineries, and biological inputs such as labour, animal power and organic manure as done by Jianbo (2006). Other approaches distinguish between direct energy inputs (e.g. fossil fuel for agricultural machinery) and indirect inputs (e.g. chemical fertilizer production) (e.g. Bailey *et al.*, 2003). Some studies calculate the input/output ratio on the basis of calories or joules (e.g. Moreno *et al.,* 2011), others take a mixed approach (calorie in – kilograms out) (e.g. Bailey et al 2003). We suggest the following three indicators to determine energy use efficiency: • Total Energy Inputs • Energy cost of protein (food) • Energy use efficiency

INDICATOR	DEFINITION	METHODOLOGY AND DATA REQUIREMENTS	MEASUREMENT UNIT
Total Energy Inputs	Energy value of all inputs directly used for production purposes	Surveys at field level	GJ/ ha and yr
Energy cost of protein (food)	Total energy used for production divided by total protein output (i.e. Total Energy inputs x 1000/ total protein in ag. products)	Surveys at field level	MJ/ kg
Energy use efficiency	Ratio between energy outputs and inputs	Surveys at field level	GJ output/ GJ input

CRITERION 13: WORKLOAD AND EMPLOYMENT CREATION
• In order to measure the workload in relation to food and bioenergy produced and income generated, we suggest the following three indicators: • Income generated per unit labour • Food produced per unit labour • Bioenergy feedstock produced per unit labour Furthermore, the indicator • Change in time collecting biomass can help to determine how much time women and children spent on collecting fuelwood for cooking and heating. In particular, the indicator shows the change in unpaid time spent by women and children collecting fuelwood as a result of switching from collected fuelwood to producing fuelwood on their own land or using modern bioenergy. Regarding employment creation, there is much variation in current literature regarding the way the term employment or job is defined (GBEP, 2011). For the sake of this AF, employment indicators will refer to: • Wage and salaried workers • Self-employed workers, including outgrowers contracted by a business • Contributing family members, even if not paid When defining the scope of the IFES project, one might draw the boundaries of the project to food and bioenergy feedstock production. Hence, on-farm labour needs to be considered. In specific cases, the scope might be extended when projects also include biomass conversion and processing, and the production, operation and maintenance of bioenergy equipment (for instance biogas digesters). In these cases, also labour involved in the processing stages need to be included. Furthermore, IFES operations may create indirect jobs in addition to those who are directly employed.

INDICATOR	DEFINITION	METHODOLOGY AND DATA REQUIREMENTS	MEASUREMENT UNIT
Income generated per unit labour	Income generated per unit labour	Surveys at field level	USD/hr or yr
Food produced per unit labour	Food produced per unit labour	Surveys at field level	Kg/hr or yr
Bioenergy produced per unit labour	Bioenergy produced per unit labour	Surveys at field level	Kg/hr or yr
Change in time collecting biomass	Change in unpaid time spent by women and children collecting fuelwood as a result of switching from collected fuelwood to producing fuelwood on their own land or using modern bioenergy.	The WFP handbook on safe access to firewood and alternative energy provides a set of different other tools which could be applied to collect data for this indicator. http://documents.wfp.org/stellent/groups/public/documents/newsroom/wfp252989.pdf	Hours per week per household, percentage
Net employment, creation of wage and salaried workers	Net employment, creation of wage and salaried workers	Number of jobs created annually gathered through interviews and surveys or stakeholder/ industry information at the field or household level.	N/A
Net employment creation of self-employed workers, including outgrowers contracted by a business.	Net employment creation of self-employed workers, including outgrowers contracted by a business.	Number of jobs created annually gathered through interviews and surveys or stakeholder/ industry information at the field or household level.	N/A
Net employment of contributing family members, even if not paid	Net employment of contributing family members, even if not paid	Number of jobs created annually gathered through interviews and surveys or stakeholder/ industry information at the field or household level.	N/A

ANNEX C: A MIXED METHODS APPROACH FOR ASSESSING THE REPLICABILITY OF IFES

ANSWERING QUESTION 1: ENABLING OR CONSTRAINING PROJECT FEATURES

We identified seven project features that simplify or complicate the upscaling of IFES (table I). Those that simplify the upscaling of IFES are considered strengths, those that complicate its adoption are considered weaknesses. In the following sections we suggest a couple of lead questions that help to describe each feature, provide detailed explanations of each issue where deemed necessary and point to relevant literature. To answer some of the questions, a survey with the main stakeholders will be required. Other features might benefit from the use of specific methodologies or tools which are presented where appropriate.

TABLE I.

PROJECT FEATURES AND SUGGESTED METHODOLOGIES

FEATURES	SUGGESTED METHODOLOGIES
i. Clarity and Credibility	Survey using questionnaire
ii. Legitimacy	Survey using questionnaire
iii. Ease in assessing results	Survey using questionnaire
iv. Business Model, including financial viability	Survey using questionnaire; optionally, specific analytical frameworks
v. Alignment and Linkage	Literature review and semi-structured interviews
vi. Complexity, Coordination and Behaviour Changes	4 R approach, semi-structured interviews
vii. Workload	Survey using questionnaire, semi-structured interviews

The features i. to vii. can be described by doing a survey among the target group, using a simple questionnaire, which might require some additional background research. Potential questions to be posed are listed in the sample questionnaire presented below.

Some data collection needs to go beyond a simple questionnaire, for example for feature iv on *the Business Model and Financial viability*. Here some additional tools and analytical frameworks might be helpful. Other features would benefit from semi-structured interviews as specified in table I above.

SAMPLE QUESTIONNAIRE TO ELUCIDATE DATA ON PROJECT FEATURES

1. CLARITY AND CREDIBILITY	a	b	c	d	e
	No evidence	A few success stories	Solid evidence	A wealth of evidence	
1.1. Is there scientific evidence that this project type will succeed?					
1.2. Is the person or agency implementing the IFES respected and trusted. Does it have a record of success?					
2. LEGITIMACY	a	b	c	d	e
	The farmer/ local entrepreneur	Local NGO/ agency	Government	Company	If other please specify
2.1. Who has the ownership of the project?					
	Target group	NGO	Government	Company	If other please specify
2.2. Where has the project idea originated from?					
2.3. Have all stakeholders been involved in consultations during the course of IFES planning?					
3. EASE IN ASSESSING IFES RESULTS	a	b	c	d	e
	Immediately	No later than one month	No later than one year	More than one year	Not visible at all
3.1. How long after project implementation until the first results/ changes are visible?					
4. BUSINESS MODEL INCLUDING FINANCIAL VIABILITY	a	b	c	d	e
	Yes	No			
4.1. Does the project build on a business model?					
	Yes	Only with government support	Only with donor support		
4.2. Is the project financially viable?					

5. ALIGNMENT AND LINKAGE	a	b	c	d	e
Please refer to the policy section					
6. TECHNICAL COMPLEXITY, COORDINATION AND BEHAVIOUR CHANGES	**a**	**b**	**c**	**d**	**e**
	No help needed	Local service provider/ extension branch	National specialists	Foreign Specialists	
6.1. Due to the technical complexity of the project, the farmer/entrepreneur requires technical help from….					
	No help needed	Local service provider/ NGO/ community service	National coordinators	External help from project implementer/ donor agency	
6.2. Due to the organizational complexity of the project, the farmer/ entrepreneur requires help in coordination from…					
	Completely new	Some new features	Exclusively well-know practices		
6.3. Is the new project a completely new activity for the main stakeholders or does it build on old, and well-known practices?					
7. WORKLOAD	**a**	**b**	**c**	**d**	**e**
	Less than before	Equal	More		
7.1. The workload of the new project is…					

ANSWERING QUESTION 2: THE ROLE OF STAKEHOLDERS AND INSTITUTIONS

We identified five key stakeholder features to determine the role of stakeholders and institutions in the scaling up of IFES (table II). As experience has shown, the main target group holds the key to success or failure of a project but is highly influenced by stakeholder interactions. This section will therefore be subdivided into the **perspectives of each stakeholder group** (features i-iv in table II and section 2.1.) and the **quality of their interaction** (feature v in table II and section 2.2.).

TABLE II.

STAKEHOLDER FEATURES

	METHODOLOGIES
i. Target group/Main actor	Participatory Rural Appraisal techniques and semi-structured interviews
ii. Implementing organization	semi-structured interviews
iii. Supporting organization	semi-structured interviews
iv. Champions	semi-structured interviews
v. Quality of stakeholder interaction	'4 R' approach

2.1. STAKEHOLDER PERSPECTIVES

Participatory Rural Appraisal (PRA) techniques facilitate the capture of the perspectives of the main target group (e.g. farmers) to inform the implementation and management of IFES. PRA further provides scope for all involved to learn from each other. They are principally used in the extraction of qualitative data.

PRA consists of a variety of tools, such as focus group, interviews, mappings and the design of diagrams supported by a trained facilitator. There is a large array of handbooks, manuals and academic papers that introduce the different tools, and explain how to use them. While it would go beyond the purpose of this document to present them all, it might be worth to have a look at a short paper by Chambers (1994) and at the FAO Participatory Rural Appraisal Manual developed by Paul (2006) which give a good overview of different tools and their application to assess farmers' perspective on integrated pest and nutrient management, a concept inherent in IFES.

For the sake of this AF, we suggest the use of both PRA techniques and semi-structured interviews to elucidate **farmers perspective on IFES**, as follows below:

2.1.1. Participatory Rural Appraisal techniques to elucidate Farmers' and community members' views on issues surrounding IFES adoption and IFES impacts

Participatory Rural Appraisal (PRA) is a set of approaches and methods for understanding and assessing the local context and the livelihoods of people and social groups within a particular geographical area (Chambers, 2008). PRA evolved in the late 1980s from Rapid Rural Appraisal (RRA), which – similar to PRA – encompasses a collection of techniques for rapid yet locally grounded data collection in rural areas of developing countries. Both approaches were developed in response to the more common usage of standardized questionnaires by statisticians and economists on the one hand and the in-depth approach of social anthropologists (Chambers, 2008). RRA/PRA was seen as a way to avoid both costly quantitative questionnaire surveys as well as drawn-out anthropological field studies both of which sometimes led to misleading results (Chambers, 2008).

While the aim and purpose varies, a PRA is usually considered a process in which an external researcher from a development programme, NGO or university helps communities to:

- Gather information on the resources they already possess
- Organize their knowledge
- Identify and prioritize local development needs
- Develop action plans in order to respond to needs (PFD, 1999)

Carrying out a PRA usually involves three major steps: selection of the community or village in which to apply the PRA; a preliminary visit to the village; and the actual application of the PRA (Selener *et al.* 1999, 16).

The main difference between PRA and RRA is the level of participation by local people. RRA is characterized by a more extractive process where the process of generating data is led by an external actor[7] while in PRA it is local people, especially the poor and marginalized, who own the process and map, make diagrams, analyse and act (Chambers 2008). Table III shows the continuum from RRA to PRA.

TABLE III.

FROM RRA TO PRA. ADAPTED FROM CHAMBERS (1994, 959)

MODE OF DATA COLLECTION	EXTRACTIVE	ELICITIVE	SHARING	EMPOWERING
Role of the researcher	Purely investigator	Mainly investigator	Mainly facilitator	Purely facilitator
Ownership of data	Outsiders	Mainly outsiders	Both local people and outsiders	Local people
Methods used	Mainly RRA plus sometimes PRA	A mix of RRA & PRA	A mix of PRA & RRA	Mainly PRA plus sometimes RRA

RRA and PRA methods overlap to a certain degree with the former favouring the use of secondary sources combined with verbal interaction (e.g. semi-structured interviews) and the latter placing greater emphasis on shared visual representations and analysis with and by local people (Chambers, 1994). RRA and PRA methods include the following (Chambers, 1994):

- Analysis of secondary sources (maps, aerial photographs, satellite imagery and documents)
- Key informant interviews (selecting and interviewing (local) experts on pertinent topics)
- Group/Focus interviews (see example of questions to be asked below in Box I)
- Do-it-yourself (local work tasks carried out by the researcher)
- They do it (engaging local people in carrying out transect walks, interviews, data analysis and presentations)
- Participatory analyses of secondary sources (often aerial photographs)
- Participatory mapping and modelling (e.g. social and natural resource mapping using local materials or paper)

7 http://www.iisd.org/casl/caslguide/rapidruralappraisal.htm

- Transect walks (walking with local people through an area while observing and listening; discussing various features such as soils, land uses and introduced technologies; discussing problems, solutions and opportunities; and mapping the results of observation and discussions)
- Timelines and trend analysis (e.g. village timelines that record important events in the history of the village; drawing/mapping of trends and changes in land use and fuels used; and the causes of these changes
- Local/Oral/Life histories (loosely-structured interviews with local people about a particular topic of relevance to local livelihoods and village life, e.g. introduction of a tree species or technology)
- Daily time use analysis (recording the relative time spent on particular activities, workload and level of drudgery)
- Livelihood analysis (analysis of livelihood strategies during stable, crisis and recovery periods often analysed by month or season)
- Venn diagrams (diagrams made using local materials or paper identifying persons or institutions important to the community in relation to a specific activity (e.g. implementation of an IFES)
- Well-being/Wealth ranking (ranking and placement of households in a village into groups according to well-being (Grandin, 1988). This approach can be tailored to a specific topic and allows follow-up questions about why the particular group is well off or not, which assets they posses, differential access to resources, etc.)
- Matrix scoring and ranking (comparing trees, soils, farming techniques, fuel types, etc.)
- Seasonal calendars (calendars created by community members that show changes in labour availability, crops planted, soil conditions, precipitation, food consumption, fuel availability, prices, income, etc.)

Box I presents an example of focus group interviews and potential questions to be asked

BOX I.

OPEN ENDED QUESTIONS FOR FOCUS GROUP INTERVIEWS

The focus group interview is a useful PRA method which can be used to obtain communities' and farmers' views on issues surrounding IFES adoption and IFES impacts. They can also be a good opportunity for farmers implementing IFES to share their experience with other farmers who might be interested in these farming systems. We suggested some open questions which could be used to this end:

(a) Regarding IFES adoption (ex-ante stage)

- Why did you adopt IFES?
- What constraints did you face in implementing your IFES?
- How did you overcome these constraints?
- What would you recommend to farmers who wish to adopt IFES?

(b) Regarding IFES impacts (ex-post)

- What impacts has IFES had on your farming system?
- What impacts has IFES had on your livelihood?
- What have you done or will you do to reduce the negative impacts of IFES?
- If you had to start again what would you change?

Box II presents an example of a PRA technique that can be used for assessing problems and opportunities associated with an IFES.

BOX II.

COMMUNITY AND FARM TRANSECTS FOR ASSESSING THE REPLICABILITY OF IFES

A transect walk can enable the researcher and members of a community or household to assess the distinct production characteristics of an IFES and how it is linked to other components of a community or landscape including the problems and potentials associated with the IFES.

The facilitators and local inhabitants go on a walk through a section of the farm or community which includes the greatest ecological diversity. Along this route the most prominent characteristics are noted and facilitators should carefully note and record what local people point out and comment on during the walk, especially changes, problems and opportunities.

After the transect walk, a transect diagram is made with local people based on what they remember and what the facilitators have written down.

In the diagram, the terrain encountered on the route is mapped in the top part of a sheet of paper including topography, crops for feed, fuel and food, rivers and location of homes. On the left-most side of the diagram a column is made which lists the most important characteristics to be analysed for each part of the landscape (e.g. soils, land use, water use, infrastructure, problems and opportunities). These characteristics are then analysed in detail for each landscape in the next columns.

For a single farm or IFES it will take 1-2 hours for both the transect walk and diagram.

Adapted from Selener (1999, p. 62-63).

POTENTIAL RISKS AND LIMITATIONS OF USING PRA

A number of risks and limitations are associated with the use of PRA techniques. These may be present to varying degrees depending on the scope, purpose and nature of the study being conducted. Transparency and honesty when working and interacting with community members and local households can do a lot to mitigate some of the risks associated with the use of PRA.

First, there is often a risk of raising false expectations in the community (Selener *et al.* 1999, 6). People may expect or assume that money, investments or project interventions will naturally follow after researchers have spent time in a village or community conducting PRAs. PRAs do not guarantee immediate action or results but do identify problems and solutions (Selener *et al.* 1999). Hence it is important to clearly state the purpose and aim of the PRA before engaging with the community or individual households.

Second, the rapid nature of PRA can limit the quality and degree of trust established between the researcher and the community, can result in superficial or even false information being obtained and can mask existing power relations and local political forces. Furthermore, certain sectors and social groups may not be well-represented (e.g. women and ethnic minorities). Also, the speed of the PRA can sometimes negatively affect the quality of participation of community members while in other cases the community and/or households may simply not be interested in participating (Selener *et al.* 1999, 6-7).

Third, group level analysis – which is often the dominant mode in PRA – does not allow for individual perceptions or interpretations. Conversely, PRAs are usually carried out at the community level while there is little experience in applying it at larger scales such as the province, region or watershed level (Selener *et al.* 1999, 6).

Finally, information is sometimes extracted for the benefit of a researcher or the organization he/she is working for, rather than for the community (Selener *et al.* 1999, 6).

In order to mitigate some of the above risks it is important to keep the following points – as advised by Chambers (1995) in mind:

- Maintaining professional ethics and personal responsibility when interacting with communities
- Having a self-critical attitude and seeking peer review of results
- Ensuring good quality PRA training and especially that social differences at the local level are taken into account
- Learning from past experiences, both success and failures

2.1.2. Semi-structured interviews to elucidate Farmers' acceptance and perception of IFES

Complimentary to these participatory workshops, we propose to conduct semi-structured interviews with the main stakeholders of IFES, e.g. the farmers and their communities. These interviews should not follow a rigid, quantitative format but allow the respondent to elaborate on certain issues. Semi-structured interviews have gained prominence as an alternative or supplement to lengthy, large-scale, quantitative questionnaires used in development studies (Mikkelsen 2005, 89). Semi-structured interviews use open-ended questions and are based on written or memorized checklists which allow unexpected yet relevant issues to be explored. These issues can be followed up using further, probing questions (Mikkelsen 2005, 89).

Semi-structured interviews can be used for key informants, household members or in a group setting. Groups can consist of either homogenous or mixed groups of people in a community (Mikkelsen 2005, 89). Certain questionnaires also incorporate elements of the semi-structured interview and contain both closed-ended and quantitative questions as well as open-ended questions.

The sample interview guide proposed below (Box III) should be used following the prompts and probes approach. *Prompts* refer to issues that the interviewer may need to remind the interviewee about. *Probes* refer to getting the interviewee to say more about a particular topic, if it is of particular interest to the specific project. Additionally, we suggest to also hold semi-structured interviews with the other stakeholders, i.e. the implementing and the supporting organizations and the champions, if possible.

BOX III.

INTERVIEW GUIDE FOR INDIVIDUAL SMALL-SCALE FARMERS (HEADS OF HOUSEHOLDS)

This interview guide is designed to ascertain the strengths, weaknesses, opportunities and threats that the respondent has experienced during and after the process of implementing an IFES. This semi-structured interview guide is designed to uncover changes in access to energy and food, changes in the workload involved in food and fuel production, perceptions of ownership of implementation and support institutions that have been most important in the implementation of an IFES.

This interview guide can be used as an initial exploratory tool and the data generated can be used to develop a structured questionnaire. NVivo7, MAXqda, Atlas.ti5 and other qualitative research software can be used to analyse the data recorded (Lewins & Silver 2007).

Date:
Location (Province, District, Village, Sub-village/hamlet/neighbourhood):
Name:
Age:
Gender:
Ethnicity:

This interview is designed to better understand the changes that have occurred as a result of the implementation of the IFES. The information you provide will be used to understand whether an IFES similar to the one you have implemented may be replicated in other geographical areas with similar [natural and socio-economic] conditions. All of your answers will be anonymous.

1. PAST ENERGY USE AND NEEDS

1.1 Does [your IFES] provide fuel for domestic energy and productive purposes? *If no, please proceed to 1.5*
1.2 What were the main sources of fuel and fuel technology for household use *prior to* the implementation of [your IFES[a]]? (probes: fuelwood, charcoal, agricultural waste/residues, biogas, cooking, heating)
1.3 Which general and particular constraints did you face in securing energy for all domestic and productive uses for the household *prior to* the implementation of [your IFES]? (probes: financial capital, lack of time)
1.4 Were these constraints mitigated after the implementation of [your IFES]? If so, how were they mitigated?
1.5 Does [your IFES] produce fuel products for the market? If yes, which products?

2. PAST FOOD PRODUCTION

2.1 Which were the main crops your household cultivated before the implementation of [your IFES]? Were they for the market or for subsistence?
2.2 Did your household start to plant new crops along with the implementation of [your IFES]? Why?
2.3 Are the [IFES] crops you currently cultivate for the market or for subsistence?
2.4 Which challenges have you experienced in producing food for the household and market after the implementation of [your IFES]?

3. IMPLEMENTATION OF [THE IFES]

3.1 Why did you decide to implement [your IFES]?
3.2 Which general and particular constraints did you face in implementing [your IFES]? (probes: financial capital, lack of time, complexity of the project)
3.3 Which factors made the implementation of the IFES easy? Which factors made the implementation difficult? (probes: upfront costs, labour required, simplicity of the project)
3.4 Did other people in your community replicate the IFES without project/external support? What reasons did they give for replicating?

4. WELL-BEING AND ECONOMIC IMPACTS OF IFES

4.1 Which changes, if any, in the health of the members of your household have you experienced as a result of the implementation of [your IFES]?
4.2 What are some of the changes, if any, in household income from food production that you have experienced as a result of the implementation of [your IFES]? (probes: increased income, decreased income, diversification of income sources)
4.3 What are some of the changes, if any, in household income from the production and selling of fuel products? (probes: increased income, decreased income, diversification of income sources)
4.4 What are some of the changes, if any, in household income from the production and selling of other products? (probes: wood products, animal feed, increased income, decreased income, diversification of income)

4.5 Do you feel that members of your household work more hours on food production than before the implementation of [your IFES]? (probes: changes in the level of drudgery, changes in the level of hard, manual labor)
4.6 Do you feel that you and members of your household are working more hours on collecting/acquiring fuel than before the implementation of [your IFES]? (probes: distance travelled to collect firewood, residues, etc.
4.7 Do you feel that you and members of your household are working more hours on producing other products than before the implementation of [your IFES]?

5. SUPPORT INSTITUTIONS AND OWNERSHIP

5.1 Did you implement [your IFES] with financial support from specific institutions and organizations? If yes, from which entity did you receive financial support?
5.2 Did you implement [your IFES] with technical support from specific institutions and organizations? If yes, who provided the technical support?
5.3 Do you and members of your household feel that you have sufficient skills and knowledge to maintain activities associated with [your IFES]?
5.4 What kind of technical and financial support, if any, do you currently need to maintain [your IFES]?

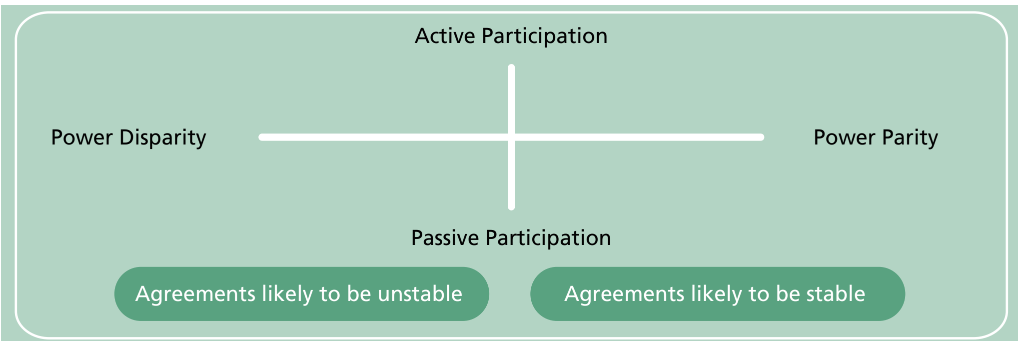
a The interviewer would state the name of the particular IFES, e.g. an agroforestry system of Acacia mangium and cassava or a Three-in-One Biogas system.

2.2. THE QUALITY OF STAKEHOLDER INTERACTIONS

To determine the quality of stakeholder interaction, we suggest to use the '4 R' approach - rights, responsibilities, revenues and relationships - developed by Dubois (1998). The 4 R approach can be used for the purpose of analysis/diagnosis or for the purpose of negotiation. It builds on the experience, that generally speaking, participatory approaches, village development plans and local development committees do not ensure sustainability of project outputs and outcomes. Indeed, project initiatives are often ill-equipped to tackle issues pertaining to the '4Rs' and power relations, and these are key to achieve stable agreements, whatever the quality of participation as illustrated in Diagram I.

DIAGRAM I.

The importance of power issues on the quality of agreements



The 4 R approach builds on the following logic:

(i) General trends in Land and Natural Resource Management indicate that power deficits can be better evaluated once the roles of the various actors are clarified and accepted.

(ii) The notion of actors' roles needs to be put into practice, and power differentials between the actors concerning natural resource issues must be taken into account.

(iii) It is difficult to directly evaluate the power of actors (power differentials are often noticed after negotiations).

(iv) Levels of power can be evaluated indirectly through the roles played by the actors. Moreover, in an era of shared management of natural resources, capacity building to that end requires an agreement on stakeholders' roles.

(v) Stakeholders' roles can be defined by their '4Rs', i.e

- Balance of Rights, Responsibilities and Revenues/Returns, and
- Relationships

The below example stems from a charcoal project in Lukolongo, Zambia. The analysis of actors' 3R imbalances (Table X) shows that:

- Farmers: Revenues from the forests are low and permits/plans are required
- Private operators: Not enough responsibilities relative to rights and revenues
- Forestry Service: Revenues/resources low compared to responsibilities

TABLE IV.

MATRIX OF THE '3RS' (RIGHTS, RESPONSIBILITIES AND REVENUES)

ACTORS\'3RS'	RIGHTS	RESPONSIBILITIES	REVENUES
Small farmers	Forest usage rights Use of land for farming Sales of forest products if allowed	"Caretakers" of the land and natural resources	Subsistence from the forest Income from farm products and some forest products
Woodcutters / charcoal manufacturers	Cutting wood	None	Income from selling charcoal and/or wages from cutting wood
Charcoal traders	Selling charcoal	None	Income from selling charcoal
Fishermen	Fishing	None	Income from fishing
Forestry Service	Collecting forest use fees	Managing the forests Enforcing regulations	Income from forest use fees

These rights, responsibilities and revenues result in specific interactions between the single stakeholders as shown in Table V.

TABLE V.

RELATIONSHIPS BETWEEN ACTORS IN LUKOLONGO, ZAMBIA. TYPES OF RELATIONSHIPS: TECHNICAL: TECHNICAL SUPPORT AND SHARING OF KNOWLEDGE; FINANCIAL: LACK OF FAIRNESS AND EMBEZZLEMENT LIKELY IF THERE IS NO ARBITRATOR; REGULATORY: MUST OFFER INCENTIVES TO BE EFFECTIVE; INFORMAL: SAVES TIME AND MONEY, BUT SHORT-TERM AND UNFAIR ARRANGEMENTS ARE THE FREQUENT OUTCOME

	FARMERS	WOODCUTTERS	CHARCOAL TRADERS	FISHERMEN	FORESTRY SERVICE
Farmers					
Woodcutters	Poor Informal				
Charcoal traders	Poor Informal	Financial Informal/formal			
Fishermen	Poor Informal	Poor Informal	Poor Informal		
Forestry Service	Technical/ Regulatory Informal/formal	Technical/ Regulatory Informal/formal	Regulatory/ Financial Informal/formal	Regulatory/ Financial Informal/formal	

ANSWERING QUESTION 3: THE POLICY AND LEGAL ENVIRONMENT

In order to identify policy and legal factors that contribute to or hinder the upscaling of IFES, the project seeks to screen existing policy instruments and determine their effectiveness and level of implementation for each case study. This will be done through a literature review and targeted interviews with employees of ministries and other relevant stakeholder groups such as farmers and NGOs. Table VI gives an overview of the methodologies used to assess the policy instruments in each policy area.

TABLE VI.

AREA OF POLICY INTERVENTION

	METHODOLOGIES
Research and development (R&D)	Literature review and targeted interviews with actors in rural schools, universities and the ministries of education, agriculture, etc
Technology deployment	Literature review and targeted interviews with experts, i.e. actors in the industry and the ministries of industry/ technology, energy etc
Building of human capacity	Literature review and targeted interviews with actors in rural schools, universities and the ministries of education, agriculture, etc
Resource and property rights, incl. secure land and resource tenure	Literature review and targeted interviews with land owners, actors from land registries, personnel from ministries etc
Encouragement of good and discouragement of bad environmental behaviour	Literature review and targeted interviews with personnel from environmental offices in local governments, the ministries of environment, agriculture, forestry etc. and local people who may be blamed for environmental degradation by governmental agencies
National or regional production targets	Literature review and targeted interviews with personnel from the ministries of energy, agriculture and forestry
Other areas	Literature review and targeted interviews

Table VII displays a screening form to track relevant policy instruments that support or hinder the uptake of IFES. It can be used for both the literature review and the targeted interviews. Some examples for the goal ”GHG emission reduction” is given to allow a better understanding of how to use the screening form.

TABLE VII.

SCREENING FORM TO TRACK RELEVANT POLICY INSTRUMENTS THAT SUPPORT OR HINDER THE UPTAKE OF IFES WITH AN EXAMPLE ON GHG EMISSION REDUCTION

GOAL	AREA OF POLICY INTERVENTION	TYPE OF INSTRUMENT	EXACT TITLE OF INSTRUMENT	APPROACH	ADDRESSEE	EFFECTS ON THE UPSCALING OF IFES
GHG emission reduction	Encouragement of good environmental behaviour	Fiscal Incentive	European Union Emissions Trading System, EU	Emission trading (Cap and Trade System)	Power plants, a wide range of energy-intensive industry sectors and commercial airlines in the EU	Indirectly: Promotes the deployment of biofuels in the aviation sector, some of which will care for sustainable production.
GHG emission reduction	Encouragement of good environmental behaviour	Fiscal incentive	The Environmental Services Payments Program, Costa Rica	Carbon tax (3.5%)	Fossil fuel users in Costa Rica	Indirectly: Carbon intensive products such as nitrogen based fertilizers will become more expensive. This might encourage farmers to apply cheaper, organic fertilizers.
GHG emission reduction	Encouragement of good environmental behaviour	Fiscal incentive	Clean Development Mechanism	Emission trading (Project)	Actors in Annex 1 countries (as specified by the UNFCCC) that need to meet GHG emission reduction targets	Directly: Some CDM projects are IFES projects, which generate carbon credits and thereby incentivize their replication.

ANSWERING QUESTION 4: HUMAN AND TECHNICAL CAPACITY

The analysis of the available human and technical capital can be a complex and lengthy process. It requires expertise from several fields and good knowledge of the target region where the upscaling of IFES is to take place. The answer of how does human and technical capacity shape the replication of IFES requires a set of semi-structured interviews with different stakeholders from public and private entities. Interviews with staff from the international cooperation sector are also recommend (see table VIII).

TABLE VIII.

HUMAN AND TECHNICAL CAPACITY AND THE NATURAL RESOURCE BASE

	METHODOLOGIES
Technical capacity	Semi-structured interviews; see also section 3 on policy analysis
Institutional know-how and management capacities	Semi-structured interviews; see also section 3 on policy analysis
Education, training and knowledge transfer	Semi-structured interviews; see also section 3 on policy analysis

ENVIRONMENT – CLIMATE CHANGE – BIOENERGY – MONITORING AND ASSESSMENT

FAO - ENVIRONMENT AND NATURAL RESOURCES MANAGEMENT WORKING PAPER

Bioenergy when *managed sustainably* and *efficiently* can be an alternative energy source that helps reduce energy access problems. Rural and urban communities can benefit from increased access to energy, and therefore improved food security when bioenergy feedstock is produced guided by principles of sustainable production intensification and energy efficiency improvements are made by applying agro-ecological practices and locally adapted technologies..

To mitigate the risks of bioenergy production threatening food security and to harness the potential benefits of bioenergy productionFAO recommends appling good practices of bioenergy production from the onset. The production of bioenergy in Integrated Food-Energy Systems (IFES) is one of such good practices since these systems meet both food and energy demands.

This publication presents an analytical framework which serves to screen different IFES options systematically and helps to define which IFES systems are sustainable and replicable. In concrete terms, this framework is envisioned to be a guidance document that allows its user to assess which factors make an IFES truly sustainable and which factors need to be considered when replicating such a system - be it a pilot project, a business innovation or a research experiment. Furthermore, it helps to systematically describe the potential contribution of IFES to sustainable agriculture and the growing bioeconomy, and to raise awareness among decision-makers about which factors can facilitate the replication of such innovative projects.

While the concept of IFES builds on the principles of sustainable intensification and the ecosystem approach, it stresses the fact that the diversification of crop and livestock species can lead to a sustainable production of both food and energy feedstock, as long as relevant practices and technologies are *locally devised and adapted*. It further emphasises that energy efficiency can be reached in these systems when applying sound agro-ecological practices and locally adapted technologies. This can be observed in many smallholder farming systems around the world, for example, agroforestry or intercropping systems that provide food, on the one hand, and generate crop residues and woody biomass for cooking or heating, on the other.

However, far less common are those IFES that build on a sustainable production of food and energy feedstock *and* combine it with renewable energy technologies, that eases access to *modern* energy. Many pilot studies, research projects and business innovations suggest that food and energy for fuel, heat and electricity can be sustainably produced in such food-energy systems. Yet the supporting evidence to bring these types of IFES to scale is still scarce and projects often remain single islands of success.

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