Assessment Framework for
Biomass Supply Chains

Biomass Supply Chain Sustainability Assessment Framework for Small Scale Bio-energy Systems

Sweden	Uganda
Villa Belona	Plot 42A Mukabya Rd
114 18 Stockholm	P.O. Box 29613 Ki'a

http://www.pamojacleantech.com/

Authors:
Deandra Perruccio
Thomas Buchholz
Stephen Christensen

Framework Version 2
6/5/2015

Pamoja is a for-profit social enterprise working in the field of rural decentralized renewable energy solutions. We solve some of the most pressing Energy needs for Rural BoP (Base of the Pyramid) people in East Africa, starting with Uganda. Pamoja uses biomass gasification as a platform to enable various energy services.

Suggested citation for framework use:

Perruccio, D,. Buchholz, T., Christensen, S. (2015). Biomass Supply Chain Sustainability Assessment Framework for Small Scale Bio-energy Systems. The Gund Institute for Ecological Economics & Pamoja. Burlington Vermont, USA & Stockholm, Sweden.

INTRODUCTION

When implementing new biomass supply chains to electrify rural communities, Pamoja is considering a variety of different biomass supply options and management schemes. The best of these supply options is chosen based on weighted sustainability criteria to ensure reliability, maximize social benefits for the farmers and community, minimize negative environmental impacts, and reduce cost.

The following framework provides the steps and guidelines followed by Pamoja in determining the sustainability of biomass supply options. Criteria covering areas of reliability, social benefits & impacts, environmental impacts and costs have been identified to rate the long-term sustainability of the biomass. This framework is meant to serve as a guide for planning and monitoring the biomass supply of bio-energy systems. The ideas may be taken adapted for use freely with proper citation.

This framework is accompanied by a manual which offers guidance on framework application. Decision support software is being developed to assist in the logistical organization and comparison of criteria performances.

CONTENTS

1 ASSESSMENT BOUNDARIES

Spatial boundary: These criteria are applied to the community level. Anything that happens outside of this boundary is addressed through leakage effects[1]

Temporal Boundary: The timescale considered for this framework is 10 years, which reflects the projected lifespan of these projects. Data collected should reflect a 10 year outlook when available.

Within the 10 year temporal scale, short and long-term supply options might differ. For instance, Pamoja might consider buying firewood from local farmers during the first year of operations while building an outgrower network that would then provide the system with agroforestry-derived fuelwood starting in the second project year.

2 MAPPING RECEIVING ENVIRONMENT

The initial step in applying the assessment framework is mapping the receiving environment. This could be accomplished through a short report about the area to be assessed, including background information, availability of data. The step should aid in developing an assessment strategy, connecting with the community and area to be assessed, identifying opportunities or constraints, and discussing tradeoffs or thresholds. For example, Pamoja will not accept a project which requires over 45% of residue supply from existing supply.

Key information for mapping receiving environment:

- Local population
- Existence of cooperative
- Community leadership: who they are, responsiveness, reputation
- Other relevant organizations/businesses active in area
- Major crops and estimated average annual yields
- Experience with agroforestry
- Energy availability and demand
- Energy market- willingness/ability to pay

[1] See leakage criteria addressed in SE2. Resource competition, E1. Deforestation, and E.8 Carbon cycle.

3 BIOMASS DEMAND AND SUPPLY ASSESMENT

The next step in assessing the sustainability of a potential feedstock is determining the total quantity of biomass that will be needed to meet the demand for the system.

3.1 CALCULATE ENERGY DEMAND

This can be done through investigating the existing and potential energy markets through a calculation of current energy use in the area, population dynamics, as well as a community needs assessment. Develop an understanding of the kinds of energy used in the community, for what purposes, in what quantities and at what costs; Cooking, agricultural processing, lighting, entertainment etc. This assessment should take into account variability in load demands, both throughout the day and throughout the year. See table one below for potential energy demand sources.

Table 1.

Possible sources of energy demand

Source
Current diesel energy use for electrical or mechanical use
agricultural processing
generators for entertainment, business, lighting
Unmet energy demands and ability to pay
Business demand
Restaurants
Shops
Schools
Healthcare facilities
Household demand
Lighting
Phone charging
Television
Refrigeration

3.2 DETERMINE ABILITY TO PAY

While energy demand may be high, and a high number of potential uses for electricity identified, ability and willingness to pay for electric services must also be considered to estimate the load demand that can be expected.

Gathering information on current energy expenses, specifically expenses related to energies which could be replaced with electricity services, can indicate current levels of spending on energy at a site and inform predictions about willingness to pay for electrical services.

For example, Pamoja pilot sites were situated in locations with energy demand for agricultural processing which was being met by costly diesel engines and could be provided by Pamoja at a lower cost/kWh.

3.3 DETERMINE REQUIRED BIOMASS

Energy demand can then be used to calculate the required amount of biomass to meet the energy needs of the community in question. This assessment should also accurately reflect the management scheme or business model being used for the system. Questions to consider when determining biomass demand include biomass type and conversion efficiencies- determining energy produced per volume or weight of the available supply. The following table offers information on the (Lower Heating Value) LHV of various potential biomass sources.

Table 2.

Heating values and conversion figures for biomass feed-stocks

Crop	Type of residue	LHV (MJ/kg)	Calorific Value (cal.)(kWh/kg)	Moisture Content (%)	Ash Content (%)	Bulk Density (kg/m3)
Maize	Stalk	16.3	4.5 3.89		2.2-2.5	170-185
	Cobs	12.6	3.5	11.5-13		
Rice	Straws	8.83	2.5			
	Husks	12.9	3.6	10-10.8	21-22.5	120-135
Beans	Trash	14.7	4.1			
Groundnuts	Trash/shells	11.2	3.1 (5.98)	10-13.8	3-6	95-105
Sugar	Bagasse	15.4	4.3 (5.25)	12.2-14	2-4.5	155-170
	Tops	15.8	4.4			
Coffee	Husks	15.9	4.4 (4.61)	12.5-15	6-7.5	220-320
Wood	50% Moisture	9.5	2.66*	50		
	20% Moisture	15.5	4.34	20		
	Sawdust	16.2	4.54	13		
	Pellets	16.8	4.70	10		
	Dry non-resinous	19	5.32	0		
	Dry resinous	22.5	6.3	0		

Note. Sources. LHV, Calorific Value: Okello et al., 2013; Moisture Content , Ash Content, Bulk Density: Okure et al., 2006; Wood figures Ashton, 2007.
Note. *KWh/kg for wood values calculated by multiplying MJ by .28 (1MJ = .28kWh)

The required biomass for a given project can be calculated by converting the total energy demand (KWh)/ year to total MJ demanded given the LHV (MJ/kg) of the biomass.

Required biomass amounts also give information regarding storage space required for a system, evaluated in section IV. Costs and Quality of Feedstock (CQ.2). A business model which incorporates briquetting into their operations may require additional biomass.

Finally, establishing the biomass demand requires establishing the overall efficiency of the bioenergy technology being used. Below are example calculations for a biomass gasification system.

Table 3. Conversion efficiency assumptions for biomass gasification system

Technology	Efficiency estimate (%)
Internal Combustion Engine	25
Generator	90-95
Whole system electricity generation	16.6*
Whole system with heat recovery	17-80

* Assumes 25% efficiency for IC Engine and 95% for generator
Source. Joerg, 2013

From these figures calculate total energy input and total biomass needed to meet energy requirements. An example calculation is below:

Energy demand: 6hrs at 10kw five days/week = 60kWh/day x 260 days = 15,600kWh/year

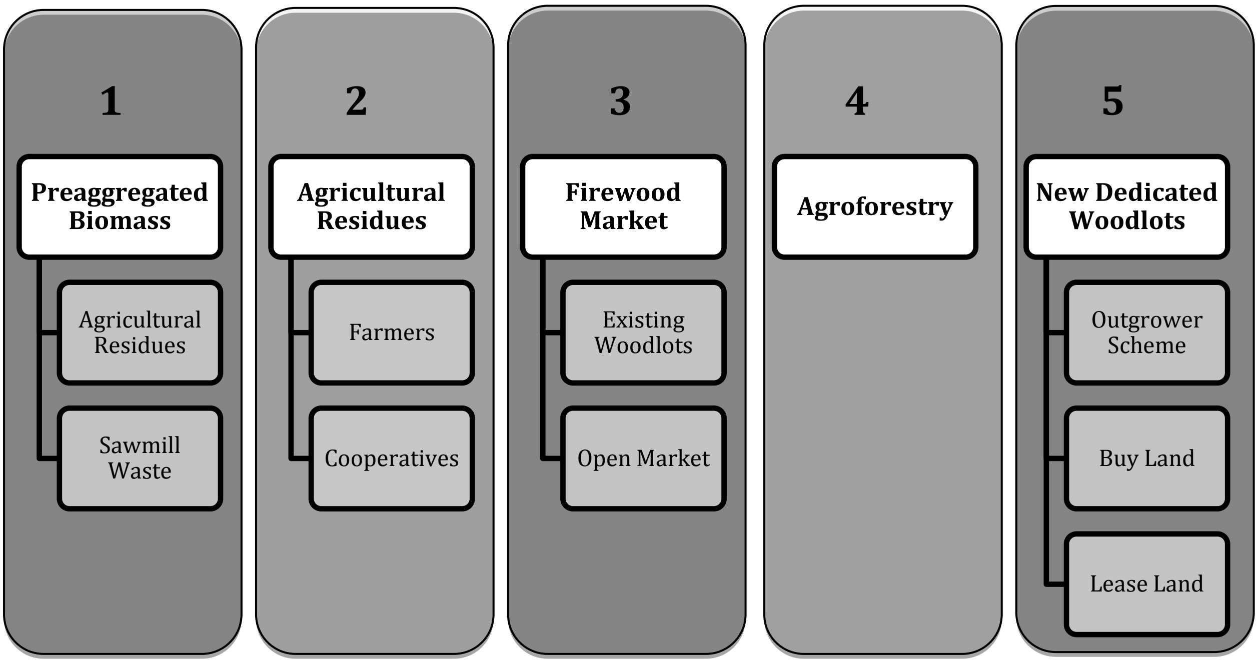
Biomass-energy statistics used for Maize Cobs: 1.2-1.5kg of biomass/kWh OR 3.5kWh/kg of biomass

Biomass requirement with Maize Cobs: 15,600kWh = 3.5kWh/kg (X)/(.116) = 27857kg/year or 27.86 metric tons/year

3.4 DETERMINE POTENTIAL BIOMASS SUPPLY OPTIONS

Because community contexts will vary widely, clearly defining the supply option and management scheme that is being assessed is an important first step in accurately considering and comparing costs and benefits. See Figure 1 for an outline of potential supply options and management schemes that can be considered through this framework:

Figure 1. Biomass Supply Options



3.4.1 PREAGGREGATED BIOMASS

Byproducts of business operations provide a potential available supply for bio-energy systems. These could include large quantities of agricultural residues near agro-processing centers or waste biomass from milling operations.

3.4.2 PURCHASE OF AGRICULTURAL RESIDUES FROM FARMER COOPERATIVES OR INDIVIDUAL FARMERS

Agricultural residues such as maize cobs, groundnut shells, and coffee husks can be processed and used effectively in the energy system technology. These could be accessed directly from individual farmers or through agreements with farmer cooperatives.

3.4.3 FIREWOOD

EXISTING WOODLOTS

Firewood can be bought directly from farmers who sell their excess firewood. There is a degree of certainty that the wood comes directly from their woodlots, and in buying this wood, money and value goes directly to the local farmers. However deforestation leakage created through purchase of current sources of firewood or charcoal supplies is a concern.

OPEN MARKET

Firewood can also be purchased from those in the community or nearby villages which sell large quantities of firewood at market price. This adds a degree of uncertainty as to where this wood comes from and if the local firewood market adds directly to regional deforestation/ degradation of natural forests.

3.4.4 AGROFORESTRY

Using agroforestry systems to supply biomass for the energy system has potentially many benefits in terms of environmental sustainability, benefits to farmers and the community, biomass quality and technology lifespan. As will be assessed through framework application, agro-forestry has been found to have positive effects on incomes of marginalized populations, as well as lessen pressure on local forest reserves (Fabe et al., 2014). By incorporating trees into agricultural systems, woody biomass can be supplied to the bio-energy system while minimizing land competition for food production. Agroforestry systems could include a combination of intercropping, hedgerows, or growing trees on fallow land using nitrogen fixing tree species.

Because agroforestry involves developing complicated systems often requiring training and support, working with support organizations is important to their success. Pamoja will work with local organizations such as Vi-Agroforestry that have a track record in working with farmers to implement agroforestry systems, providing seedlings, training, support and monitoring.

The management scheme and impact of woodlots is further defined by the biomass species chosen. This level of analysis required when implementing an agroforestry scheme requires a partnership with a qualified partner to ensure success with this supply option. For instance, species need to be evaluated on the following criteria:

- Coppicing ability in case of perennial applications
- Water efficiency
- Nitrogen fixing
- Non-invasive
- Harvesting process

3.4.5 NEW DEDICATED WOODLOTS

In starting small woodlots on farms, the species selected must be compatible with agriculture. Consideration of new woodlots will also need to clarify land-use change to minimize interference with land already being used for agriculture. Planting on land unsuitable for farming such as degraded land or hillsides could reduce competition with crop production. Land untenable for farming may be used as pasture.

OUTGROWER SCHEME

Pamoja could contract out the task of establishing and managing woodlots to local community members, then purchasing wood grown and harvested specifically for use in the bio-energy system. While farmer choice ultimately dictates land-use change for establishing woodlots, Pamoja wants to be aware of the impact outgrower strategies may or are having on social and environmental conditions. Most small-holder farms are maximizing land productivity, with little space going unused.

LEASING LAND

If leasing or buying of land is a common practice in the community, Pamoja can lease land for an extended time (around 5-10 years). In this case, Pamoja would manage the woodlot, internalizing costs and risks.

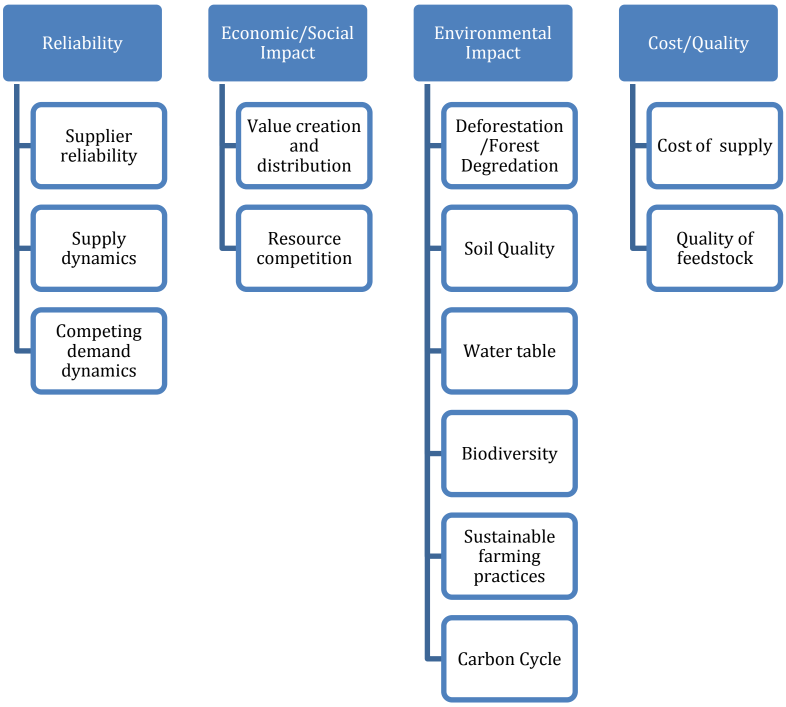
BUYING LAND

Purchase land and establish woodlots that are owned and managed internally. Securing land titles can be a major challenge for this option.

4 CRITERIA AND STANDARDS FOR A SUSTAINABLE BIOMASS SUPPLY

Four criteria (Figure 2) can be used to evaluate the biomass supply. Criteria and sub-criteria are listed below:

Figure 2. Sustainability Criteria and Sub-Criteria



Indicators within each sub-criteria can be measured to evaluate the performance of the supply. Decision support software is being developed to assist in the logistical organization and comparison of criteria performances.

I. RELIABILITY

R1. SUPPLIER RELIABILITY

Local farmer cooperatives, private and government landowners, business owners and market participants can be considered as potential suppliers. It is important to have a primary supplier of biomass, while also keeping backup options available. The following supplier criteria can be considered:

R1.1 SUPPLIER LEVEL OF ORGANIZATION: This can be assessed by looking at years in operation, group or individual productivity and production levels, finances, management, satisfaction of customers or members. It is important to gather information from independent organizations.

R1.2 SUPPLIER NUMBERS: Sourcing from a large number of farmers avoids reliance on a single supplier, which can build resiliency. However, having one reliable point source for a supply can greatly reduce management costs of the supply chain. The organization of a cooperative helps to bring together the collective resources of farmers in a way which may ease management of a supply incorporating a large number of suppliers.

R1.3 SUPPLY CONTRACT: Willingness to enter into a contract guaranteeing a certain amount of biomass supply at a fair market price can also enhance the reliability of the supply.

R1.4 SUPPLY PROXIMITY: Biomass supply radius: The collection distance for the site. Eg. A site with poor road conditions or transportation may only be able to collect materials from a distance of 3km, whereas a site with access to a truck and/or better road conditions can collect materials from a larger radius. Collection ability for these projects range from a minimum of 3km to a maximum of 13km depending on transportation infrastructure.

R1.5TRANSPORTATION INFRASTRUCTURE

Accessibility of the roadways and transportation options available (Truck, boda, bicycle) will be used to determine the strength of the existing transportation infrastructure.

R2. SUPPLY DYNAMICS

We will consider the recent and projected dynamics of the potential supply in the area; ideally choosing a market with a large and relatively stable supply of biomass.

R2.1. SEASONALITY/VARIABILITY OF SUPPLY AVAILABILITY

Agricultural residues

- Types of crops and crop seasons: In order to design the biomass supply chain, we need to know the type of crops grown in the village whose residues can be used in the energy system, as well as their harvest seasons. Crop productivities between the two seasons will also be considered.
- Area cultivated for each type of crop and any major fluctuations past 5 years

- Local land productivity (dry-tons/ha/season) past 5 years
- Diseases, crop fluctuations, or natural disasters in the last 5 years

Pre-aggregated biomass

- Types, amounts of incoming biomass, seasonal fluctuations and any fluctuations over last 5 years.
- Residues created per amount of primary biomass.
- Technological history last 5 years (breakdowns etc. that would interrupt the flow of biomass through the aggregation point)

Woody biomass

- Area of planted trees/species
- Coppice cycle for each tree species
- Total wood harvested (dry-tons/ha/season)
- Harvest times, staggering of plantings

R2.2 STORAGE CAPACITY

Storage capacity is an important consideration in supply dynamics. Some technologies such as gasification systems require a feedstock with maximum moisture content of 15-20%. Without proper storage, variable influxes of biomass can result in major amounts of unusable feedstock, which cannot be counted in the available supply. Therefore, when weather has the potential to render feedstocks unusable, available supply cannot exceed the available storage space.

R3. COMPETING DEMAND DYNAMICS

In implementing a sustainable biomass supply, Pamoja must consider the dynamics of demand in markets that compete with the potential biomass supply. Different aspects are taken into account:

R3.1 LOCAL POPULATION DYNAMICS: An increase in population will naturally lead to an increase in demand for wood and/or other demands on the supply option. For example, it may be important to know the rate of the population using agriculture residues for cooking as this demand has an impact on availability.

R3.2 COMPETING USE BUSINESS TRENDS Are there other businesses creating a competing market for the biomass supply? At what quantities and prices and how have these changed in the past 5 years? Eg. What are wood prices for other markets competing with fuelwood (wood for construction, charcoal), eg. Use of agricultural residues by chicken farmers for bedding. Investigate alternative uses and markets for the biomass in question.

R3.3 COMMUNITY BEHAVIORAL DYNAMICS: Studies indicate access to electricity can significantly change demands and behaviors in a community (Madubansi & Shackleton, 2006). These trends can be used to predict possible shifts in demand for competing uses. Investigation into community behavioral trends in response to electricity access can inform predictions of possible behavior change impacting supply reliability.

II. SOCIAL/ECONOMIC IMPACTS

Bioenergy systems have a unique opportunity to create additional economic activity and social benefits in a community not only through the generation of electricity and valuable byproducts, but also through the establishment of the biomass supply chain.

The incorporation of, and symbiotic relationship between energy generation, natural resources, and human stewardship is an important element which sets bioenergy systems apart from other renewable energy options.

SE1. VALUE CREATION AND DISTRIBUTION

The sustainability criteria also measure value creation through social capital development for the local community. Creating income generation and new skills at the local communities is a crucial aspect for the overall sustainability of the biomass supply chain.

SE1.1 INCOME GENERATION

In order to assess the total income from biomass production the following inputs are required to calculate the total impact.

- Number of farmers participating in biomass supply chain (Category 1: 1-3 acres, Category 2: >3-5 acres, Category 3: above 5 acres)
- Net earnings per farmer ($/ha/year/farmer)
- supply levels by farmers (Reported from existing system monitoring)

- Use gestation period to grow the biomass and demand characteristics of bio-energy system to calculate biomass supply provided/season and or/year
- Total amount of supply available from farmers (dry tons)
- Multiply price of biomass (what Pamoja will pay for supply) by total supply needed to calculate total additional income from biomass supply.
- Other local income from biomass supply chain: Income through transportation, pre-processing, storage maintenance, etc.

SE1.2 INCOME DISTRIBUTION

Income distribution is important for accurately understanding the social impact of the community as income generation can mask pooling of wealth, increased inequality, and further marginalization of poor community members. To calculate the income distribution of a system gather the following information:

- Total additional income divided by number of suppliers to get at portion of population impacted-
    - Compare current income to income per amount of product and demographics of suppliers to find %income increase numbers
- Variation of income generated: How does additional income from the biomass supply chain affect current relative distribution of wealth? What are the percentage changes of income and where is additional income being distributed?

SE1.3 SOCIAL CAPITAL

Social capital can be measured and accounted for by determining the social impact through local capacity building.

Employment Environment and Supply Impact

To measure social capital the framework can measure the number of jobs created by the supply chain. New employment opportunities connected to the supply chain could include growing/supplying biomass, transportation, and processing.

Calculate the number of and types of jobs created through the biomass supply chain.

Skill Environment and Supply Impact

Survey data and business models can provide information on skill development resulting from the biomass supply chain. Content area and capacity development could include forestry and agroforestry knowledge and skills, agricultural management training, as well as increased cooperative organizational capacity.

In order to assess the impact of capacity building, the following information needs to be provided:

- Number of trainings conducted
- Number of local people trained
- Number of trainees getting a job within three months after training
- Average income of trainee who got placed

SE2. RESOURCE COMPETITION

SE 2.1 LAND-USE COMPETITION

There is a risk for potential land use competition between biomass production and food production when establishing woodlots or introducing agroforestry practices. In contrast, using agricultural residues are not associated with a risk for land use competition. Rather, residue use causes environmental impacts including leakage from cooking and fertilizer addressed below (E1; E2).

WOODLOTS

The use of degraded lands may be used for biomass production if the land is unsuitable for food crop production. Degraded lands are sites which are too hilly, too rocky or with little soil depth making it unsuitable for food crop production. New woodlots should be developed on marginal lands not suitable for food crop production.

Creation of woodlots may also eliminate community or private grazing land. Establishing a baseline figure for grazing lands in the project site are and monitoring changes in size of grazing spaces through surveying can provide information about the impact of woodlots on grazing land.

AGROFORESTRY

In order to avoid the food vs. fuel debate the following land-use management schemes can be considered for promotion of biomass plantations:

- Monitor changes in cropping patterns
- Crop productivity vs reliability: Agroforestry systems have been shown to increase the stability and reliability of harvests (Thorlakson, 2012; Leaky, 2010, Kristjanson,

P. et al., 2012). Future crop productivity estimates (harvested tons/ha/season) will be compared with the harvest of the previous years (before agroforestry model). The percent reduction of productivity needs to be considered, along with the trends in reliability of crop production associated with agroforestry systems.

- Avoid displacement of food crops for biomass production
- Boundary plantations/Hedge rows: The use of farm boundaries for biomass plantations. This may have a lower impact on space planted for food crops which could be offset by positive impacts on soil quality, and run-off prevention depending on the species planted (Lenka et al., 2012).
    - Can have positive impacts on income returns, which are in some instances offset by high opportunity costs of adoption (Pattanayak, 1997).
- Intercropping: Can positively impact soil conditions but may also reduce overall yields depending on the intercropping species and works especially well with shade plants like coffee or yerba mate (Ilany et al., 2010).

SE2.2 COMPETING USES FOR BIOMASS

The sustainability criteria can also measure the impact of the use of a particular biomass and its effects on other competing uses. Is the biomass being used by others? In what amounts and when? Specific categories of competing use are:

- Fertilizer
- Cooking
- Fodder for animals
- Business uses: Bedding at chicken farms, fuel for kiln
- Etc.

BIOMASS REQUIREMENT

Total biomass required to produce electricity should be compared to supply available after accounting for competing uses. The biomass requirement is calculated by finding the required biomass to produce estimated or actual electricity demand as well as the total biomass available in the community. By calculating this number as a percentage of total biomass available in local area, as well as calculating estimates of percentage of biomass used for competing purposes, decision-makers can be informed about potential resource competition thresholds in each context.

Data can be gathered and analyzed about current biomass use trends as data is available, possibly as a percentage of available biomass Eg. What is the percentage of available biomass used for cooking or fertilizer?

III. ENVIRONMENTAL IMPACTS

E1. DEFORESTATION AND DEGRADATION OF FORESTS

Deforestation and degradation of natural forests are currently the most serious concerns when implementing a bioenergy system and supply chain. It is crucial that the fuel-wood supply does not contribute to the deforestation/degradation problems already facing Uganda. The current forest cover of the project area, recent changes, and deforestation issues will be noted.

Supply chains can be assessed to determine if the production of the biomass is alleviating pressure on local managed or natural forests and local tree cover; or, due to leakage, contributing to deforestation. The boundary of the project will be defined as a community boundary. However, leakage concerns need to also be addressed.

By-products (biochar): If there are any by-products which are getting produced that are mitigating the pressure on deforestation this can be quantified by determining how much of such byproducts are generated and what amounts of wood/charcoal products are being replaced.

Reforestation: the establishment of woodlots on degraded land may contribute positively to forest cover when species biodiversity and proper management is observed. Therefore, in the case of establishing woodlots, Pamoja assumes no risk of contributing further to deforestation/degradation.

Scoring the supply chain on the level of certainty with which you can determine the source of the supply and its direct contribution level to deforestation (eg. open wood market purchases) can also allow consideration of deforestation/ forest degradation issues.

E2. SOIL QUALITY

Efforts will be taken to maintain soil quality in fertile lands and restore soil quality on non-arable or degraded land. Growing suitable trees on degraded lands and hillsides has documented potential to conserve soil, reduce soil runoff, and add nutrients and organic matter to the soil, through N-fixing trees and mulching leaves and branches agroforestry has more favorable effects on soil fertility and other soil properties (Shoga'a Aldeen, 2013; Pandey et al., 2000; Thevathasan et al., 2014).
Does the proposed supply chain cause environmental impacts regarding soil quality and in what way?

E2.1 NUTRIENT CYCLE

Nutrient content of soil within agricultural systems is critical to productivity across all time scales. The biomass supply chain has the potential to contribute to the soil nutrient balance or negatively impact soil nutrients through significant nutrient removal. Agroforestry systems have been shown to improve soil quality. (Shoga'a Aldeen, 2013, David & Raussen, 2003).

To evaluate if a biomass supply is positively impacting soil nutrient content, review the following criteria:

- **Change in nutrient availability:** What amount of nutrients are being removed or added (ash/biochar) from the agricultural system due to biomass supply?
- **Agroforestry and woodlot impacts:**
    - What is the total acreage and/or number of trees planted on degraded/fallow land planted?
    - What is the increase in plant-available soil nutrients (Nitrogen fixing trees)?
    - What is the total acreage of intercropping for soil improvements?
    - Are leaves staying on ground?

Because most of the corn residue remains following a cob and grain harvest, and because the nutrient removal is relatively low from cob harvest (approximately 5 lb N/a), the impact of cob harvest on soil erosion or soil organic matter levels is likely to be low. Also, because the nutrients removed in a cob harvest of 1,200 pounds per acre was estimated to be 4 lb N/a, 1.3 lb P_2O_5, and 7 lb of K_2O, the value of the nutrients removed in the cobs will also be relatively low (Roth & Gufstovson, 2014)

E2.2 SOIL STRUCTURE

Soil structure impacts the movement of air and water within the soil, as well as biological activity, root growth, and seed behavior. Improvements to soil structure can contribute to sustained agricultural productivity. To evaluate the biomass supply impact on soil structure the following criteria can be investigated:

- **Trees increase water holding capacity, and improve soil structure:** Does the biomass supply chain improve water management through planting of trees?
- **Annual crops to perennial crops and no till agriculture:** Does the biomass supply result in a shift to perennial crops or no till agriculture which is less disturbing of soil?

- **Erosion control:** Does the introduced biomass supply chain result in a decrease of erosion by providing cover for fallow land and a permanent buildup of soil depth? What is the total acreage of erosion control measures implemented?
- **Crop rotation:** if agricultural residues are used, is the practice of crop rotation kept at current levels or increased to contribute to soil health?
- **Impact on organic matter:** Does the introduced biomass supply chain result in an increase in organic matter in the soils contributing to increased water holding capacity and nutrient availability? Does the supply remove organic matter?
    - This can be measured by identifying the number of farmers using residues for fertilizer, and estimated amount used each season, and calculations regarding its contribution to nutrient levels.
        - Calculation of removal of nutrient content of biomass can provide further details on nutrient removal impact for biomass supply. For example, maize cobs have been found to contribute only a small percentage of nutrient total for maize residues. See Table 5:

Table 5. Nutrient contents of maize parts

Component	Dry Matter (% Total)	Nitrogen (%N)	Phosphorus (%P205)	Potassium (%K20)
Grains	48	1.44	.69	.5
Stalks	22	.43	.14	.9
Leaves	10.6	1.8	.69	2.05
Sheaths	5.3	.64	.37	1.74
Husks	4.3	.36	.21	1.32
Shanks	1.5	.5	.18	1.68
Cobs	7.5	.33	.11	.62
Tassels	.5	.97	.5	1.7
Lower ears	.5	2.04	.87	3
Silks	.2	3.5	.87	2.57

Source. Iowa State University, 2007

E3. WATER TABLE

The water efficiency of the biomass species can be evaluated using the following data:

- Water requirement for the biomass
- Rain water harvesting technologies used
- Total acreage planted for water conservation- Are agroforestry systems being used which utilize trees to retain water in soils and fields through hedgerows or intercropping?

E4. BIODIVERSITY

The biomass supply chain should further enhance rather than diminish the local biodiversity. Risks towards local biodiversity can be minimized through providing a diverse landscape incorporating elements such as hedgerows or intercropping with trees (agroforestry) or preference of indigenous over non-native biomass species.

Indigenous/Native Species: The use of indigenous and native species should be given preference. There must be at least one biomass species and 25% of the total biomass from native species.

E5. SUSTAINABLE FARMING PRACTICES

In cases where the establishment of the supply chain contributes to or enables sustainable farming practices including the use of agroforestry, positive environmental impacts are assumed. Providing a qualitative score for the supply chain's encouragement of sustainable practices allows broad assessment of the integration of sustainable concepts.

Does the energy system supply chain encourage the use of sustainable agricultural and silvicultural practices in growing trees?

Does the system encourage the use of natural fertilizer?

Does it encourage the use of other sustainable and beneficial systems such as agroforestry systems, crop rotations and fallows, among others?

Does it provide for or facilitate training, discussion, and skill development around sustainable farming practices?

E.6 CARBON CYCLE

Carbon emissions from bioenergy systems are driven in the first case by the net carbon fluxes to the atmosphere from the ecosystems where the biomass is sourced from rather than the fossil fuel emissions from e.g. processing biomass or producing the conversion technology (Buchholz et al. 2015).

Additionally, various changes in land use and/or land management practices can be used for potential SOC sequestration in different regions, including reducing tillage intensity and frequency or conversion to no-till agriculture, reducing bare fallow, conversion of highly erodible land to grassland or woodlots, increased use of cover crops in annual cropping systems, and natural woodland regeneration (Lal, 2009; Lorenz et al., 2014; (Paustian et al., 1997; Hutchinson et al., 2007) Woodland plantations have been found to mitigate atmospheric carbon levels over the long term (Van Minnen et al. 2008).

Carbon impacts from the bioenergy system will be assumed at least neutral as long as the system is not contributing to deforestation (Zanchi et al., 2013). Assuming carbon neutrality must include an assessment of competing uses potentially contributing to leakage. Examining the data gathered in the resource competition section (SE2) can help determine if leakage contributing to deforestation issues is a concern for the biomass supply.

- What are the competing uses of the biomass in question?
- At what levels is the supply being used for these purposes and what percentage of available biomass is being used?
- Are these uses mitigating use of forest products and does the establishment of the supply chain contribute to increased reliance on forest products?

IV. SUPPLY COSTS/QUALITY

CQ.1 COSTS OF SUPPLY

Cost of biomass contributes significantly to the economic viability of bioenergy systems. While including reliability, social, and environmental considerations into management decisions, Pamoja's goal is to choose a supply which creates a financially sustainable final cost of biomass, including costs associated with processing and transportation. Quality considerations are also important to project sustainability as the quality of feedstock can have major implications for technology life span and maintenance costs. Aspects Pamoja will consider in final biomass cost include fixed and variable costs listed below:

Table 6. Fixed and Variable Project Costs

Fixed Costs	Variable Costs
Storage space	Market prices
Training	Processing
	Transportation
	System management, monitoring, assessment

Wood biomass options have high variability in moisture content and in density amounts for storage dependent on processing methods which should be considered in cost analysis.

CQ.2 QUALITY OF FEEDSTOCK

The quality of the feedstock being used can have important impacts on the lifespan and maintenance requirements of the bioenergy technology. In gasification systems specifically this also effects the quality and energy content of the gas. Poor feedstock can lead to significant difficulties with the technology due to ash creation, as well as tar and silicate presence that build up in the engine.

Biomass options will be evaluated against the following quality metrics:

- Moisture content
- Ash content (also as a proxy for acidity)
- Handling features (e.g. flow characteristics) and processing requirements
- Bulk density and energy density

5. CRITERIA WEIGHTING

Weighting of the criteria establishes comparative importance levels between criteria under consideration. Decision makers can make decisions regarding weights of criteria, can investigate how varying weights impact management decisions, and can make weighting decisions regarding thresholds (yes/no scenarios that could lead to immediate rejection of a potential site or project). Literature reviewing multi-criteria analysis and bioenergy project planning can provide guidance regarding appropriate decision structuring for applying this framework (Scott et al., 2012; Buchholz et al., 2009).

6. DECISION MAKING PROCESS

A simple multi-criteria utility decision support tool is being developed in conjunction with this framework using Analytica decision support software (Decision Analytics, 2015). This tool and a guide to its use will be available via the Pamoja website and provides one application method for the framework. The decision tool and guide provides instruction and guidance on implementation including suggestions for criteria weighting, data collection, indicator measurement techniques, and building a decision process. Reviewing literature regarding decision support processes and programs for bioenergy systems can also provide further guidance in determining a decision structure for framework application (Scott et al., 2012; Buchholz et al., 2009, Kurka & Blackwood, 2013).

Based off the weighting of criteria, goals and priorities of the company, a decision can be made which clearly defines and takes into account the many elements necessary to secure a sustainable biomass supply. Combination assessments and short vs long term supply chain options can be developed with company explanation of scoring, clear biomass option descriptions and timescales being considered.

REFERENCES

Ashton, S.; Cassidy, P. (2007). Energy Basics. In: Hubbard, W.; Biles, L; Mayfield, C. ; Ashton, S. (Eds.). 2007. Sustainable Forestry for Bioenergy and Bio-based Products: trainers curriculum notebook. Athens, Ga: Southern Forest Research Partnership, Inc. Retrieved from: http://www.forestbioenergy.net/training-materials/fact-sheets/module-5-fact-sheets/fact-sheet-5-8-energy-basics.

Biomass Feedstock Chart: Information for Power Pallet & GEK Usage. (2015). Accessed online 3/31/2015. Available at: http://www.allpowerlabs.com/wpcontent/uploads/2013/11/APL_Fuel-Chart_12-2013.pdf

Buchholz, T., Hurteau, M., Gunn, J., Saah, D., (2015). A global meta-analysis of forest bioenergy greenhouse gas emission accounting studies. *Global Change Biology- Bioenergy.*

Buchholz, T., Rametsteiner, E., Volk, T. A., & Luzadis, V. A. (2009). Multi Criteria Analysis for bioenergy systems assessments. *Energy Policy*. *37*(2). 484–495. DOI:10.1016/j.enpol.2008.09.054

Decision Analytics. (2015). Lumina Decision Systems. Accessed online 2015: http://www.lumina.com/technology/decision-analytics/

Fabe, A., Winter, E. Grote, E. (2014). Bioenergy and rural development: The role agroforestry in a Tanzanian village economy. *Ecological Economics*. *106*. 155-166.

Hutchinson, J., Campbell, C., Desjardins, R. (2007). Some perspectives on carbon sequestration in agriculture. *Agr. Forest. Meteorol*. *142*. 288–302.

Ilany, T., Ashton, M., Montagnini, F., Martinez, C. (2010). Using agroforestry to improve soil fertility: effects of intercropping on Ilex paraguariensis (yerba mate) plantations with Araucaria angustifolia. *Agroforesty Systems. 80.* 399-409. DOI: 10.1007/s10457-010-9317-8.

Iowa State University, 2007. *Integrated Crop Management.* Webpage. Available at: http://www.ipm.iastate.edu/ipm/icm/2007/8\6/nutrients.html

Kristjanson, P; Neufeldt H, Gassner A, Mango J, Kyazze FB, Desta S, Sayula G, Thiede B, Forch W, Thornton PK, Coe R. (2012). "Are food insecure smallholder households making changes in their farming practices? Evidence form East Africa". *Food Security 4*(3). 381–397. DOI: 10.1007/s12571-012-0194-z.

Kurka, T., Blackwood, D. 2013. Participatory Selection of Sustainability Criteria and Indicators for Bioenergy Developments. *Renewable and Sustainable Energy Reviews. 24*. 92-102.

Lal, R. (2009). Sequestering atmospheric carbon dioxide. *Crit. Rev. Plant Sci., 28*. 90–96

Leakey, R. (2010) Agroforestry: a delivery mechanism for multi-functional agriculture. In Handbook on Agroforestry: Management Practices and Environmental Impact. Edited by Kellimore LR. New York, NY: Nova Science Publishers. 461-471.

Lenka, N., Dass, A., Sudhishri, D., Patnaik, U. (2012). Soil carbon sequestration and erosion control potential for hedgerows and grass filter strips in sloping agricultural lands of Eastern India. *Agriculture, Ecosystems & Environment. 158.* 31-40. DOI:10.1016/j.agee.2012.05.017

Lorenz, K., Lal, R. (2014). Soil organic carbon sequestration in agroforestry systems. A review *Agronomy for Sustainable Development*. *34*(2).443-454.

Madubansi, M. Shackleton, C.M. (2006). Changing energy profiles and consumption patterns following electrification in five rural villages, South Africa. *Energy Policy. 34*. 4081–4092.

Minnen, J., Strengers, B. et al. (2008). Quantifying the effectiveness of climate change mitigation through forest plantations and carbon sequestration with an integrated land-use model. *Carbon Balance and Management.* 1470.

Okello, C., Pindozzi, S., Faugno, S.,Boccia, L. (2013). Bioenergy potential of agricultural and forest residues in Uganda. *Biomass and Bioenergy*. *56.* 515-525.

Okure, M., Ndemere, J.A., Kucel, S.B., Kjellstrom, B.O. (2006). Suitability of Agricultural Residues As Feedstock for Fixed Bed Gasifiers.[whitepaper]Kampala: Makerere University.

Pandey, C. B., Singh, A. K., Sharma, D. K. (2000). Soil properties under Acacia nilotica trees in a traditional agroforestry system in central India. *Agroforestry Systems*. *49*. 53–61.

Pattaynak, S., Mercer, E. (1998).Valuing soil conservation benefits of agroforestry: contour hedgerows in the Eastern Visayas, Philippines. *Agricultural Economics*. *18*(1). 31-46.

Paustian, K., Andrén, O., Janzen, H., Lal, R., Smith, P., Tian, G., Tiessen, H., Noordwijk, M., Woomer, P. (1997). Agricultural soils as a sink to mitigate CO2 emissions. *Soil Use Management. 13*. 230–244.

Roth, G., Gustafson, C., Corn Cobs for Biofuel Production. eXtension. Available at: http://www.extension.org/pages/26619/corn-cobs-for-biofuel-production#cite_note-2

Shoga'a Aldeen, A. H., Majid, N. M., Azani, A. M., Awang, N., Ghani, Shukri, M. (2013) Agroforestry Impacts on Soil Fertility in the Rima'a Valley, Yemen. *Journal of Sustainable Forestry. 32*(3). 286-309. DOI: 10.1080/10549811.2012.654723

Scott, J., Ho W., Dey P. (2012). A Review of Multi-Criteria Decision-Making Methods for Bioenergy Systems. *Energy*. *42*. 146-156. DOI: 10.1016/j.energy.2012.03.074.

Siriri , D., Raussen, T. (2003). The agronomic and economic potential of tree fallows on scoured terrace benches in the humid highlands of Southwestern Uganda. *Agriculture, Ecosystems and Environment. 95*. 359–369

Thevathasan , N., Gordon, A., Simpson, J., Peng, X., Soolanayakanahally, R., de Gooijer, H. (2014). Sustainability Indicators of Biomass Production in Agroforestry Systems. *The Open Agriculture Journal,* 2014, 8: 1-11. DOI: 10.2174/1874331501408010001

Thorlakson, T., Neufeldt, H. (2012). Reducing subsistence farmers' vulnerability to climate change: evaluating the potential contributions of agroforestry in western Kenya. *Agriculture & Food Security. 1*(15). DOI:10.1186/2048-7010-1-15

Zanchi, G., Frieden, D., Pucker, J., Bird, D., Buchholz, T., Windhorst, K. (2012). Climate benefits from alternative energy uses of biomass plantations in Uganda*. Biomass and Bioenergy.* 1-9.