Powering production.
The case of the sisal fibre production in the Tanga region, Tanzania

Authors:
Francesco Fuso Nerini[a,b *], Antonio Andreoni[c], David Bauner[b, d], Mark Howells[b]

[a] *University College London (UCL), Energy Institute, UK*

[b] *KTH Royal Institute of Technology, Sweden*

[c] *School of Oriental and African Studies, SOAS University of London, Department of Economics, UK*

[d] *Renetech AB, Stockholm, Sweden*

**Corresponding author: Brinellvägen 68,100 44 Stockholm, Sweden; E-Mail: f.fusonerini@gmail.com*

Abstract
Energy plays a crucial role in economic development. The article presents a framework for the analysis of alternative energy technology mixes in agricultural production and applies it in the context of sisal production in the Tanga region, Tanzania. Through scenario analysis, the paper presents both case-specific and generalizable insights. Case-specific insights show the key role that modern uses of energy and modern agricultural technologies could play in increasing productivity and revenues, in minimizing environmental degradation, and in promoting local development. Generalizable insights demonstrate the value of using sector-specific micro-structural frameworks and scenario analysis for assessing different technologies mixes in the energy and agriculture planning process.

Keywords
Productive uses of energy; Agriculture; Energy systems analysis; Biogas; Sisal; Tanzania

1. INTRODUCTION

Energy is essential at all levels of development, ranging from catering for basic human needs to fuelling modern society needs (AGECC, 2010). In developing countries, access to energy for consumption uses, residential energy access for instance, is one of the necessary conditions for improving living standards. However, productive uses of energy have a potentially higher transformative impact on countries' socio-economic development (ESMAP, 2008) (Brew-Hammond, 2010). The reasons why the productive use of energy is a major driver of countries' structural transformation are twofold (UNDP, 2010; UNIDO, 2011; Andreoni and Chang, 2015).

First of all, in developing countries, powering production activities is a pre-condition for increasing productivity and adopting better production technologies ((Kay, 2009) (Andreoni, 2011) (Alston & Pardey, 2014)). In the analysis of the *energy-production nexus* in the developing countries context, the agricultural sector takes central stage given its contribution to income generation and employment creation. Today, some 2.5 billion people, 45% of the developing world population, live in households depending primarily on agriculture and in agri-based economy for their livehoods (Practical Action, 2014). In addition, it is estimated that by 2050 a 70 percent increase in current food production will be necessary to meet the expanding demand for food, primarily through yield increases (FAO, 2011).

In the majority of developing countries, agricultural productivity is low, mainly due to lack of mechanization and of production processes powered with modern energy technology mixes. For instance, in most sub-Saharan countries farm-work is done mostly with animal and human energy inputs, and with little mechanization (Clarke & Bishop, 2002). In the African continent, agriculture accounts for only 2% of the total energy and 3% of electricity consumed in the continent, despite employing 60-80% of the working population (Sokona, et al., 2012). Only approximately 4% of cropland is irrigated and fertilization is seldom used. Also, in low-GDP countries considerable food losses occur in the supply chain due to inadequate harvesting techniques, poor storage capabilities and ineffective transportation (FAO, 2011). As a result, agricultural outputs per hectare in sub-Saharan Africa are considerably lower than in developed countries (Hazell & Wood, 2008).

Thus, modern energy technology mixes powering agricultural machinery and irrigation systems, agro-processing, preservations, storage of agricultural yields amongst others (Sokona, et al., 2012), would be essential to unlock the growth potential in developing countries. The productivity and technology advancements in the agricultural sector would also create the conditions for productive diversification towards manufacturing industries.

The second reason why the productive uses of energy, especially in agriculture, tends to have a higher transformative impact, is related to its positive impact on consumption and employment patterns as well as on the sustainable production of energy. As for the former, it is widely acknowledged that agrarian change leads to increased food production and, thus, lowering consumer prices (Onwude, et al., 2016), while opening new opportunities for export and employment shift towards industrial sectors ((Lewis, 1954) (Kalecki, 1976) (Kay, 2009) (Andreoni, 2011). As for the sustainable production of energy, by powering the agricultural sector with an appropriate energy technology mix, agriculture can be also combined with the production of various energy carriers. Those energy carriers (such as biofuels and electricity) can be obtained as a primary output from the agricultural processes and as a by-product of other agricultural processing. Combining agricultural production with renewable energy generation is possible at the subsistence, small-scale and large-scale levels and can bring co-benefits to farmers, landowners, businesses and rural communities (FAO, 2011). This can trigger a cumulative process of production transformation and energy access increases along more sustainable structural transformation pathways.

The complex set of multidimensional relationships linking agricultural production (and technologies) to energy have received significant attention. This is due to the level and volatility of energy costs as well as the persistent scarcity of reliable energy in developing countries. Several studies have looked at the ways in which modern energy technologies can transform the agricultural sector, while others have focused on the reverse link, that is, from agricultural production to renewable energy and production sustainability. For instance, (Tullberg, 2014) looks at the energy inputs in modern agriculture, with a focus on energy efficiency while (Bates, et al., 2009) explore the possible role of mechanical power in agriculture. As for the reverse-link, from agriculture to energy, (Romijn & Caniels, 2011) study the scope for developing biofuels from an oil-seed bearing plant called Jatropha in Tanzania and the associated social, economic and environmental challenges. (Fuso Nerini, et al., 2014) investigated the advantages of combining the production of vegetable oils in the Brazilian amazon with power production. Finally, (van Oosterhout, et al., 2005) focus on the energy transitions from wood to natural gas systems in the rural stucco and chicha (local beer) industries of Cochabamba, Bolivia.

A relatively smaller number of sector-focused and micro-level studies have also relied on scenario modelling to provide quantitative evidence of the different opportunities offered by different energy technologies mixes. (Baruah & Bora, 2008) investigate the energy needs for different mechanization scenarios for the rice production in the Assam region in India. (Kebede, et al., 2016) look at cost and benefits of investing in biogas plants for smallholder farmers and evaluate the potential energy and agricultural productivity improvements related to that technology. (Painuly, et al., 1995) rely on a linear programming model for investigating the interactions between energy and agriculture in the Indian state of Karnataka.

Gaining insights from a targeted case study, this research aims at enriching the literature on the energy – agricultural production nexus in three main ways.

First, going beyond aggregate studies on the role of energy in development we show how the assessment of alternative energy technology mixes can be improved by conducting a sector-focused *micro-structural analysis* of production. Micro-structural frameworks allow for the identification of the specific tasks composing each sector- and context- specific production process as well as a detailed analysis of the feasible set of production technologies. Building on this framework, we conduct an experiment focused on the agricultural sector and provide a detailed case study of sisal production in the Tanga region. In this context, we specifically focus on the tasks, processes and agricultural technologies deployed and we match these with alternative sets of energy technologies. We claim that this micro-structural and sector-specific approach represents an improvement on a number of more aggregate studies as it allows for the identification of otherwise untapped opportunities for enhancing production and energy efficiency.

Second, building on this micro-structural framework, we develop and test a new scenario modelling tool for the agricultural sector. The adoption of this quantitative tool allows for a comparative assessment of alternative energy technology mixes against costs-performances metrics. Doing so, it permits the comparison of different production pathways, and the inclusion of both energy supply and efficiency, and productivity considerations. The adoption of this tool allows for an optimization of the energy – production nexus, as the production-specific resource constraints faced by producers (farms and agro processing firms) are factored in the tool. This overall approach is expected to help managing technologies mixes both in a static and dynamic setting, that is, supporting the development and profitability of production activities with changes in the energy technology mix.

Third, the micro-structural framework and scenario modelling tool is finally expanded to reconsider the possibility of an energy-production-consumption nexus. In this latter scenario, the residential consumption of energy in communities located in the proximity of the production areas is increased as a result of an energy technology mix which allows for the generation of energy in production. In this expanded framework household appliances usage are related to a specific tier of energy access.

The micro-structural framework and scenario modelling tool are applied in the context of sisal production in the Tanga region, in Tanzania. The sisal facility considered in the case study is the Mkumbara Sisal Estate, one of the major sisal producers in the northwest of the Tanga region. With the application of the framework both case-specific and generalizable insights are gained. Case-specific insights show the key role that modern uses of energy and modern agricultural technologies could play in increasing productivity and revenues, in minimizing environmental degradation, and in promoting local development. Generalizable insights demonstrate the value of using sector-specific micro-structural frameworks and scenario analysis for assessing different technologies mixes in the energy and agriculture planning process.

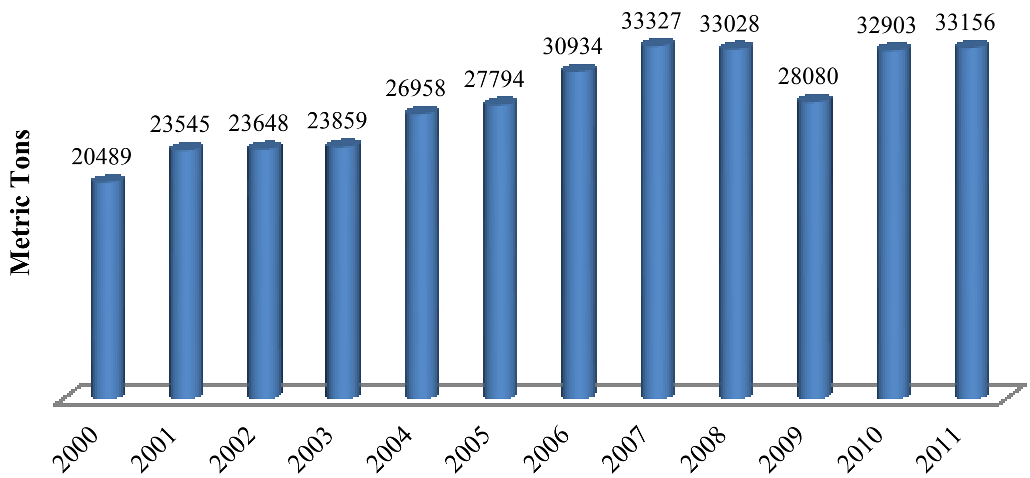
The case of the sisal fibre production in the Tanga region, Tanzania

In Tanzania, it is estimated that only approximately 15% of the population had access to electricity in 2012, with most of the electrified population located in urban areas of the country (The World Bank, 2015). Moreover, over 95% of the population relies on traditional use of biomass for cooking (International Energy Agency, 2015). Tanzania is regarded as one of the energy-poorest countries in the world, as shown by its high Multi Dimensional Energy Poverty Index (the MEPI – an index measuring the incidence and intensity of energy poverty) (Nussbaumer , et al., 2013). Throughout its history, the Tanzanian economy has been highly reliant on agriculture (UNIDO, 2011). In 2014, almost 19 million people worked in the agricultural sector in Tanzania, of a total population of nearly 51 million people (FAO, 2014). Agriculture is responsible for approximately 30% of the GDP of the country, and for 90% of its freshwater usage (FAO, 2014).

In this context, Tanzania is the third largest producer of sisal in the world, after Brazil and China (FAO, 2015). Sisal is one of the most important natural fibres in the world. It was introduced in German East Africa, now Tanzania, in 1893 from Mexico via Hamburg. Sisal is a fibre obtained from Agave, a crop that grow on semi-aride land. In Tanzania two sisal species are predominantly used, the *Agave sisalana* and the Hybrid 11648, each of them allowing for different levels of total production along the 8 years life cycle (respectively 12.5 tonnes and 17.6 tonnes of dry fibre for one hectare) (Lock, 1962)[1]. Sisal fibre has various applications, both traditional (such as carpets, ropes and clothing) and modern. The latter includes specialized applications in multiple sectors and complex product systems: composite materials for the automotive, aircraft and marine sector; geo textiles and pulp based products; fiberglass and plastic reinforcement in construction and furniture. In comparison to other materials such as wood pulp, not only is sisal biodegradable, natural and safe, it also presents a number of qualities – strength, shorter life production cycle, recyclability and price – that makes it particularly desirable in multiple applications.

Tanzania's sisal fibre production has increased significantly starting from the nineties (Brenters & Romijn, 2003) (Terrapon-Pfaff, et al., 2012). Reasons are, among others, a request for sustainable materials and the funding of a public-private Tanzania Sisal Board that supports the privately owned sisal estates. Over the last decade, overall sisal production stabilized at a level over 33.000 Tonnes (with the only exception of 2009 when sisal production collapsed due to the economic downturn) (Figure 1). Most of the country's sisal is produced in the Tanga region in the northeast of Tanzania.

Figure 1 Sisal fiber production in Tanzania from 2000 to 2011 (Tanzania Sisal Board, 2015)



[1] The quality of Tanzania sisal fibre (non-energy uses) is graded in 3L (at least 90cm fibre, whitish), 3S (60-90 cm fibre, whitish), UG (at least 60 cm fibre, brownish), SSUG (at least 60 cm, spotted or dark fibre). The full classification of sisal fibre can be found at (The London Sisal Association, 2016).

The Tanzania sisal production is characterized by several large estates, producing sisal fibers in centralized facilities. This is considerably different to the sisal production in e.g. Brazil, where sisal is harvested in many smallholder farms and decorticated by entrepreneurs travelling with mobile decorticators (Brenters, 2000)[2]. In Tanzania, sisal production is labor, energy and water intensive. Energy represents from 30% to 45% of the cost of sisal production, and in several estates lack of reliable energy is a fundamental bottleneck to production and limits productivity. In fact, most sisal estates rely exclusively on the local grid for their electricity, which is characterized by power cuts for up to 50% of the time. As a result, when power energy is not available, the production processes have to be stopped. In most estates in Tanzania sisal harvesting is done by hand, making it labor intensive. Additionally, less than 10% of the sisal leaves are fibers. As a result, after the wet-production process, approximately 18 tons of wet waste is produced for every ton of final sisal product (Salum, 2008). This includes the large quantities of water used in the production process. Nowadays, in most production facilities the waste is washed away from the decorticators to some dumpsites or to nearby water streams. Uncontrolled sisal waste disposal has the potential to cause significant ground- and surface water pollution and also atmospheric pollution through methane generation (UNIDO, 2005).

New approaches for the disposal of sisal residual are being investigated. One of the most promising is anaerobic digestion of the residuals for biogas production. Biogas can be used for producing electricity both for grid-based and mini-grid applications, and also as a cooking and heating option. Moreover, biogas residue resulting from anaerobic digestion of organic waste has significant potential as a crop fertilizer and soil conditioner (Arthurson, 2009) (Kivaisi & Rubindamayugi, 1996). One 300 kW pilot facility have been installed in the Tanga region (Muthangya, et al., 2009). Furthermore, it has been estimated that up to 102 GWh of electricity could be generated in Tanzania each year producing biogas from sisal wastes, equivalent to about 3% of the country current power production (Terrapon-Pfaff, et al., 2012). This electricity could be used both to power the sisal production activities and to provide energy services to the population.

2. METHODS

The relationship linking energy technologies to production activities (and technologies) is particularly complex and develops in a context specific way. Whatever sector is considered, each production activity presents very specific energy needs. These needs are primarily determined by the ways in which production is performed, in particular the type of production technologies deployed, but also the types and degrees of complexity of the different produce.

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[2] In fact, while in Tanzania the harvest, production and sale of sisal is centrally done in large estates (e.g. over 1000 hectares), in Brazil different productive organisations specialise on different processes and tasks. In Brazil, smallholder farmers (e.g. with areas smaller than 10 hectares) produce sisal. Entrepreneurs collect sisal from those farms and process the leaves with travelling equipment. On average each entrepreneur has 94 days of man travelling/year visiting around 50 farms (Brenters, 2000). Then another organisation does the final processing and reselling. As a result the process chain (and the technologies) for producing sisal in the two countries are considerably different, with higher productivity (per hectare) and higher sisal quality in Tanzania than Brazil (Dellaert, 2014). More in detail, one of the key differences between the two production processes is the usage of small, diesel-powered, mobile technologies for dry decortication of sisal leaves in Brazil, versus the usage of large, electrical-powered, technologies for wet decortication in Tanzania.

For instance, higher quality standards of the produce often rely on the deployment of more sophisticated production technologies which, in turn, tend to be more reliant on modern energy access and sensitive to the quality of the energy inputs. The satisfaction of these energy needs can be obtained by appropriate and cost-effective combinations of energy technologies. These alternative combinations define the energy technology mix for each production activity in each sector. The above mentioned differences in sisal production in Tanzania and Brazil provide an illustrative case in point.

In order to address this complex set of relationships linking production (and, thus, processes, tasks and technologies) to energy we draw on micro-structural theories of production ((Georgescu-Roegen, 1970), (Georgescu-Roegen, 1976), (Landesmann & Scazzieri, 1996), (Morroni, 1992), , (Andreoni, 2014)). Within these theoretical frameworks the production process is stylized as "a particular system of interrelated tasks through which a sequence of transformations of materials are performed according to different combinations of flow inputs (such as productive agents and mechanical artefacts) and fund inputs (such as fuel, chemical catalysts and electricity), subject to certain scale and time constraints" (Andreoni, 2014). From this micro-structural perspective, the energy needs of a productive unit operating within a given sector are determined by the specific set of processes (and tasks as their components) and the production technologies adopted.

The execution of these processes and tasks can rely on the adoption of traditional or more modern technologies, that is, on different combination of production technologies, equipment, organisational solutions and human skills. Generally, in developing countries we tend to observe more traditional technologies across the existing productive sectors. However, while the adoption of different technologies is affected by the firms' absorption capacity and the overall level of productive development of a country, the adoption or more or less traditional technologies often depends on the technical and quality standard conditions that have to be met in different sectors. For certain sectors, the adoption of traditional techniques is not an option, and firms have to rely on modern technologies with different energy needs. For instance, as we detail in section 3, to obtain different qualities of sisal farms have to deploy different types of processing technologies.

In the agricultural sector, the type of crop and production technologies can change both the total amount of energy consumed as well as the proportions of energy used for various inputs (Jackson & Hanjra, 2014). Up to these days, human labor and draught animal power continue to provide energy at the traditional subsistence scale (Sims & Flammini, 2014). In agriculture, a three-stage evolution of productivity can be considered as follows: from human work, to animal work to modern-energy based technologies (FAO, 2000). The mechanization level increases with modern production technologies, and with it the reliance on modern energy technologies increases. Building on a systematic literature review and meta-analysis of agricultural production, the most common processes, tasks and production technologies in the agricultural sector for rural areas were selected, and related to their energy inputs both in traditional and modern agriculture technology setting. The results are presented in Table 1.

Table 1 Key agricultural processes in rural areas, and energy needs for traditional and modern methods. Elaboration of the authors from sources: (IPCC, 2011), (FAO, 2011), (FAO, 2000), (Bates, et al., 2009), (Practical Action, 2014), (ESMAP, 2008), (Bundschuh & Chen, 2014)

Processes	Tasks	Traditional methods & technologies	Energy sources	Modern methods & technologies	Energy sources
Primary production	Land preparation/ Tilling	Hand hoe, animal drawn tiller	Human and animal	Power tiller/two-wheel tractor	Fossil fuels, biofuels
	Seeding	Hand planting	Human	Bed planter, row planter/seed drill	Fossil fuels, biofuels
	Irrigation	Container/bucket for lifting + carrying water, wind pumps, rain fed	Human, animal, traditional renewable	Mechanical irrigation (with diesel pump, treadle pump, rope pump, ram pump, persian wheel, river turbine)	Fossil fuels, biofuels, electricity, mechanical energy, and direct usage of renewable energy (solar, wind and hydro)
	Fertilizing	Organic fertilizer	Human and animal	Organic and inorganic fertilizer applied with modern methods	Energy embedded in the fertilizer, fossil fuels, biofuels
	Harvesting	Scythe, animal drawn mower, manual practices	Human and animal	Harvester, attached to a power tiller/tractor	Fossil fuels, biofuels
Crop Processing	Drying	Hand-held fan, sun drying	Human, traditional renewable	Artificial drying, powered fan	Electricity, fossil fuels
	Milling, pressing	Hand ground, flail	Human	Electric motors, direct mechanical supply, powered mill, oil espellers	Electricity, fossil fuels, biofuels, mechanical energy
	Cutting, shredding	Knife	Human	Saw mills, power shredder	Electricity, fossil fuels, biofuels, mechanical energy
	Winnowing, decorticating	Winnowing basket	Human	Powered shaker, grinders	Electricity, fossil fuels, biofuels, mechanical energy
	Spinning	Manual spin	Human	Powered spinner	Electricity, fossil fuels, biofuels, mechanical energy
	Packing	Manual packing	Human	Automated packing	Electricity
Crop conservation and distribution	Refrigeration (dairy products, fish, meat)	None	-	Refrigerated storage	Electricity
	Distribution to local market	Walk and distribution with animal	Human and animal	Modern transportation by road	Fossil fuels, biofuels

	Transport to national and international market	-	-	Modern transportation by road, rail, sea or air	Fossil fuels, biofuels, electricity

The theoretical framework points to the existence of different energy needs in the agricultural sector depending on the types of production process (including subset of tasks) and deployed factors (and the changes of these needs resulting from production transformation). The satisfaction of these energy needs can be met by different energy technology mixes.

The analytical framework was then used both for the micro-structural analysis of the case study and to create a model for the subsequent scenario analysis. The model was developed in the Long range Energy Alternatives Planning System (LEAP). LEAP is a widely-used accounting modeling tool for energy systems and policy analysis, adopted by thousands of organizations in more than 190 countries worldwide (Community for Energy, Environment and Development, 2015). With the model, several scenarios were evaluated to compare different interventions in the energy and productive sector of the local activities. The considered timeframe for the model is from 2014 to 2030.

The developed model was structured as for Table 1, and then applied to the case study analysis as described in section 3. Doing so, the model provides a 'bare metal' basis for the development of future case studies.

Additionally, the model includes the possibility of modelling the energy supply and demand for residential sector in the area where the productive activities are located. This is done providing a soft-link to the residential energy access model described in (Fuso Nerini, et al., 2016). Doing so, it permits to evaluate the linkages between the productive uses and residential energy systems. In this context, the multi-tier framework elaborated by the World Bank for the Global Tracking Framework of the Sustainable Energy For All Programme was used as a metric for residential energy access (The World Bank, 2013). This metric relates household appliances usage to a specific tier of energy access as defined in Table 2.

Table 2 Tracking electricity access with a Multi-Tier framework[a], Source: World Bank Global Tracking Framework, Source: Elaboration of the authors from (The World Bank, 2013)

TRACKING ACCESS TO ELECTRICITY	GLOBAL TRACKING	NO ACCESS	NO ACCESS	ADVANCED ACCESS			
		No electricity	Solar lantern or rechargeable battery lantern	Home system or grid connection			
	COUNTRY-LEVEL TRACKING	**Tier-0**	**Tier-1**	**Tier-2**	**Tier-3**	**Tier-4**	**Tier-5**
	Indicative electricity services	-	*Task lighting + Phone charging or Radio*	*General lighting + Air circulation + Television*	*Tier 2 + Small appliances*	*Tier 3 + Medium or continuous appliances*	*Tier 4 + Heavy or continuous appliances*
	Consumption (kWh) per household per year	*<3*	*3–66*	*67–321*	*322–1,318*	*1,319 – 2,121*	*>2,121*

TRACKING ACCESS TO COOKING	GLOBAL TRACKING	NO ACCESS	BASIC ACCESS	ADVANCED ACCESS
		Self-made cookstove	Manufactured non-blen cookstove	Blen cookstove

COUNTRY-LEVEL TRACKING	Tier-0	Tier-1	Tier-2	Tier-3	Tier-4	Tier-5

[a] *For this study a simplified version of the multi-tier framework for household energy is used with a focus on aspects relating to the services to be powered with electricity. The aspects of affordability, legality, convenience as well as health and safety are not represented in the cost comparison. A complete description of the framework can be fund in* (The World Bank, 2013).

A few studies have already used the metric as a basis for models for household energy access, gaining both case-specific (Fuso Nerini, et al., 2015), and generalizable conclusions (Fuso Nerini, et al., 2016).

The costs and technology assumptions for the energy model are reported in Annex A.

3. CASE STUDY EXPERIMENT

The results of the micro-structural analysis for the agricultural sector reported in Table 1 were used to analyze the case study of the productive activities in at the Mukbara Sisal Estate in the Tanga region. The estate has a cultivated area of 1724 hectares, and a sisal production of approximately 900 tons of final produce a year. The estate analyzed in this case study deals primarily with 3L quality fibers.

The most relevant processes and tasks in the sisal production at the estate are visible in Figure 2. They include: (1) harvesting, (2) decortication of the leaves, (3) sun-drying of the fibers, (4) open air disposal of the decortication process residuals, (5) brushing of the fibers, (6) pressing and bailing. At the production facility most of the processing equipment used is more than 50 years old, and considerably energy inefficient. In this context, electricity is obtained from the national grid and from a locally owned backup diesel generator. The diesel generator is in use when the grid power is not available, on average 4 to 6 hours a day. Energy represents a considerable cost in the production process, contributing to over 40% of the total costs.

Figure 2 Key sisal production tasks-processes at the Mkumbara Sisal Estate

The estate has over 200 employees working with the production of sisal, most of whom are dedicated to harvesting. Of those employees, approximately 40 live in households attached to the production site with their families. The other employees live in nearby villages. In this context, there are three villages within 5 km from the estate. Those are reported in Table 3.

Table 3 Characteristics of the villages within 5 km from the Mkumbara Sisal Estate, 2015

Village name	Population	Grid connected	% of households grid connected
Magila	4,948	Yes	25 %
Goha	2,106	No	-
Kwenangu	1,125	Yes	25 %

After semi-structured interviews with representatives from the local villages, it emerged that local households use limited amounts of electricity. Of the households connected to the national grid, electricity is used primarily for lighting (nearly all the households), then for radio and phone charging (approximately 80% of the households), for television (approximately 15% of the households), and ironing (approximately 5% of the households).

In the households not connected to the grid, lighting is done mostly with candles and kerosene lanterns. All the interviewed households, electrified and not, cooked food with either charcoal or firewood. The average spending per household for cooking is around 6 USD/month for purchasing charcoal, and around 4.5 USD/month for purchasing firewood[3].

The following alternative technology scenarios, were evaluated for the productive and residential energy systems in the case study:

1. *Reference scenario (REF):* This scenario assumes that energy usage at the production facilities will not change significantly during the modeling time-frame.
2. *Energy Efficiency scenario (EE):* In this scenario the existing energy-intensive and low-efficiency machineries are replaced with more energy and water-efficient ones.
3. *Productive Uses scenario (PU):* This scenario assumes a more ambitious level of mechanization of the agricultural processes, and the installation of a biogas-generation power plant to meet the local electrical demand and to sell the surplus electricity production to the local grid.
4. *Energy for All scenario (EA):* In this scenario the PU scenario is brought a step forward. The scenario evaluates how the local productive activities can be combined with electricity and other energy commodities generation to benefit the nearby communities. Several energy technologies are compared to provide different levels of energy services to the local villages.

As for the EA scenario, it was evaluated how the energy systems for the villages nearby the facilities could develop. In Table 4, the specific interventions for the evaluated scenarios are reported, including as well the local residential uses of energy. The assumptions for the scenarios are reported in Annex 1. The following section presents the results of the scenario modelling experiment.

Table 4 Agricultural processes in the case study by scenario (when nothing is reported it means that the scenario is equivalent to the Reference scenario for that process)

Processes	Tasks	Reference scenario (REF)	Energy Efficiency scenario (EE)	Productive Uses Scenario (PU)	Energy for All Scenario (EA)
Primary production	Land preparation/ Tilling	Caterpillar (73 years old)	Efficient caterpillar		
	Seeding	Nursery establishment and transplanting			
	Irrigation	No irrigation		Irrigation in the dry season	As the PU scenario
	Fertilizing	No fertilization		Fertilization with the biogas production residuals	As the PU scenario
	Harvesting	Harvesting by hand		Mechanically-assisted harvesting	As the PU scenario

[3] These expenditures do no take into account the time spent for collecting firewood, when not purchased.

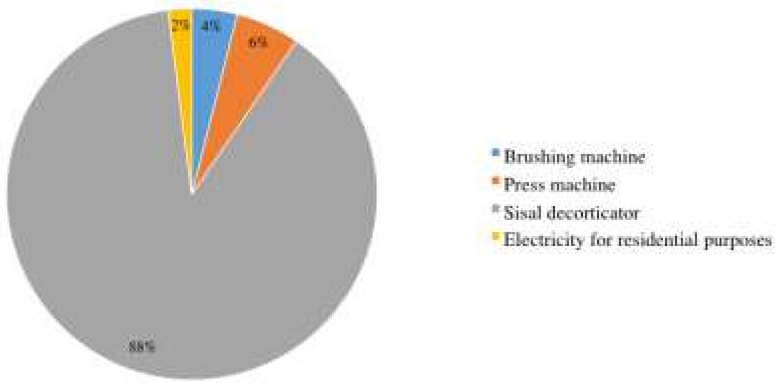
Crop Processing	Drying	Sun drying		Artificial drying	As the PU scenario
	Milling, pressing	Press machine (70 years old)	Efficient press machine		
	Cutting, shredding	Brushing machine (70 years old)	Efficient brushing machine		
	Winnowing, decorticating	Decorticator (70 years old)	Efficient decorticator	Combined with biogas and electricity production	As the PU scenario
	Spinning	None			
	Packing	None			
Crop conservation and distribution	Refrigeration (dairy products, fish, meat)	None			
	Distribution to local market	None			
	Transport to national and international market	Outsourced to local company			
Residential	Access to electricity services	Current situation	As the REF scenario	Tier-4 of electricity access by 2030 for only the people living on the site of production, and extra production of electricity sold to local grid	Production of enough electricity for allowing a Tier-4 access to electricity services by 2030 for the people living withing 5 km from the production facilities
	Access to cooking services	Current situation	As the REF scenario	As the REF scenario	Tier 4 access to cooking services by 2030 with biogas-based cookstoves

4. ENERGY SCENARIO MODELS: RESULTS

Reference (REF) scenario

In the reference scenario, approximately 370 MWh of electricity are used each year at the production facility. Most of the electricity is used for the mechanical treatment of the sisal product, and approximately 2% of the total yearly electricity demand is associated with the residential demand of the workers living on-site (Figure 3). Approximately 80% of the electricity demand is met with electricity from the local grid. The rest is obtained from a locally owned diesel generator, in use during grid power cuts.

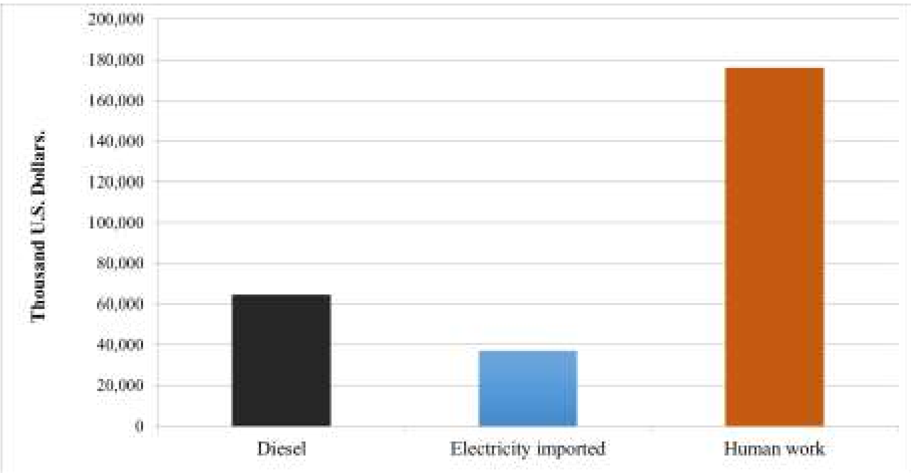
Figure 3 Electricity usage at the sisal production facilities



In addition to the electricity usage, diesel is used for the land preparation and harvesting procedures (approximately 46,800 l of diesel/year for the caterpillar and tractors).

Looking at the yearly costs for running the sisal factory (Figure 4) energy represents a large share of the production costs (approximately 115 thousand US$/year). Labor costs for harvesting and productive processes also present considerable costs. In fact, labor costs at the facility is almost 180 thousand US$/year. Over 80% of the labor cost is incurred with the harvesting processes. In this context, there is a margin for improving the process mechanization, as investigated in the productive uses scenario.

Figure 4 Yearly running costs at the sisal production facility, reference scenario year 2014



Energy efficiency (EE) scenario

In the EE scenario, the effect of substituting the most energy intensive and inefficient processes is evaluated.
In the EE scenario, the following actions are taken in the first model-year (2015):

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a. Replacement of the 70 year old decorticator and brushing machine with an energy and water efficient combined decorticator and brushing machine (energy efficiency improved by approximately 25%,)
b. Replacement of the 73 year old caterpillar with fuel-efficient one (fuel usage diminished by approximately 50%)
c. Replacement of the 70 year old press machine with new a one (energy efficiency improved by approximately 31%,)

The model results for the EE scenario show the large margin of improvement in energy efficiency at the facility. Even by only intervening on the most energy-intensive production processes, the electricity usage could be diminished by 70% from around 370 to 110 MWh/y, and the diesel usage for the caterpillar decreased by one third.

Additionally, the substitution of the water-inefficient decorticator would save approximately 50 cubic meters of water every day. Further, the interventions would avoid over 3,200 tons of emissions of CO2 eq during the period 2015-2030.

Finally, in Table 5 the estimated investment costs for the machineries are reported, together with the possible energy savings associated to each interventions and the estimated payback time for each intervention. Only considering the monetary savings resulting from energy savings, the substitution of the decorticator and brushing machine would have payback times as low as 5 years. Also, the substitution of the old caterpillar would have a payback time of approximately 10 years, while the substitution of the press machine would have payback times of around 20 years.

Table 5 Interventions for the EE scenario

Intervention	Investment cost (US$, min)	Investment cost (US$, max)	Energy savings 2015-2030	Payback time (years)
Substitution of decorticator and brushing machine	160,000	200,000	3,960 Mwhe	5
Substitution of caterpillar	125,000	165,000	215,000 l of diesel	10
Substitution of press machine	25,000	45,000	30 Mwhe	>15

Productive Uses scenario

In this scenario a series of measures for improving the productivity at the sisal estate are evaluated. Those are:

a. The usage of the over 25,000 tons/year of sisal residuals to produce biogas combined with a 500 kWe power generation system
b. The usage of the residuals from the biogas production for fertilizing
c. An irrigation system for irrigating the crop in the driest months

Additionally, the possibility of mechanically assisted harvesting is investigated, to decrease the need of labor inputs to the production. In this scenario the produced electricity is used to substitute the power from the diesel generator when necessary, and the surplus is sold to the grid at Tanesco's standardized small power projects tariff (Tanesco, 2015).

Regarding the possibility of producing biogas-based electricity on-site the results are encouraging on a number of levels. With an estimated capital investment for the biogas and power production facilities of approximately 1.9 million dollars, the project would result in a total income of over 4 million 2015 US$ over the period 2015-2030 for selling approximately 3,500 MWh/year of electricity to the grid. That is added to over 1 million 2015 US$ of savings of avoided fuel costs for producing electricity with the diesel generator. As a result the project would have a payback time of slightly over 5 years.

Additionally, the biogas-based electricity generation would considerably decrease the green house gases (GHG) emissions. Over the modeling period, around 26,500 tons of CO2eq could be avoided for substituting grid electricity. Also, 20,000 tons of CO2eq could be avoided for improving the disposal of sisal waste and 800 tons of CO2eq for the avoided emissions from the diesel generator. Those avoided emissions could also represent an additional source of income. For instance, with a CO2 cost of respectively 5, 10 and 25 USD/ton, additional incomes of approximately 170, 340, and 850 thousands 2015 US$ would be made available over the modeling period.

Regarding the measures to increase sisal productivity at the facility, literature on the possibility of increasing sisal yields with irrigation and fertilization is limited. (Hartemink, 1995) found that sisal grow best with about 1,200 mm of rain per annum. In the Tanga region sisal is cultivated near the coast with 1,300 mm of annual rainfall and inland with 600 mm of annual rainfall. At the considered estate rainfall is estimated to be approximately 800 mm/year. However, rainfall is not constant throught the year. An experiment in Israel (Carr, et al., 2015) found that targeted irrigation only in the 2 driest months of the year could result in significant sisal yield increases. In fact, in the experiment, non-irrigated yield produced only 60% as much sisal as the irrigated one. Also, combined experiments on sisal productivity in Kenya and Tanzania found that rainfall is the most critical factor affecting sisal leaf production (UNIDO, 2005). Regarding fertilization, (Hartemink, 1995) observed that there is a profound fertility decline in many soils under sisal cultivation in the Tanga region, and when fertilized, sisal bulbs in nurseries grow to plants up to 7 times as large. Also, (Hartemink, 1997) analyzed nutrients in the soil under mono-cropping of sisal, finding that the nutrient balance in the absence of fertilizers or manure is negative for each nutrient. Additionally, while fertilization could increase emissions of GHG such as NO2 or CH4, those emissions could potentially be offset by the carbon sink created by faster growing sisal plants. In this case study, the usage of the biogas production residual as fertilizer would minimize additional GHG emissions, in accordance with (Feng, et al., 2013), which found that biogas residues have low GHG emissions compared to other fertilizers. It is difficult however to estimate the impacts of irrigation and fertilization without additional experimental data. For this research the impact of a yield increase between 30% and 50% as a result of irrigation and fertilization was investigated. The suggested increase in yield would result in an increased production of 270 to 450 ton of sisal/year, resulting in an additional income of 430 to 720 thousand US$/year respectively.

Regarding irrigation, an irrigation system would have to be put in place to provide irrigation in the dry months. (The Food and Agricultural Organization, 2015) gathered data for a number of irrigation projects in Tanzania, reporting irrigation costs between 16 and 2,500 US$/hectares, depending on location and irrigation technology. This preliminary estimation was used to evaluate the cost range for irrigating the agricultural area considered in the case study. Regarding fertilization, while fertilizer would be available from the biogas generator at a near-zero cost, spreading the fertilizer to the large cultivated area would present costs for machineries to distribute the fertilizer over the estate area. The estimated cost for a spreader machine could vary from around 15.000 US$ for a used machine, to up to 100.000 US$ for a larger and new machine (TractorHouse, 2015). Even if the options of fertilization and irrigation would have to be more thoroughly investigated with a site-specific project, the preliminary cost and income estimations are shown in Table 6. The results depict the potential high cost-effectiveness of improving agricultural productivity at the facility.

Table 6 Investment and O&M costs and potential income resulting from irrigation and fertilization at the facility over the years 2015-2030 (thousands 2015 US$)

Action	Min investment cost	Max investment cost	Min O&M cost[a]	Max O&M cost[a]	Potential additional income due to an improved harvest by 30%	Potential additional income due to an improved harvest by 50%
Fertilization	15	100	130	210	4,700	7,850
Irrigation	27.5	4,310				

[a] *Includes personnel cost (1 to 2 full time employees) and potential fuel and electricity costs due to fertilization and irrigation*

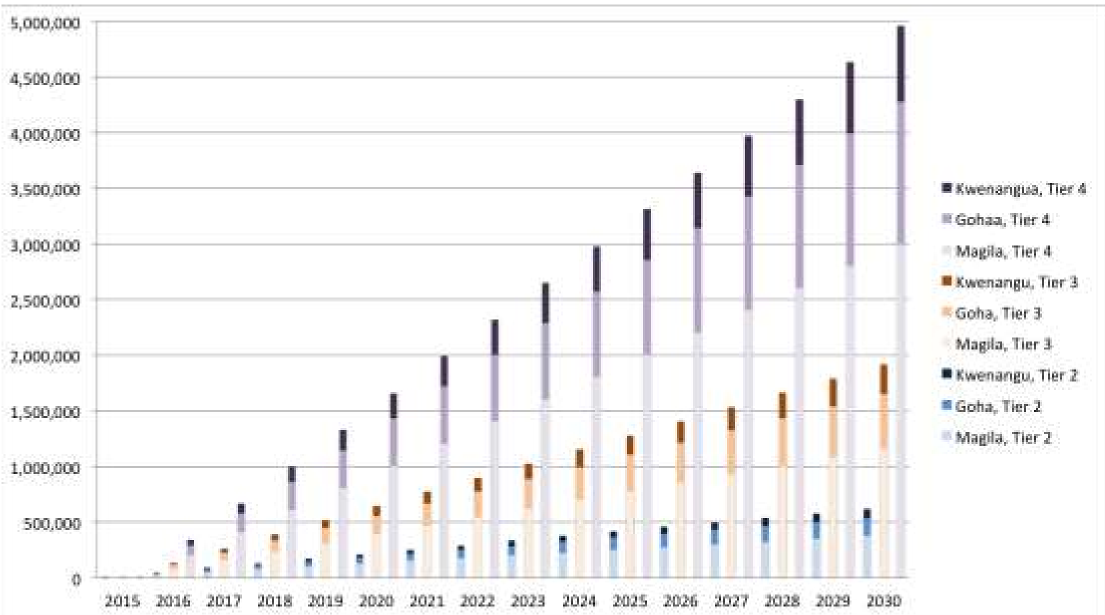
Finally, harvesting of sisal is a highly labor-intensive process. In this context, the authors could not find any machine in the literature developed for mechanized harvesting of sisal. Cutting and removal of leaves from the plant are unique and selective-type operations that have never been mechanized. Additionally, harvesting requires much stooping, lifting and carrying of sizable weights. As a result, depending on the availability of jobs nearby the estates, finding harvest labor can be challenging. In fact, when available, workers prefer less strenuous and less hazardous jobs (MATIRU, et al., 2011). In estates near to the coast, where several jobs possibilities are present for low-skilled labour, estate owners have had troubles finding labor for the daily harvesting operations on several occasions. This does not seems to be true in the drier inland of the Tanga region, where less job opportunities make sisal harvesting jobs more attractive. Thus, there appears to be some potential for mechanizing parts of the harvest operations. Also, an increased mechanization could support the expansion of the sisal production. It was estimated that for the considered facility, each 10% decrease in the labor needs, would result in almost 50.000 hours of work saved each year. That would result in of almost 140 thousand 2015 US$ between the years 2015-2030 for each 10% decrease of harvesting work. These numbers show the high potential savings for increased harvesting mechanization, and can give an indication of the potential budget to invest in new harvesting machinery.

Energy for All scenario (EA):

Using the PU scenario as a basis, this scenario focuses on how the local productive activities can be combined with electricity and other energy commodities generation to benefit the nearby communities. More in detail this scenario looks at how the sisal activities could provide energy to the communities within 5 km from the estate (see Table 3). These communities comprise almost 9400 inhabitants.

Starting from the current usage, the electricity demand in the three communities was projected in order to achieve a Tier 2, 3 and 4 of electricity access by 2030 (Figure 5). By 2030, the combined electricity demand for the three villages is projected to increase to approximately 600, 1,900 and 4,950 MWh/year for a Tier 2, 3 and 4 of electricity access respectively.

Figure 5 Residential electricity demand for the villages within 5 km from the sisal estate



To meet the electricity demand, selected generation options were ranked depending on their levelised cost of producing electricity (LCOE) and availability at the sisal estate (Table 7).

Table 7 Electricity generation options

Technology	Considerations	LCOE (2015 US$/kWh)
Biogas generation	As in the PU scenario.	0.086
Solar PV generation (no battery backup)	Solar availability: 5.0 to 5.5 kWh/m2/day (IRENA, 2015)	0.225
Diesel generation	Diesel generator already available on site.	0.4
Wind generation	Low average wind speeds at 10 m: between 3.5 and 4 m/s (IRENA, 2015).	Not economically feasible
Mini hydro	Absence of exploitable streams for mini hydro generation nearby the facility. High seasonal variability of water availability.	Not technically feasible

With the characteristics at the site, biogas electricity generation is the cheapest option, followed by solar generation and diesel generation. As seen in the PU scenario, considered the available sisal waste, biogas generation can produce up to 3,500 MWh of electricity a year. That would be more than enough to power the local productive activities and the electricity demand of the three settlements for a tier 2 and 3 of energy access up to 2030, and for a tier 4 up to 2024. Then, the cheapest option to increase power production at the sisal estate would be to include solar PV generation with an LCOE of 0.225 US$/kWh.

Given the standard power purchase agreements for small power producers in Tanzania, the electricity generated at the estate could be sold to the local grid for 0.157 US$/kWh or provided directly to the communities at a selling price of 0.240 US$/kWh (Tanesco, 2015). This last option could be of interest for the community of Goha, which does not have any grid connection yet. To provide electricity directly to the village, it was estimated that an additional investment cost between 290 and 410 thousand US$ would be needed for transmission and distribution (T&D) of electricity[4], depending on the projected electricity demand. That would result in an additional LCOE due to T&D in the village of Goha from 0.2 US$/kWh for a Tier 2 target, to 0.04 US$/kWh for a Tier 4 target. Therefore, investing in T&D for connecting the village of Goha would be cost effective only at residential electricity consumptions over Tier 3.

Finally, several options could be evaluated for providing the excess biogas for cooking in the nearby communities with modern cooking stoves. It is estimated that each household in the region needs 1.25 to 1.5 m^3 of biogas for cooking/day. To provide biogas to the communities, however, adequate infrastructure should be put in place, for either selling the compressed gas or distributing it with a pipeline.

Scenarios comparison:

Finally, in Table 8 some parameters regarding the REF, EE, PU scenarios are compared. Also the possibility of combining the interventions of the EE and PU scenarios is evaluated.

Table 8 Comparison among selected scenarios for the years 2015-2030[a]

Scenario	Interventions cost ('000 2015 US$ min-max)	Increased revenue from REF[b] ('000 2015 US$)	Total diesel usage (l)	Total electricity usage (MWh)	Total electricity production (MWh)	Net GHG emissions 2015-2030 (Tons of CO2eq)
REF	-	-	1,027,500	4,750	1,070	5,830
EE	310-410	680	864,100	1,390	330	2,610
PU[c]	1,800-2,000	4,170	702,000	4,755	52,500	- 43,800
EE + PU	2,110-2,410	4,850	486,000	1,390	52,500	- 44,450

[a] *The results from the EA scenarios are not reported in the table. In fact, the EA scenario focuses on the provision of electricity to communities nearby the facility, but for the parameters shown in Table 8 it is comparable to the PU scenario.*

[b] *The possible revenues derived from selling carbon credits are not considered in the results shown in table 8*

[c] *The effects of the PU scenario reported in the table do not include possible productivity increases with fertilization, irrigation and mechanization of the agricultural processes*

[4] The village is situated at approximately 3 km from the sisal production facility. The methodology for calculating the T&D needs can be found at (Fuso Nerini, et al., 2016)

Comparing the scenarios, the potential impacts of the energy efficiency interventions and of biogas-based electricity generation at the estate are comparable. The introduction of biogas-based electricity generation would have by far the largest impact in terms of both electricity production and GHG emissions. On the other hand the proposed energy efficiency interventions would significantly decrease electricity and diesel usage at the estate. Combining the two scenarios (EE + PU row in Table 8) would maximize the benefits of the two scenarios, with the energy efficiency interventions resulting in an increased amount of electricity to be sold to the local grid and nearby communities.

5. CONCLUSIONS AND POLICY IMPLICATIONS

With a case-study approach, this paper shows the value of micro-structural analyses and energy modelling for supporting the development of productive activities. The created analytical framework for the analysis of the agricultural production-energy relationship was combined with tailored energy models to explore the case study of the sisal production activities in Tanga, Tanzania. The case-study analysis shows how the lack of modern energy usage can be both a limiting factor and a considerable cost for agricultural productivity and development. At the same time combining modern and efficient usage of energy and the production of energy carriers in agriculture shows great potential for boosting productivity and local energy access.

In the analysis of the current situation at the studied estate, it emerged how energy is currently being used in an inefficient and costly manner. Currently, electricity and diesel costs represent over 40% of the total production costs at the considered facility. At the same time most of the production machineries used are over 70 years old. As a result, the installation of new and more efficient machineries could decrease by two thirds the usage of electricity and by one-third the usage of diesel. Without any subsidies, some of those replacements would have payback times of less than five years. At the same time, there is a great potential for better integrating the energy and agricultural systems. The usage of the currently unexploited wastes from the productive processes could support the production of around 350 MWh/year of electricity. Locally biogas-based production of electricity would cost 30% less than purchasing electricity from the grid, and almost one fifth of producing electricity with the locally owned diesel generator, on a kWh basis. Additionally, as the electricity produced would largely exceed the estate's needs, the agricultural producer could diversify its business becoming a small power producer. Locally produced electricity has the potential of sustaining the electricity needs of all the communities living within 5 km from the facility, up to a Tier 4 of residential electricity access. Also, biogas could be used for substituting traditional cooking methods. In addition, the biogas plant has the potential to avoid the emission 47,300 tons of CO_2eq between the years 2015-2030, and the residuals from the biogas production could be used as fertilizer. That fertilizer, could be used to revert the registered profound fertility decline in the region's soil. Targeted fertilization and irrigation, in turn, have the potential to largely increase sisal productivity and thus, incomes. The model also showed possible opportunities for increased process mechanization.

The main conclusion from the case-study analysis is that a better integration of the energy and agricultural systems could benefit both the agricultural producer and the local communities.

However, the limited advances in the local productive processes in the last half a century may derive from a series of market failures, such as poor knowledge of the potential profit/gains to be made with new fuel/appliance combinations, and the lack of financial services to finance new and capital-intensive processes (Howells, et al., 2010). For the suggested modernization of the productive system to happen, quantified studies such as the one presented in this paper will have to be coupled with targeted interventions to support those changes. Those may include agricultural loans at affordable rates, financial assistance for the promotion and expansion of sisal markets and new policies to attract investments in agricultural growing and processing (UNIDO, 2005).

Further work may attempt to develop new cases studies in different productive sub-sectors to generalize the results and refine the created framework.

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ANNEX A – MODEL ASSUMPTIONS

In this annex the model assumptions that were not already included in the paper are reported. Table A.1. reports the power and usage characteristics of the used machinery at the estate. Tables A.2., A.3., A.4. and A.5. report scenario-specific values used in the model. When the references are missing the data came directly from field observations.

Table A. 1 Current machinery usage at the estate

Machinery	Power or specific diesel consumption	Hours of usage/year
Press machine	*15 kW*	*1,872*
Brushing machine	*8.5 kW*	*1,872*
Decorticator	*135 kW*	*2,496*
Caterpillar	*30 l/h*	*960*
Tractors	*10 l/h*	*21,600*

Table A. 2 SE4All scenario, projected population in the villages within 5 km from the estate, [people] (Population growth projections from (UNDESA, 2015))

Village	2015	2020	2025	2030
Magila	*4,948*	*5,728*	*5,898*	*6,073*
Goha	*2,106*	*2,438*	*2,510*	*2,585*
Kwenangu	*1,125*	*1,302*	*1,341*	*1,381*

Table A. 3 PU and SE4All scenario, electricity generation and distribution parameters

Plant type	Investment Cost 2015	O&M costs (% of investment cost/year)	Efficiency	Life (years)	Source
Biogas power plant	*3800* $/kWe	*9 %*	-	*15*	(UNIDO, 2010) *and field data*
Solar PV	*3400* $/kWe	*3 %*	-	*20*	(Fuso Nerini, et al., 2015 (in press)).
Diesel Genset	*721* $/kWe	*10 %*	*33%*	*15*	*(Fuso Nerini, et al., 2016).*
T&D needs for connecting the village of Goha – Tier 2 of access	1,603,971	*2 %*	-	*30*	*The methodology for the T&D estimations can be found in* (Fuso Nerini, et al., 2015 (in press)).
T&D needs for connecting the village of Goha – Tier3 of access	1,805,394	*2 %*	-	*30*	
T&D needs for connecting the village of Goha – Tier 4 of access	2,173,013	*2 %*	-	*30*	

Table A. 4 CO2 savings

Parameter	Factor	Unit	Source
Grid electricity carbon base in Tanzania	*0.5*	*kg CO2eq/kWh el*	(UNIDO, 2010)
Sisal waste methane carbon base	*0.06*	*kg CO2eq/Ton of waste*	(UNIDO, 2010)
Diesel-based electricity production carbon base	*0.246*	*kg CO2eq/MWh fuel*	(IPCC, 2006)

Table A. 5 Other model parameters and assumptions

Parameter	Value	Unit	Source
Daily pay in 2015 for agricultural workers (harvesting)	*4,160*	*Tanzanian shillings*	-
Daily pay in 2015 for agricultural workers (processing)	*5,000*	*Tanzanian shillings*	-
Standardized Small Power Projects	*0.157*	*US$/kWh*	(TANESCO, 2015)

Tariff for Biomass, 2015			
Mini-Grid Connection using Avoided Cost Tariff, 2015	*0.24*	*US$/kWh*	(TANESCO, 2015)
Discount Rate	*5*	*%*	-

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