EU- UNEP AFRICA LOW EMMISIONS DEVELOPMENT STRATEGIES

AFRICA-LEDS

LOW EMISSION DEVELOPMENT FROM ENERGY SECTOR AND AGRICULTURE SECTOR IN MOZAMBIQUE

REPORT ON MODELLING AND CAPACITY BUILDING

CEAGRE

CENTRO DE ESTUDOS DE AGRICULTURA E GESTÃO DE RECURSOS NATURAIS

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1. Executive Summary

The objective of the framework of the Low Emission Development Strategy (LEDS) is to develop technical and technological modeling capacities, establish a sound analytical framework to facilitate the decision-making, and implementation of long-term LEDS policies that respond to the decisions of the Agreement of Paris through the Nationally Determined Contribution (NDC). Mozambique identified as priority sectors Sustainable Agriculture based on clean energies, i.e. micro irrigation projects (in clean energy) and agro-forestry systems (Agriculture). Thus, for the development of modeling actions in these areas identified by the country modelling team are the Long-range Energy Alternatives Planning System (LEAP) for Energy and REDD Abacus for agriculture and land use change systems. The models provide relevant information on mitigation of emissions using renewable energy sources, avoided emissions, and carbon sequestration from silvicultural practices as well as socio-economic benefits such as increased income (including job creation and profitability).

An integrated methodology was used to build mitigation scenarios of 21 years (spanning 2010 to 2030) for the energy and agriculture sector. The fuel powered irrigation system (FPI) emission was used as business as usual (BAU) of energy sector, while solar powered irrigation system (SPI) as its mitigation scenario. Slash and burn agriculture (SAB) was used as BAU scenario in the agriculture sector and agroforestry system (AFS) as its mitigation scenario. All scenarios of mitigation in both sectors were used for the whole country using LEAP for the energy sector and REDD Abacus for the agricultural sector, while a merged (agriculture and energy system) scenario was done in spreadsheet. LEAP is a widely used tool for energy policy analysis and assessment of climate change mitigation. The irrigation scenarios were built using the main irrigated crops of Mozambique as reference to estimate the mitigation impact of SPI in energy sector. The main crops were classified as vegetables, roots and tubers, cereals, pulses and sugar cane. Although sugar cane represents 60% of the irrigated area in Mozambique, it was not included in the scenarios, considering that it is manly a commercial crop and the main source of energy is electricity from the main grid generated from hydropower dam. REDD Abacus is a freely available software developed to analysis the opportunity cost of land use changes in a landscape or area within a period of time and generates the abatement cost curve of different land use change options. AFS impact assessment on mitigation was used as option to replace traditional slash-and-burn agriculture, mainly cassava and maize dominated agricultural systems, two of the main cash crop of smallholder farmers in Mozambique. The activity data, emission factors and assumptions made were gathered from various documents published by the national government departments, peer-reviewed and published academic research and information disseminated by technology suppliers. At the last modelling stage, findings from LEAP were used in REDD Abacus model to generate a scenario of both mitigation options for both energy and agriculture sector.

1.1.1. Replacing fuel powered irrigation by solar powered irrigation

Based on our estimations, fuel powered irrigation (FPI) in Mozambique emitted a national total of 2,721 tCO2-eq in 2010, and it is projected to emit 17,981 tCO2-eq in 2030, following a trend presented in national irrigation strategy to increase the irrigated area. Average emission for business as usual from 2010 to 2030 is about 14,735 tCO2-eq per year of FPI. On the contrary when solar powered irrigation system (SPI) is used, average annual emission during the same period falls from 14,735 to 11,092 tCO2-eq per year.

1.1.2. Replacing slash and burn agriculture by agroforestry system:

Our findings indicate that replacing slash and burn agriculture (SAB) with agro-forestry system (AFS) resulted in 33% reduction in average annual net emission, falling from 5.8 million to 1.8 million tCO2-eq per year. While AFS does not actually reduce emissions, it is an important sink of carbon; therefore, reducing net emissions from land use change systems.

1.1.3. Scenario to reduce GHG emission from Agriculture and Energy sector (soft-linking approach)

The mitigation scenarios will serve as an outstanding effort involving activities that lead to reduced greenhouse gas (GHG) emission in both energy and agricultural sectors. Findings from the BAU scenario suggest that both land use change and irrigation will reach an emission of about 6.0 million tCO2-eq by 2030.

Mitigation scenario actions for both sectors (energy and agricultural) have potential to lower cumulative GHG emission to 1.9 million tCO2-eq per year by 2030. Compared to historical baseline emissions (BAU), replacement of SAB with AFS and FPI with SPI reduces emissions, respectively, by 33% and 79%. Although emission reduction is lower under SPI than under AFS due to considerably small irrigated land in Mozambique, SPI has higher potential in relative terms to reduce emissions compared with AFS. Combining SPI and AFS, our results show a potential emission reduction of 54% under mitigation scenarios for irrigation and land use systems.

1.1.4. Economic and social benefit of solar powered irrigation system against fuel powered irrigation system

We compared FPI (BAU scenario) to SPI in terms of net present cost (NPC), job creation, and emission reduction. Estimated NPC for FPI is more than threefold higher than that for SPI (62,494 versus 16,472 USD)[1]. For BAU scenario, our results show that CO2-eq emissions are largest for vegetable crops, but it is worth noting that vegetable crops generated highest employment gains compared to all crop groups considered in the analysis. Compared to BAU scenario, vegetable crops' emission drops to close to zero and job creation doubled under SPI scenario. Similar patterns are registered for other crop groups such as roots and tubers and pulses.

1.1.5. Economic and social benefit of Agroforestry against other land use

Land use transitions were analyzed in terms of economic and social impacts, such as profitability of land use systems, job creation, and potential for carbon sequestration. Tradeoff analysis shows that potential benefits in terms of contribution to emission reduction, job creation and profitability should be further evaluated. The potential of AFS for carbon sequestration is largely associated to growth of trees in agricultural systems, which in turn establishes a carbon stock close to natural forest while producing annual crops. AFS showed highest profitability among all land use systems considered. Analysis of land use changes reveals that a general transition from SAB (maize and cassava) towards AFS generates higher profits and lower emission.

Tradeoff analyses of carbon emissions and employment also suggest that some win-win solutions are achievable. Carbon-sequestering land use changes increase job creation, as AFS is the only land use system that falls into the "moderate-carbon-high-jobs" cluster; on the other hand, SAB (cassava and maize) falls into the "low-carbon-moderate-jobs" cluster. This is consistent with the fact that SAB is typically practiced by subsistence farmers with low productivity mainly emanating from low use of yield-enhancing inputs.

Cluster analysis between profitability and employment under different land cover systems shows that AFS fall into “high-jobs-high-profitability” cluster, While cassava and maize (SAB) fall into “moderate-jobs-moderate-profits” cluster. Overall, these results further emphasize that AFS is the only land cover system which generates higher profits, higher job creation and moderate carbon stocks, suggesting that AFS generate social, economic and environmental benefits.

Remarks and recomendations

- The Government of Mozambique has its INDC and needs to move towards the next steps, above all, to estimate emissions. Therefore, there is technical demand to deal with models to estimate GHG emissions. However, required data are generally unavailable, suggesting that comprehensive data gathering exercises should be undertaken.
- Ultimately, LEDS measures will only be successfully implemented if they are understood and supported by local stakeholders. Taking this into consideration, it is necessary to inform policymakers about the economic, social and environmental benefits of SPI and AFS as suggested by the findings presented in this study. SPI’s and AFS’s potential to reduce emissions while increasing profitability and generating employment opportunities makes them appealing to be considered as policy options.
- Required data to run simulations with LEAP and REDD Abacus are still limited. Therefore, the magnitude of the estimates presented in this study should be interpreted as caution, but the findings of this study reflect the general trends and patterns. Intensive and comprehensive data collection is needed to have a more precise estimates – in terms of magnitude – of the potential to reduce emissions in Mozambique.
- Findings of this study could inform policy in many regards. For instance, by highlighting the potential of AFS to reduce emissions and to contribute to poverty reduction, these

findings could provide empirical evidence for better guidance for the National AFS Strategy (still under formulation).

- Specific gaps on irrigation and agroforestry data must be identified and corresponding data gathered in the foreseeable future. For this purpose, *Instituto Nacional de Irrigação* (INIR) and *Instituto de Investigação Agrária de Moçambique* (IIAM) – both institutes are under the Ministry of Agriculture and Food Security – should provide updated relevant information related to irrigation systems (for example irrigated area, number and characteristics of fuel powered pumps, area cultivated by farmers, projections of the irrigated area based on the policies and national strategies, and the characteristics of the solar powered pumps as well as the solar systems used in irrigation).
- This study also stimulated research ideas taken from the identified gap knowledge. Areas considered yet as black boxes or gray areas, such as the national land use emission factors, geographical variations on potential of AFS and the solar power generation capacities, among others can be taken as research themes for graduate students.
- While this study may not respond all questions regarding to land use change and fuel powered irrigation systems (indeed no study addresses all possible issues), further work is needed to deepen the understanding of the links between the processes evaluated here and priority development aspects such as food security, poverty reduction, and technology adoption.

2. Introduction

This exercise focuses on building tactical, technical and technological capacities on LEDS modelling. The aim is to establish a strong analytical framework to facilitate long-term LEDS policy decision making and implementation, consistent with Mozambique's climate objectives and socio-economic development priorities as stipulated in the NDCs and other LEDS plans.

At the scoping meeting held on 29th March 2017 in Maputo, several stakeholders reiterated the need for LEDS actions to complement Mozambique's socio-economic development measured by, among other measures, higher GDP growth and job creation. It was also noted that Mozambique's NDCs are similarly aligned and aimed at gaining synergy between adaptation and mitigation. To concretize the above-mentioned objectives, stakeholders noted that it was important to recognize that Mozambique's economy is to a large extent sustained by agriculture as the most inclusive sector capable of catalytic socioeconomic transformation. Energy was also highlighted as the other leading government priority sector. Accordingly, to ensure the Africa LEDS project complements country development priorities, stakeholders prioritized Agriculture and Energy and their amalgamation to maximize socioeconomic impact as well as ecosystems resilience and carbon offsetting impacts.

Hence, the modelling undertaken in this study will complement developments in these two sectors by providing the analytical framework to forecast carbon offset and ecosystems resilience built against job creation and inclusive economic growth coupled with alternative investment decisions in each of these sectors as well as their amalgamation vis-à-vis business-as-usual (BAU) options. The goal is to provide guidance to identify optimal policy trajectories in implementing Mozambique's NDCs for LEDS and socio-economic development priorities.

Consequently, the modelling will establish an analytical framework to identify optimal project level investment trajectories in agriculture, clean energy and their amalgamation that will maximize carbon offset and enhance ecosystems while providing socioeconomic opportunities (such as income generation, sustainable GDP growth, and increased job creation among others).

Based on the above, tentatively two deliverables are envisaged: one on energy and the other on agriculture. First, under energy, it was agreed modelling would inform on carbon offset and water savings achieved against income increases, cost savings (including fuel cost savings from switching from diesel to solar irrigation), jobs created and proportion of GDP contributed/increased by a decision trajectory to invest in solar powered micro-irrigation vis-à-vis BAU scenario of conventional diesel powered, canal irrigation systems. And then extrapolate impacts over time and space (covering the whole country). Second, similar to energy, under agriculture, it was agreed modelling would inform on carbon offset vis-à-vis income increases, jobs created and proportion of GDP contributed/increased by a decision trajectory to invest in increasing agro-forestry coverage in the country. Expected socio-economic impact includes catalyzing relevant upstream and downstream enterprises such as tree-nurseries. And finally extrapolate the findings over time.

3. Context

3.1. Population

Mozambique is experiencing a rapid population growth. Data from the United Nations' Population Department indicate that population growth rate is slightly higher in Mozambique than in Sub-Saharan Africa (SSA) over the period 1997-2017 (2.7% versus 2.4%), putting Mozambique among the countries with rapidly growing population in SSA. Data from Mozambique National Institute of Statistics (INE) show that Mozambique's population increased from 16.1 million in 1997 to 27.1 million in 2017; while projections point out that population would reach 37.2 million in 2030. These data also indicate that population growth rate over the period 1997-2017 is higher in urban (3.2%) than in rural areas (2.4%) in Mozambique despite the fact that the largest share of the population live in rural areas (69.5%) where agriculture is the main livelihood strategy. Population is concentrated in two provinces: Nampula in Northern Mozambique accounting for 19.4% of the total population in 2017 and Zambezia in Central Mozambique accounting for 18.6%; compared with 22.7% accounted for by Southern Mozambique comprised of four provinces (Maputo City, Maputo province, Gaza province and Inhambane province). Each of the remaining five provinces contributes individually to less than 11.0% of total population.

The above-mentioned rapid population growth, especially urban population, puts pressure on natural resources in particular and the economy in general as an increasing number of people need to be fed. This suggest that economic growth should outpace population growth if Mozambique is at least to stand still. Given that a sizable share of the population live in rural areas and have agriculture as their main livelihood strategy, agricultural sector should be among the major drivers of economic growth.

3.2. Gross Domestic Product Projection

Data from INE show that annual growth rate of Mozambique's real Gross Domestic Product (GDP) averaged 7.6% over the period 1995 to 2013, increasing from USD 10.6 billion to USD 13.2 billion. With this impressive GDP growth rate, Mozambique was among the fastest growing economies in Africa. However, it is worth noting that real GDP grew at much slower rate of 4.6% per year between 2014 and 2017. Despite this slow growth rate in the last four years, Mozambique is projected to continue to experience sizeable annual GDP growth in the foreseeable future. Figure 1 displays projected trends in population and GDP between 1990 and 2030. This figure suggests that both population and GDP have been, and will continue, growing at considerable rate until 2030[2]. The main reason behind the high projected economic growth until 2030 could be associated with two main factors. First, Mozambique emerged as one of the world's fastest growing economies between the late 1990s and the early 2010s. Second, recent discoveries of natural gas and oil will certainly increase the prospects for impressive economic growth in the future. However, despite the impressive economic growth experienced in between the 1990s and 2010s, poverty inequality increased as findings from the nationally representative Household Budget Surveys (IOF) reveal that the Gini coefficient jumped from 0.40 in 1996 to 0.42 in 2002 and to 0.47 in 2014. This indicates that the gap between the rich and the poor has widened.

Over the period 2000 to 2017, the main sectors in terms of average contribution to GDP in the Mozambique's economy are agriculture with 23.9%, manufacturing with 11.9%, commerce with 10.7%, and transport with 8.8%; the remaining sectors, each individually accounts on average for less than 7.0%. It is worth noting that the structure of the economy has changed in the last ten years with increased importance of extractive industry and decreased of both agricultural and manufacturing sectors. Agriculture's share of GDP declined from 24.7% in 2007 to 21.3% in 2017; while manufacturing's share declined from 14.3% to 9.0% during the same period. On the contrary, the contribution of the extractive industry to GDP registered a considerable increase of 587.6%, jumping from 1.5% in 2007 to 10.3% in 2017. This growing importance of the extractive industry is related to the above-mentioned discoveries of natural gas and oil as well as intense extraction of coal. For instance, Biggs (2012) documented that Mozambique holds one of the World's largest reserves of natural gas (estimated at 250 trillion cubic feet) and coal (estimated at 25 billion metric tons).

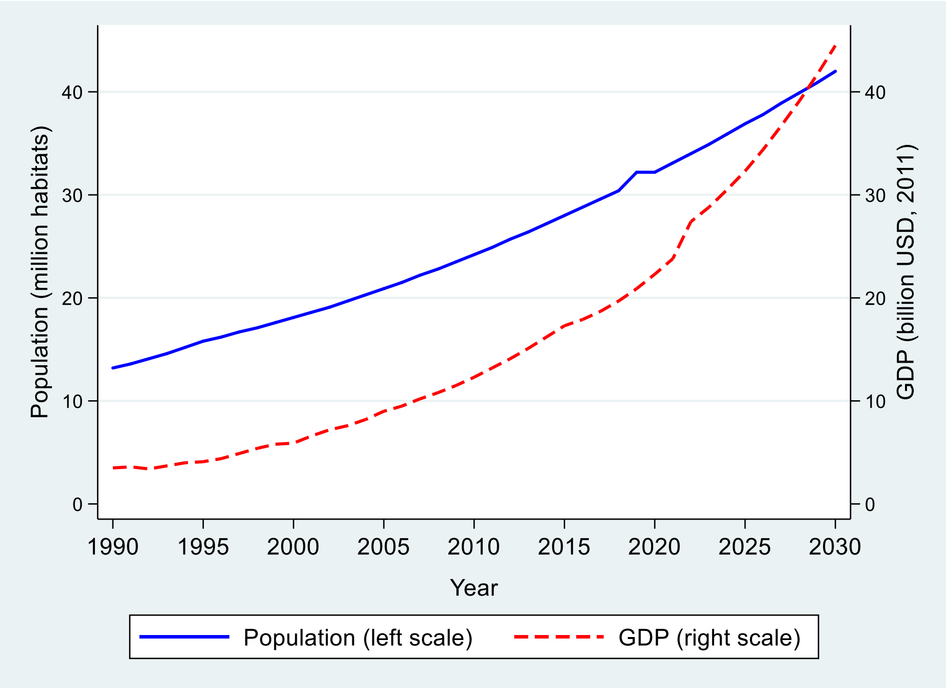


Figure 1 Population and GDP trends from 1990 to 2030

Although the country ranks very low, Mozambique made some progress in terms of Human Development Indicator (HDI). Mozambique with HDI of 0.437 in 2017 ranks 180 out of 189 countries in the world; however, Mozambique's HDI doubled between 1990 and 2017, rising from 0.209 to 0.437 and registering a steady upward trend with an average annual growth rate of 2.8%. This HDI growth rate puts Mozambique among rapidly growing low-human-development countries (countries ranking between 152 and 189 in 2017). Despite this progress in terms of HDI growth rate between 1990 and 2017, Mozambique HDI's performance in 2017 relative to other countries is alarming. Mozambique's HDI is below the average for both low human development countries (0.437 versus 0.504) and countries in SSA (0.437 versus 0.537). Furthermore, when HDI is adjusted for inequality, Mozambique’s HDI falls to 0.294, representing a loss of 32.7% due to inequality in human development dimensions. This loss is slightly higher than the average losses for low human development countries (31.1%) and for countries in SSA (30.8%).

Estimates from the Irish Aid in 2017 pointed out that Mozambique GDP could decline by a range from 4% to 14% as a result of climate change, which in turn could lead to considerable reduction in welfare by 2050. They also estimated that if no mitigation measures are put in place, climate change costs could amount to USD 7.6 billion, equivalent to more than USD 400 million per year[3]. This suggest that implementing mitigation measures to deal to climate change should be a paramount concern to Mozambique.

3.3. Poverty reduction goals

The impressive and strong economic growth experienced by Mozambique in the last twenty years appears to not be translated into significant poverty reduction in the last ten years. Data from nationally representative Household Budget Surveys (IOF) show that poverty incidence in Mozambique reduced considerably from 69.7% in 1996 to 52.8%; followed by a modest decline to 51.7% in 2008 and then to 46.1% in 2014. Over the period 1996 to 2014, as shown in Figure 2, poverty rate is consistently considerably higher in rural than urban areas (61.8% versus 71.8% in 1996 and 37.4% versus 50.1% in 2014) although it registered a steady downward trend in both regions. This suggests that poverty is a rural phenomenon in Mozambique. On the other hand, the distribution of poverty shows no clear pattern across regions over time. In 1996, poverty rate was lowest in Southern Mozambique (65.5% in Southern versus 67.3% in Northern versus 74.1% in Central); whereas in 2002, it was lowest in Central Mozambique (49.2% in Central versus 51.9% in Northern versus 59.9% in Southern). In 2014, poverty incidence was again lowest in Southern Mozambique (32.8% in Southern versus 46.2% in Central versus 55.1% in Northern).

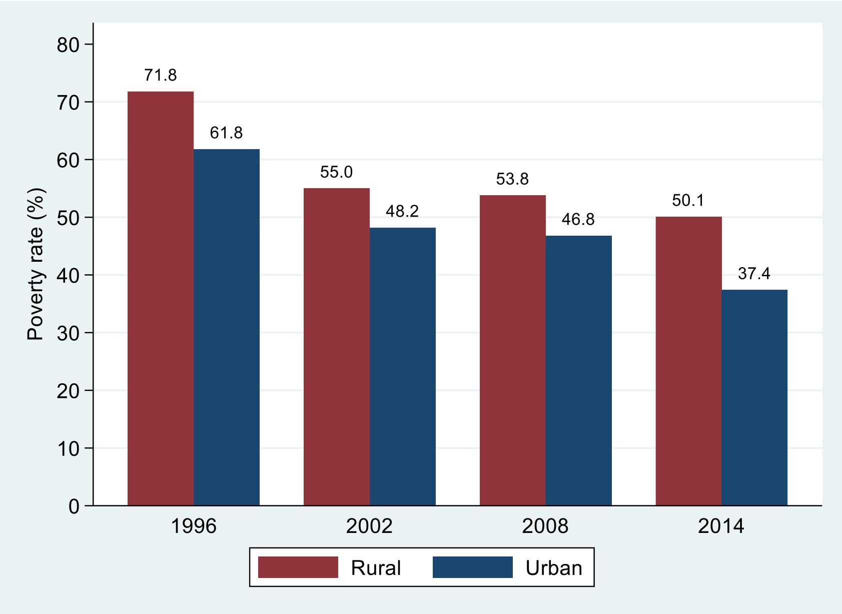


Figure 2 Poverty rate over the period 1996 to 2014

The weak relationship between economic growth and poverty reduction is to a large extent related to low productivity in the agricultural sector. As shown below, agriculture is predominantly rain fed with low use of yield-enhancing inputs such as fertilizer, pesticide and improved seeds. Furthermore, as mentioned above, a sizable proportion of the population lives in rural area and agriculture is the main livelihood strategy for a considerable share of the population. Hence, efforts to tackle poverty reduction should focus on improving agricultural productivity complemented with improving inclusive market participation by smallholder farmers who make up about 95% of cultivated area in Mozambique by strengthening inclusive value chain development as well as sustainable natural resource management.

Increasing agricultural productivity as one of the main channels through which both poverty and food insecurity could be reduced is recognized in various Government of Mozambique's strategic documents. Some examples of these documents include the five-year Government Plan for the period 2015-2019 (commonly known as *Plano Quinquenal do Governo - PQG*), Strategic Plan for Agricultural Sector Development (PEDSA) 2010-2020 including its Investment Plan (PNISA) 2013-2017, Action Plan for Poverty Reduction (PARP) 2015-2019 and Multisectorial Action Plan for Reduction of Chronic Malnutrition in Mozambique (PAMRDC) 2011-2020. All provinces have their own Provincial Strategic Development Plan.

PQG 2015 – 2019[4] is the key medium-term programming instrument of the Government of Mozambique (GoM) and is based on Agenda 2025 and national and sector strategies. The central objective of PQG 2015-2019 is to increase standards of living of Mozambicans. PQG defines three crosscutting pillars: Consolidate the democratic rule of law, good governance and decentralization; promote a balanced and sustainable macroeconomic environment and reinforce international cooperation. PARP 2011–2014, based on strategic objectives established by the PQG, serves as the key framework document for international assistance to Mozambique and as a benchmark for monitoring the Paris Declaration commitments and post Busan actions. As stated in PARP, Mozambique aims to reduce the incidence of poverty by promoting 'pro-poor' growth.

3.4. National Climate Change Strategy

The National Climate Change Strategy (NCCS) aims to reduce vulnerability to climate change and improve the standard of living of Mozambicans[5]. It proposes climate change adaptation and disaster risk reduction measures and also focuses on mitigation by targeting low carbon development. The NCCS is structured around three core themes: (i) adaptation and climate risk management; (ii) mitigation and low carbon development and (iii) cross cutting issues. These include institutional and legal reform for climate change, research on climate change, and training and technology transfer.

Covering the period 2013-2025, the implementation of the NCCS is planned in three phases. The first phase (2013-2015) focuses on improving the response of local communities to climate change, reducing poverty, planning adaptation measures, as well as identifying opportunities for the development of low-carbon economy in local communities. The Strategy also proposes the establishment of a Centre of Knowledge on Climate Change (CGC) within the Ministry of Science and Technology. The primary objective of the center is to collect, manage and disseminate scientific knowledge on climate change, providing crucial information from the development of policies and plans.

3.5. Greenhouse gas emission for Mozambique

Forest Reference Emission Level for Reducing Emission from Deforestation of Natural Forests estimated that on average, 267 029 ha per year were deforested between 2003 and 2013, and the annual and total of the emissions in that period are in the order of 46.2 million tCO2eq and 50.8 million tCO2eq, respectively[6]. A study conducted by CEAGRE and Winrock International[7] found that shifting agriculture is the major cause of deforestation in Mozambique, being responsible for 65% between 2000 and 2012. The other major causes identified were urban expansion (12%), extraction of timber products (8%) and production of firewood and charcoal (7%).

According to the World Resources Institute Climate Analysis Indicators Tool (WRI CAIT), Mozambique's 2014 GHG profile was dominated by emissions from the land-use change and forestry (LUCF) sector, which latest total emissions values including LUCF were at 68.10 tCO_2eq with per capita emissions of 2.50 tCO_2eq and 23.78% as absolute change from earliest to latest value. The emission values excluding Land Use Change and Forestry (LUCF) were 28.43% with per capita GHG emissions of 1.04 tCO_2eq per capita emissions presenting 55.82% absolute Change from earliest to latest value. Within the LUCF sector, changes in forest land contributed 95% of emissions, agriculture was the second highest emitting sector (26.8%). Energy, waste, and industrial processes (IP) accounted for 8.9%, 4%, and 1.5%, respectively, of total emissions[8].

The national INDC[9], Mozambique estimates, on a preliminary basis, to reduce emissions by a total of about 76.50 Mt CO2eq in the period from 2020 to 2030, with 23.0 Mt CO2eq by 2024 and 53.4 Mt CO2eq from 2025 to 2030. These reductions are estimates with a significant level of uncertainty and will be updated with the results from the Biennial Update Report (BUR) which will be available in early 2018[10]. Mozambique's INDC highlights that the implementation of any proposed reduction is conditional on the provision of financial, technological and capacity building from the international community[11].

3.6. Forest Reference Emission Level for Reducing Emissions from Deforestation in Natural Forests

The third National Forest Inventory (NFI) documented that forests in Mozambique have suffered high rates of deforestation, estimated at 267,029 ha/year[12]. Acknowledging this situation, and understanding its impact to the economy and to the livelihood of rural population, the Government of Mozambique became part of 47 Countries that benefited from funds from the Forest Carbon Partnership Facility (FCPF) to develop the National REDD+ strategy with the aim of reducing emissions from deforestation and forest degradation and enhancement of carbon stocks (REDD+).

The process began in 2008 with the elaboration of the REDD+ readiness plan (R-PP), which was approved by the Committee of Participants of the FCPF in March 2012. In 2016, the country received additional funds from the FCPF to establish a National Forest Monitoring System (NFMS) and the Forest Reference Emission Level / Forest Reference Level (FREL) of greenhouse gas emissions (GHG) for REDD+. With the aim of consolidating the process of REDD+, Mozambique embraces the opportunity to submit a proposal of FREL to the United Nations Framework Convention on Climate Change (UNFCCC), responding to decision 1/CP.16, referring to the requests of developing countries with intention to perform activities related to REDD+.

The objective of the country, in submitting this proposal, is on the perspective of building capacity for the implementation at all levels, the National REDD+ Strategy approved by the Government in December 2016 aiming to promote sustainable development, resilience to climate change, integrated rural development focused in forest, agriculture and energy. The reduction of emissions caused by deforestation and forest degradation (REDD+), is an initiative of the Signatory States to the United Nations Framework Convention on Climate Change (UNFCCC), has its primary objective the promotion of actions which result in the reduction of deforestation and forest degradation, as well as an increase forest cover through forest plantations, restoration of degraded forests, conservation of forest ecosystems and improvement of sustainable forest management practices.

3.7. Agriculture

Agriculture is the mainstay of the economy in Mozambique. The sector accounts for about 25% of the GDP and employs about 80% of the workforce. Data from the nationally representative Integrated Agricultural Survey (IAI) 2015 indicate 77.1% of individuals aged 15 years and older worked in the agriculture sector in the agricultural season 2014/2015. Agriculture is predominantly practiced by smallholder farmers. According to data from IAI 2014, small- and medium-scale farmers (smallholder farmers) accounted for 98.9% of the total cultivated area under annual crops in the agricultural season 2013/2014; large-scale farmers contributed to the remaining 1.1%. Smallholder farmers accounted for 99.0% of the total number of farmers in the same agricultural season and similar patterns are observed in other agricultural seasons. According to IAI 2015, total cultivated area by smallholder farmers amounted to 4.7 million hectares in the agricultural season 2014/2015; of which 4.3 million hectares were allocated to annual food crops.

According to data from IAI 2015, the main livestock in terms of proportion of households with ownership of animals are chickens with 48.3%, goats with 15.6%, ducks with 11.8%, and pigs with 10.3%. In terms of total number of animals owned by farmers, the most important animals are: chickens with 14.4 million, goats with 3.3 million, ducks with 2.5 million, cattle with 1.6 million, and pigs with 1.6 million. The relative importance of each animals varies from province to province. For instance, the most important animals in Tete province are chickens with 48.3% of households owning this animal (with a total of 1.2 million animals), goats with 28.8% (0.6 million animals) and cattle with 20.9% (0.5 million animals); while in Inhambane province are: chickens with 69.5% (1.1 million animals), pigs with 46.0% (0.2 million animals), and goats with 38.8% (0.3 million animals). With the exception of cattle, access to veterinary services appears to be very limited. Data from IAI 2015 show that among cattle owners, 57.8% of households had access to cattle bath, only 4.1% had access to slaughterhouse, 68.9% vaccinated their cattle, and 34.3% had their cattle treated for diseases. By contrast, among chicken owners, only 10.1% of households vaccinated their chickens and only 3.3% had their chickens treated for diseases.

3.7.1. Cropping systems

As mentioned above, agriculture is dominated by smallholder farmers totaling 4.0 million and cultivating on average 1.4 hectares in the agricultural season 2014/2015, according to data from IAI 2015. These data also shows that the share of smallholder farmers who cultivated less than 1.0 hectare and less than 1.4 hectares stood, respectively, at 51.3% and 65.4% in the agricultural season 2014/2015, suggesting that the distribution of cultivated area is very skewed. Of the total of 4.7 million hectares cultivated smallholder farmers, they allocate on average 94.4% to annual food crops, 0.8% to perennial crops, and 4.8% to fallow. Maize and cassava are undoubtedly the main food crops grown by smallholder farmers. Data from IAI 2015 indicate that the main crops in terms of total cultivated area in the agricultural season 2014/2015 are: maize with 1.6 million hectares, cassava with 0.6 million hectares, groundnuts with 0.4 million hectares, and cowpea with 0.3 million hectares. These are also the most important crops in terms of total number of growers: maize with 2.8 million growers, cassava with 1.9 million growers, groundnuts with 1.6 million growers, and cowpeas with 1.6 million growers.

According to data from IAI 2015, smallholder farmers grew on average 5 crops in the agricultural season 2014/2015, allocating on average 0.3 hectares per crop predominantly in intercropping systems and owning on average 7 perennial trees. Usage of yield-enhancing inputs such as fertilizers, pesticides, and improved seeds is very limited, resulting in low agricultural productivity. Data from IAI 2015 show that 9.1% of smallholder farmers used animal traction, 3.8% used fertilizer, 3.4% used pesticide, 0.5% used herbicide, and 1.8% used manure. The share of growers who used improved seeds stood at only 7.2% for maize and 1.2% for rice; which extremely low by any standards. On the other hand, market participation is also very limited. The share of smallholder farmers who sold their production is 14.9% for maize and 12.2% for rice.

3.7.2. Agroforestry Systems

Agroforestry systems (AFS) is a land use management system in which trees or shrubs are grown around or among crops or pastureland. This intentional combination of agriculture and forestry has varied benefits, including increased biodiversity and reduced erosion. AFS can create additional sources of income, spread farm and land management activities throughout the year, and increase the productivity of the land, while protecting soil, water and wildlife[13]. They are also increasingly recognized as a tool for mitigate climate change and aid in adaptation of farming communities[14]. AFS has created an opportunity to cut back on the amount of carbon that agriculture releases, by instead increasing levels of soil organic carbon (SOC)[15].

Mozambique is among the few countries with a reasonably large forest cover in Southern Africa. However, the rate at which the forest is being deforested is relatively high (0.7 %). The challenge is find innovative ways to motivate farmers to use the land in a way that would save the natural forest as well as giving farmers sustainable possibilities to produce enough crops to feed a rapidly growing population[16]. According to Linyunga et al. (2004), experience has shown that building local capacities can effectively be combined with scaling-up of technology use among large numbers of farming families. These authors have stressed that in order to make significant strides in scaling-up AFS in the region, with scanty fiscal and trained human resources, donors, the World Agroforestry Center (ICRAF) and the other stakeholders have to heavily rely on strategic or complementary partnerships. Indeed, a systematic approach is required to promote multi-purpose AFS compatible with farmers' needs under local farming systems and current dryland socio-economic contexts.

3.7.3. Costs and Inputs for Agroforestry Implementation

The most common activities in the establishment of AFS are land preparation, digging the holes, planting of trees and shrubs and planting of annual crops. The cost estimate that the farmer makes for each option reflects his/her level of experience with the specific requirements of planting and maintaining trees as part of his/her productive activities. In general, farmers report the amount of labor required within an acceptable range, varying from about 40 to 50 man-days necessary to establish an AFS with 650 to 800 trees per hectare, such as taungya and enriched fallow. Table 1 shows that the average cost of establishing, monitoring and maintaining an AFS with 650 to 800 trees planted is about USD 890 per hectare[17].

Table 1: Average costs of establishment and maintenance of AFS (Based on introducing 625 trees/ha).

Category	Type	Cost (USD/ha)
Labor	Man days (USD 6/day)	260
Plants	Production and transport	120

Material	Planting, protection	50
Training and design	Workshops	50
Monitoring (first 3 years)	Man days, transport	60
Monitoring (first 3 years)	Man days, plants	350
Total		890

Adapted from De Jong et al. (2004)[18]

The profitability of different land use systems and agroforestry technologies is shown in Table 2. The Net Present Value (NPV) ranging between USD 233 and USD 309 per hectare, AFS practices were more profitable than *de facto* farmers practice (continuous maize production without fertilizer) which yielded an NPV of USD 130 per hectare. However, AFS practices were less profitable than subsidized fertilizer, which yielded a NPV of USD 499 per hectare and non-subsidized mineral fertilizer which had an NPV of USD 349 per hectare. However, in terms of returns per unit of investment, the three variants of improved tree fallows are financially more attractive than continuous maize production with or without fertilizer[19].

Table 2. NPV of cropping systems

Cropping system	NPV (USD per ha)
AFS	233-309
Continuous maize production without fertilizer (BAU)	130
Maize with subsidized fertilizer	499
Maize with non-subsidized mineral fertilizer	349

Adapted from Ajayi et al. (2010)[20]

Although Mozambique practices traditional agroforestry systems, such as the combination of coconut palms, cashew nut trees, and citrus trees with annual crops, these aimed at improving land use intensity, and are not fully documented in terms of their potential to protect soil properties. Improved AFS aiming such as those designed to reduce slash and burn practice through protection of soil properties with the use of nitrogen fixing trees are still at the experimental phase. Literature on alternative to slash and burn (SAB) agriculture suggest that agroforestry is a potential technique to reduce SAB associated deforestation and land degradation.

3.8. Irrigation

Due to its geographic location, Mozambique is systematically affected by natural disasters (mainly droughts, floods and cyclones), and it is therefore important to invest in technologies that use water for irrigation as part of an overall development strategy for the agricultural sector. Data from IAI 2015 show that 30.9% of smallholder farmers reported to have at least one of their plots affected by either floods or droughts in the agricultural season 2014/2015. These data also indicate that only 3.3% of smallholder farmers used irrigation in the same agricultural season, covering a total of 78.4 thousand hectares which is equivalent to 1.8% of total cultivated area allocated to annual food crops. It is not justified that with so many water resources, the country cannot explore possibilities to utilize these water resources for the benefit of its population and the country. Irrigation is one of the key elements through which improvements in agricultural productivity could be reached, but current diesel-powered irrigation pumps are costly, highly polluting, and carbon intensive[21].

Opportunities for the accelerated and sustainable development of irrigation, such as the effects of climate change, the need for partnerships between private and community sectors, and the improvement of governance reforms in land and water management, and the growing interest stakeholders are important aspects and are integrated into the National Irrigation Program[22]. According to Irrigation Strategy, in 2010, it was estimated that about 27.0 thousand hectares were irrigated in Mozambique, and the plan was to ensure that by 2020 the irrigated area for food crops expanded to at least 90.0 thousand hectares, of which at least 40.0 thousand hectares were reached through private investment. Therefore, it was expected by average agricultural productivity under irrigated systems would be higher by at least three fold, compared to current rain fed agricultural productivity for selected food crops and irrigated systems through intensification.

3.8.1. Renewable energy atlas of Mozambique

Renewable energies constitute a priority for Mozambique’s energy policy. In general, Mozambique shows enormous potential in renewable energies, more than 23 TW and thousands of possible projects from small projects of rural electrification to large hydropower plants of the Zambezi River. Of this potential, about 7 GW, which is more than 500 projects, mostly hydropower but also wind, solar, biomass and geothermal, constitute an alternative for Mozambique's electrical system to be considered and possibly integrated into future electricity generation plans.

Besides the small, medium and large dimension projects identified, present technological evolution enables, at present, the exploitation of renewable energy in micro scale projects, generally units of 5 to 100 kW which are adequate for rural electrification. For example, the use of solar panels, together with a combination of batteries and generator can be considered as the most economical electrification solution when the electric grid is situated far away. Other solutions for rural electrification can also be considered, based on isolated photovoltaic systems, although providing lower service levels, still constitute a good electrification alternative and require low level of investment.

There are countless advantages in renewable energies to Mozambique's sustainable development. First of all, the great hydropower projects, apart from being multi-purpose projects, are also the most economical alternative for power generations and Mozambique has many alternatives at its disposal. At the same time, small and medium-dimension projects constitute an opportunity for investment, grid optimization, whether by means of small creation or regional development. Finally, rural electrification, whether by means of small solar power plants with battery and generator backup or by the use of pico-hydro and small sized decentralized solar solutions are the most economically viable solution to bring power to thousands of Mozambicans. In the context of climate change, where water availability will be limited, photovoltaic systems appear to be a more resilient solution than the hydro power generation.

3.8.1. Diesel powered irrigation and solar powered irrigation

The major energy usage in the agriculture sector is in the form of diesel used in tractors, agricultural implements and in irrigation pump-sets. Farmers in rural areas still depend on diesel-powered irrigation pumps due to limited access to electricity[23].

According to Agrawal and Jain[24], the revolution is taking place in how water is being pumped in remote locations beyond the reach of electric power lines. Solar power, or photovoltaic power has proven to be an ideal way to lift water for drinking, sanitation, stock tanks, and irrigation. Photovoltaic panel is one of the simplest possible ways to generate electricity beyond the reach of power lines. They have no moving parts and last for decades with virtually no maintenance making solar panel irrigation (SPI) systems no longer an expensive, experimental energy source.

Table 2: Comparison between fuel powered irrigation system and solar powered irrigation system.

Type	Advantages	Disadvantages
Solar Powered Irrigation (SPI) System	Unattended operation Low maintenance Easy installation Long life	High capital costs Water storage is required for cloudy periods Repair often require skilled technicians
Fuel Powered Irrigation (FPI) System	Quick and easy to install Low capital costs Widely used Can be portable	Fuel supplies erratic and expensive High maintenance costs Short life expectancy Noise and fume pollution

Source: Abu-Aligah (2011)[25]

A recent study by FAO[26] published relevant information from the questionnaire responses, coming from 25 countries around the world shows that 47% of respondents strongly agreed that changes in income were significant after the installation of SPI systems; 43% agreed and 10 percent disagreed. Fifty five percent strongly agreed that the performance of the SPI systems was described as good and 45 percent agreed. Yet, 52 percent strongly agreed that there were significant positive changes in agricultural productivity after the installation of SPI systems, and 48 percent agreed.

One of the biggest benefits of the irrigation scheme has been employment creation. A project evaluation by Oxfam shows that household incomes increased by 286% for the very poor, 173% for the poor and 47% for the middle-income groups. Furthermore, employment creation increased as farmers no longer had to target large-scale farm employment in exchange for food, producing instead food and new job opportunities on their own land[27]. The fact that operating costs are drastically reduced comes as a double-edged sword: the net income of farmers can increase as running costs are reduced, but the farmers no longer have a cost barrier imposed on their water access. A consequent threat to the sustainable use of water resources arises[28].

In 2017 the Mozambican National Institute of Irrigation (INIR) received 350 kits of SPI systems each with capacity for 500 m^2 of area, to distribute around the 11 provinces in Mozambique. The aim of the SPI systems kits is to help small farmers to minimize the cost of production, in terms of buying fuels, electricity, and saving water from the rivers, bore hole, lake, for crops growth. In addition, this kind of irrigations schemes will contribute to reduce GHG emissions from the traditional FPI systems[29].

Figure 3: Fuel Powered and Solar Powered water pumps used in two irrigation systems

In the province of Gaza most of the small farmers use fuel powered pumps with an average consumption of 25 liters of fuel to irrigate about a hectare per day. According to DPAG[30], the irrigation of farmer's fields in the small-scale family sector is subsidized for electricity and diesel. Yet, this is currently being neglected by the institutions of the Government responsible for the implementation of these subsidies. Thus, the small-scale family sector is bearing the full cost of fuel, and electricity, for the irrigation of their fields.

With the introduction of low-cost and climate-resilient alternative systems such as photovoltaic panels, it would make the family farmers' production process less costly, considering that the costs associated with the electricity and fuel will be subtracted from the production costs. In any case there will also be a reduction of CO_2 emissions, other gases resulting from the combustion of Diesel in the operation of the fuel powered pumps.

One potential drawback of the SPI systems in Mozambique is the widespread of robbery of solar panels, which can represent a threat to the expansion of the SPI systems in rural areas.

3.8.2. *Solar resource*

On a global scale, SPI systems essentially depend on geometry and movement of the planet in relation to the sun. However, on a local scale the changes in solar irradiation are mainly due to the topography as result of variation in elevation, slope, aspect and shading. Mozambique has high global irradiation on the horizontal plane when compared with other good locations in Europe and Asia, being quite close to some of the best locations in the world, like South Africa and California. Solar irradiation varies between 1,785 and 2,206 kWh/m²/year.

Based on the global irradiation on sloped surface, in the analysis of terrain slope, forest density and flooded areas, the solar potential of Mozambique is 23 TWp. Therefore, solar resource in Mozambique offers many possibilities for grid connection and rural electrification projects. For grid connection, without support of batteries, here is a potential of 2.7 GW of Solar photo voltaic (PV) close to existing substation. The provinces of Maputo and Tete are the ones with highest potential for grid connected solar projects, essentially due to the robustness of transport infra-structures.

The consistency of the solar resource throughout the country and the proximity to substations results in a large number of projects with similar costs from north to south. The main difference between projects is more because of size than resource. Projects with capacity below 5 MW tend to be more expensive per unity of energy generated. Solar energy cost can also vary a lot according to financing cost given strong weight of initial investment. An adequate financing strategy, benefiting from concessional rates or export credits could make solar power competitive. PV technology has experienced strong cost reductions in recent past, which are expected to continue. These perspectives, together with fast deployment, make solar power a solution that will become even more attractive in years to come for Mozambique.

4. Materials and Methods

4.1. GHG measurements and mitigation scenario of Energy sector

The mitigation scenario addressed in this study is the replacement of FPI by SPI. The analysis was simulated using LEAP (Long-range Energy Alternatives Planning System) and manually as is described further. LEAP is a widely-used software tool for energy policy analysis and climate change mitigation assessment developed at the Stockholm Environment Institute. LEAP is an integrated, scenario-based modeling tool that can be used to track energy consumption, production and resource extraction in all sectors of an economy[31]. It can be used to account for both energy sector and non-energy sector greenhouse gas (GHG) emission sources and sinks. In addition to tracking GHGs, LEAP can also be used to analyze emissions of local and regional air pollutants, and short-lived climate pollutants (SLCPs) making it well-suited to studies of the climate co-benefits of local air pollution reduction.

Table 3: LEAP basic parameters used to simulate the emission of CO_2eq.

Parameter	Current account	Source/Obs.
Time horizon	20 years	
Scale	National	
Scope	Transformation and resources; Energy sector and Non-energy sector effect loadings	
Population size	28 million	www.ine.gov.mz
Population Growth Rate	2.9%	www.ine.gov.mz
Income Growth Rate	6.7%	https://tradingeconomics.com/mozambique/gdp-growth-annual
GDP (2014)	10.15 Billion USD	https://tradingeconomics.com/mozambique/gdp
Initial Data collected from field	Irrigation systems of Inhambane, Gaza and Maputo Provinces	Based on data from 3 provinces an extrapolation was performed to consider a national scale.
Total irrigated area in 2010	27,000	National Irrigation Strategy
Total irrigated area in 2017	60,000 ha	National Institute of Irrigation statistics
Crop water requirements	Varies according to crop	IIAM and UEM (2010)[32] crop technical fact sheet
Fuel emission factors (Diesel)	2.65 $kgCO_2$/liter fuel	Juhrich (2016)[33]

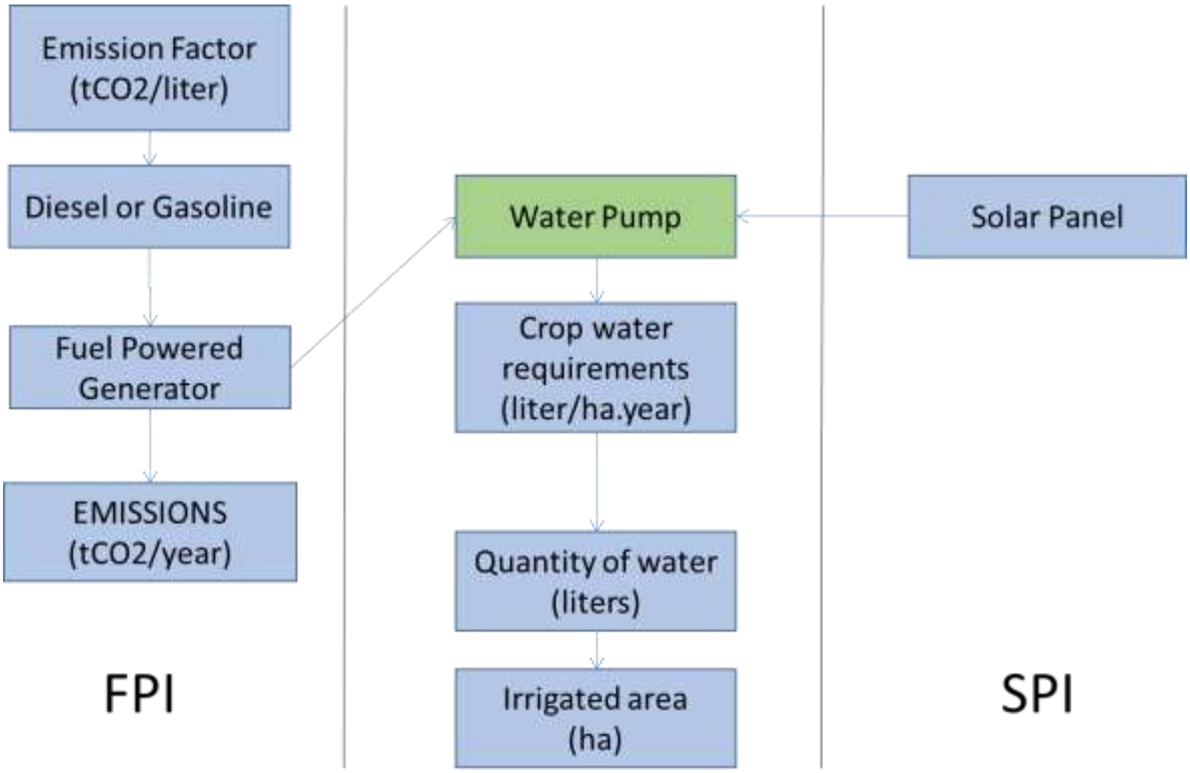


Figure 4: Frame of calculation procedure of emission factor of each crop group irrigated by fuel powered system.

The results of LEAP were manually linked with crop data and were built a scenario which captures a more realistic situation. Thus, we used crop water requirements (liter water per hectare per year), crop production season and irrigation efficiency (rate liter fuel:liter water) (Figure 3). Based on the national literature[34], we selected the main irrigated crops of Mozambique. From that source, we identified 12 reference irrigated crops which falls in four groups as follow: vegetables (tomato, cabbage and onion), pulses (peanut, common bean, pigeon peas, and soy bean), cereals (corn, wheat and rice), root and tubers (potatoes) and sugar cane. However, the cereals crop group is not commonly irrigated by FPI, as most of the crops of this group are irrigated by gravity (e.g. corn and wheat), or grown in flooded areas (e.g. rice). This is the reason why we did not include the cereals group for emission factor calculation. In addition, although sugar cane accounts for 60% of the national irrigated land, they are mostly in the large scale industrial sector with water pumps powered by the grid electricity for the hydropower. The emission factor of diesel is 2.65 kgCO_2/liter fuel, and the emission estimates will be expressed in tons of carbon dioxide equivalents per hectares year (tCO2e/ha.year). The basic equation used in this report for calculating the GHG emissions by multiplying the activity data and emission factor.

National irrigation strategy stated that Mozambique had 27,170 hectare of irrigated area in 2010, with sugar cane as the largest irrigated area (60% of the total area), followed by vegetables (18%), cereals (15%), pulses (5%) and roots and tubers (2%). Thus, the irrigated area of each crop group was used in order to estimate their total emission per year, and the projections were assumed to be linear throughout the simulation period (Figure 4).

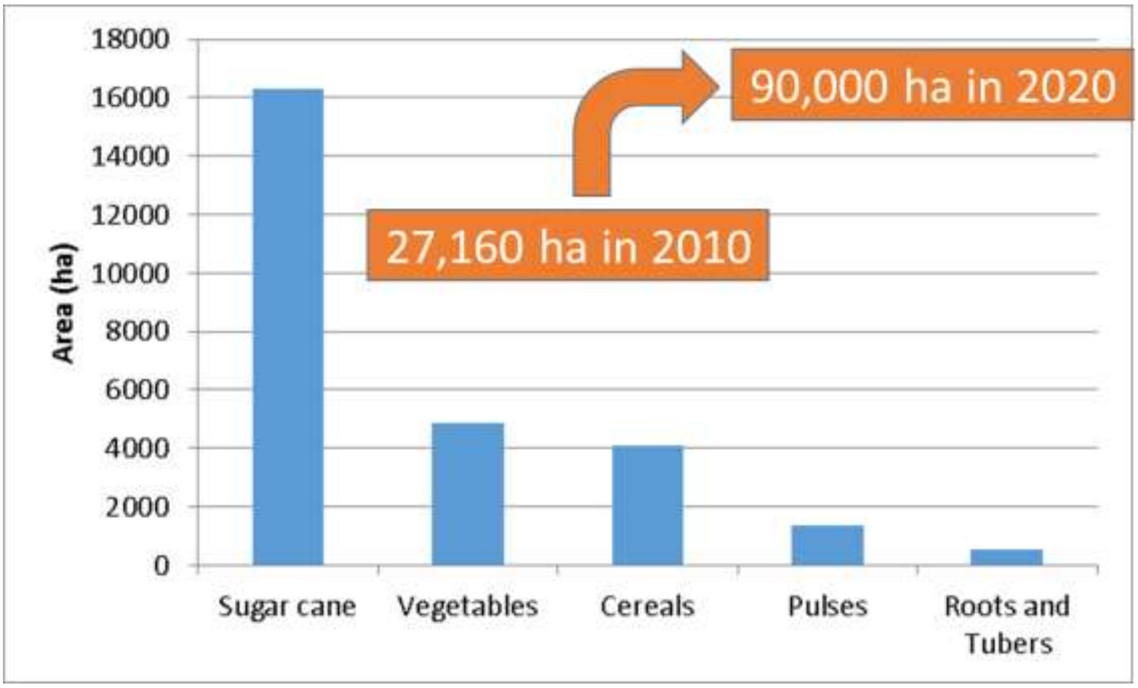


Figure 5: Irrigated land by crop type.

Using the irrigated area in 2010 and its emission factor in the same year we projected the emissions of FPI from 2010 to 2030 as business as usual (BAU). According to national irrigation strategy the irrigated land will reach 90,000 hectare by 2020, we used this information and assume that the irrigated land will increase in linear trend from 2010 to 2030. Replacement of FPI by SPI systems were projected from 2016 to 2030 following a linear trend. No detailed information on policy documents were found regarding the desired trend.

4.2. GHG measurements and mitigation scenario of Agriculture sector

The REDD Abacus SP software version 1.1.7[35], developed by the World Agroforestry Center (ICRAF) was used to analyze opportunity cost of replacing traditional agricultural systems (slash-and-burn) by AFS as well as estimate the GHG emissions source and sinks for the period 2010-2030 from land use/land-cover change. REDD Abacus was developed to analyses the opportunity cost of land use changes in a landscape or area within a period of time and generate the abatement cost curve. The opportunity costs curve allows us to view and compare the foregone benefits of the analyzed projects and land uses if avoiding the conversion of natural forest to other land use types, in this case our target land use systems is slash-and burn agriculture against AFS. Opportunity cost of avoiding forest conversion was estimated using information of five main inputs from literature review: (1) identification and description of major national land uses which include AFS; (2) estimations of averaged carbon stocks for the major land uses; (3) estimations of the private profitability of the land uses in terms of discounted net present value (NPV); (4) land use change matrix analysis; and (5) processing this information into a two-dimensional graph charting the opportunity costs of avoiding land use changes emissions against volume of CO_2eq emissions. The analysis was built at national level instead of regional level because of lack of detailed data at provincial and district levels, and all inputs data were collected in the national and international statistics and literature as summarized in Table 4.

Table 4: Carbon stock and net present value (NPV) of land use systems in Mozambique

LULC class	Time average carbon stock (ton C/ha)	Source	NPV (USD/ha)	Source
Forest Plantation	363	Guedes et al. (2018)[36]	200	Unpublished field data (Hofiço 2016)
Natural Forest	116	Guedes et al. (2018)	150	
Grassland	3	Expert estimation	50	Expert estimation
Cassava	7	Unpublished field data	225	Unpublished field data
Maize	5	Unpublished field data	300	Unpublished field data
Other land	1	Expert estimation	25	Expert estimation

Other				
Agroforestry systems	85	De Jong et al. (2004)[37]	463	De Jong et al. (2004)
Fuel Powered Irrigation	1.4*		350**	
Solar Powered Irrigation	0*		900**	

(*) Mean emission factors (tCO2eq/ha.year) of all crop groups. (**) Estimation based on the study of FAO (2018)[38], Kumar and Dias (2015)[39] and Magrath (2015)[40], they have stated that SPI can increase twice the householder incomes than FPI.

The main land use and land cover change considered in this study include agriculture (maize and cassava) and AFS (Table 4). They were added some extra land uses which are not the target of this analyses only for transition matrix propose (e.g. FP – forest plantation, NF – natural forest, GL – grassland, OL – Other lands). The transition matrix was built using information from field and national forest inventory of Mozambique[41]. The historical time period used in transition matrix was from 1997 to 2007. Nevertheless, there is new transition matrix data from 2018 national forest inventory, which is not publicly available, but will be available later in the 2018. Therefore, this will be a good opportunity to create a new scenario with updated data.

4.3. Soft-linking emission scenario development

The mitigation scenarios to reduce GHG emissions based on historical emission baseline was performed using REDD Abacus as previously described by Harja[42]. Scenarios used in this study reflect possible emission reduction interventions in agriculture sector and energy sector. The current trend is reflected in the Business as Usual (BAU) scenario where there is no implementation of a good practices of agriculture (AFS) into smallholder slash-and-burn agriculture and no replacement of FPI (we called this as historic scenario). The main crops used to build the scenarios of agriculture sector were maize and cassava as defined as smallholder main cash crops in Mozambique. The second scenario was created in optimistic thinking where the emission is less than BAU when half area of slash and burn agriculture (maize cropping) replaced by AFS, and there is diversification of production, good governance and good implementation of national climate change strategy. The last scenario is regarding to energy sector where we believing that all area with FPI will be replaced by SPI. All information regarding to FPI and SPI are from LEAP model brought into REDD Abacus model as non-land use change emissions for soft-linking approach. The model was run for 30 simulation-years to cover a complete cycle of simulated combined systems (AFS and SPI) effect on emission reduction.

5. Results

5.1. Replacing fuel powered irrigation by solar powered irrigation

Fuel powered irrigation (FPI) in Mozambique emitted a total of 2,721 tCO2eq in 2010, while projections indicated 8,515 tCO_2eq in 2018 and 17,981 tCO2eq in 2030 (Figure 5). The average emission for business as usual FPI from 2010 to 2030 is about 14,735 tCO2eq per year. Irrigation of vegetables is the main source of emissions with about 79% of the total emissions. As data on the irrigated land of group crops were available only for 2010.

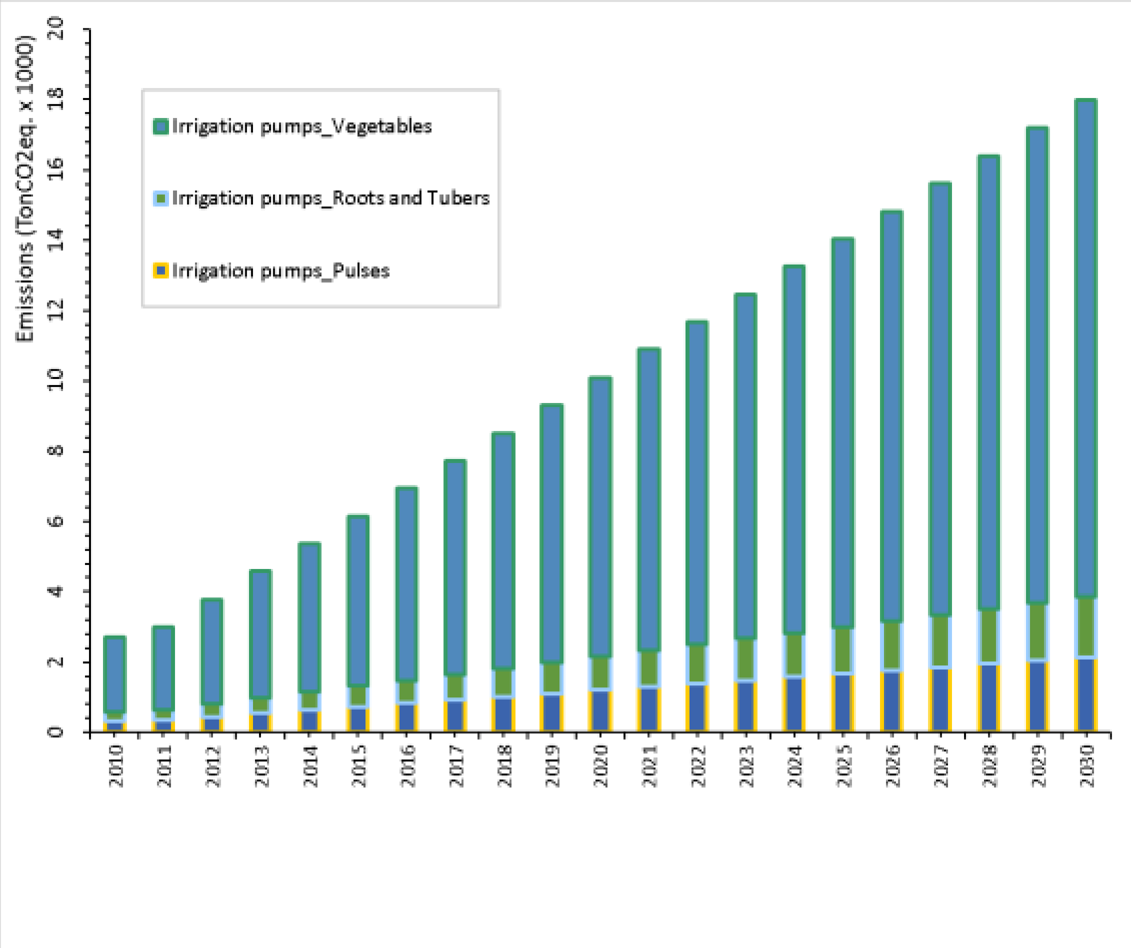


Figure 6: Emissions of CO2eq from FPI systems by crop type between 2010 and 2030.

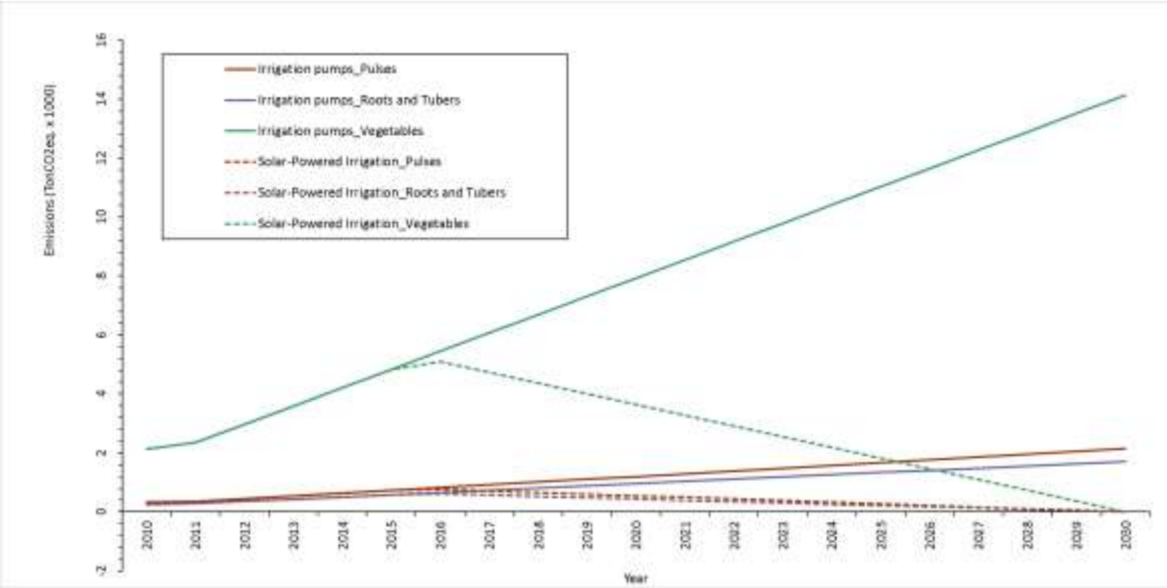


Figure 7: Emission of tCO2eq of fuel powered irrigation (BAU) by solar powered irrigation for each crop group.

Figure 6 shows that when we replace FPI by SPI the emissions fall markedly down to zero by 2030. The same result can be showed in Figure 7 where emission from SPI reached zero by 2030 when all proposed FPI systems are replaced by SPI with an average emissions of the period reducing from 14,735 to 11,092 tCO2eq/year.

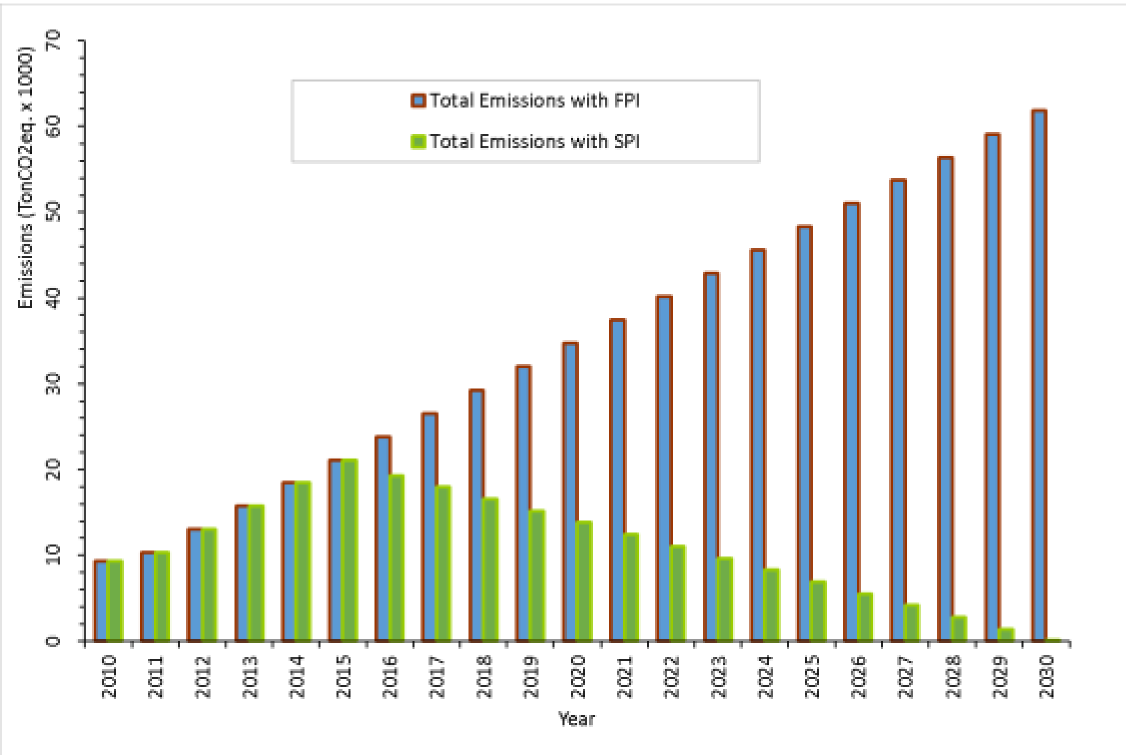


Figure 8: Emission reduction from FPI (BAU) by SPI between 2010 and 2030.

5.2. Replacing slash and burn agriculture by agroforestry system

Replacing slash and burn agriculture (SAB) by AFS results in emissions reduction. AFS works two ways to reduce emissions: first by avoiding deforestation as it improves soil fertility, therefore no need to convert forests to crop land every year; second by increasing carbon sequestration and storage as permanent crops (trees and shrubs) remain on the field with high biomass stock compared to annual crops alone. Net emission (the balance between emissions and sequestration) will be higher in AFS that under annual crops. Figure 8 shows that replacing SAB (business as usual scenario) by AFS the net emission will contribute in 33 % of net emission reduction falling from 5,860,763 tCO2eq to 1,870,866 tCO2eq by 2030. The simulation considers other land use change categories, such as conversion of forests to other land including settlements, which cannot be resolved by AFS. However, while considering that 65% of the emissions from the land use change processes is from SAB agriculture, the impact of replacement of these land use systems by AFS has a huge impact.

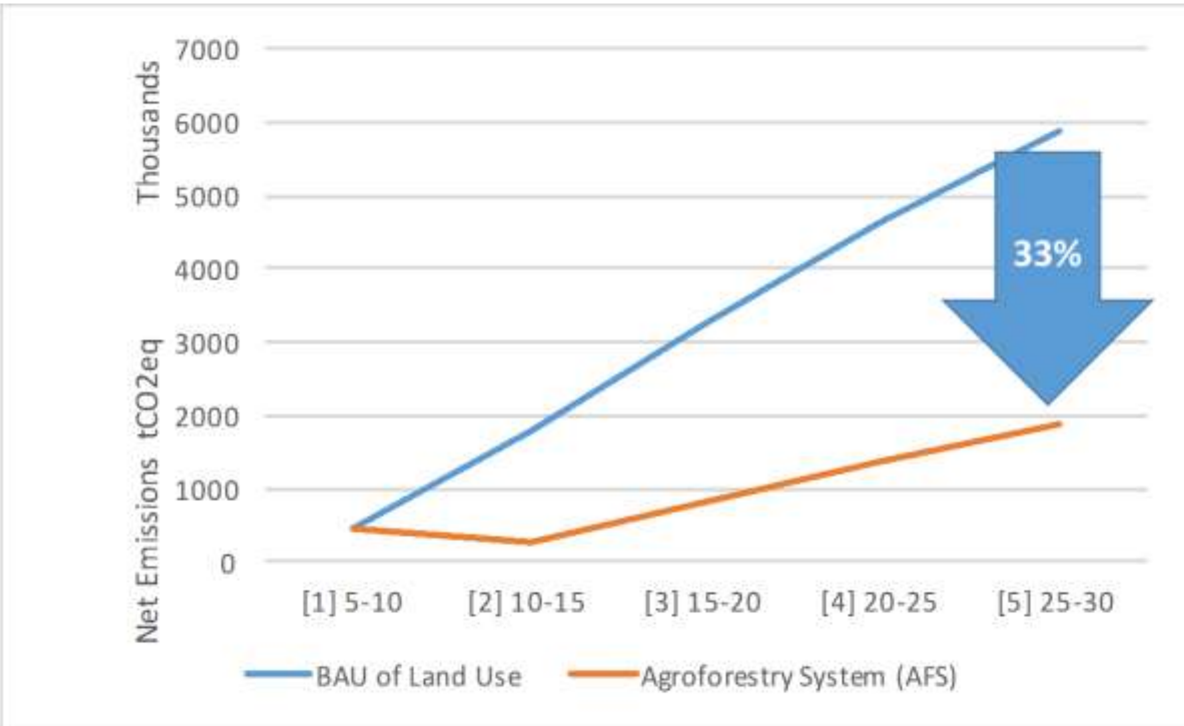


Figure 9: Emission reduction resulting from slash-and-burn agriculture as (BAU scenario) and replacement of 50 % of the slash-and-burn agriculture area by AFS.

5.2.1. Cost of emission reductions/Opportunity cost

An opportunity cost curve provides a comparison of the opportunity costs of different types of land use change. Figure 9 below presents this information from national context used in this study, over a five-year period (2010-2014). The vertical axis represents the opportunity cost of the emissions reduction option (in monetary units per ton of CO2eq), while the horizontal axis shows the corresponding quantity of reduction (expressed in million tons of CO2 eq per year). The bar width is proportional to the potential emission reduction, so that wider bars indicates higher potential emission reductions than the narrow ones. The height of each bar shows the opportunity cost for avoiding the conversion of one land use to another (USD/tCO2eq). The bars on the left side represent the cheapest emission reduction options, while the bars on the right side comprise the most expensive GHG emission reduction options. Thus, avoidance of land use changes on the left side provide relatively cheap GHG emission reduction potential and serve as a crucial basis to prioritize cost-effective measures to avoid emission.

Figure 8 shows potential emission reductions in the country by 2030, assuming that all potential emissions with an opportunity cost below 5 USD per tCO2eq can be avoided. The cumulative potential emissions in the country in 2030 is estimated at 41.31 tCO2eq/ha/yr, while the reduced emissions by excluding all land use conversion below at 5 USD per tCO2eq threshold is estimated at 27.09 tCO2eq/ha/yr. The results show that the majority of the land use changes generated less than 5 USD / tCO2eq lost.

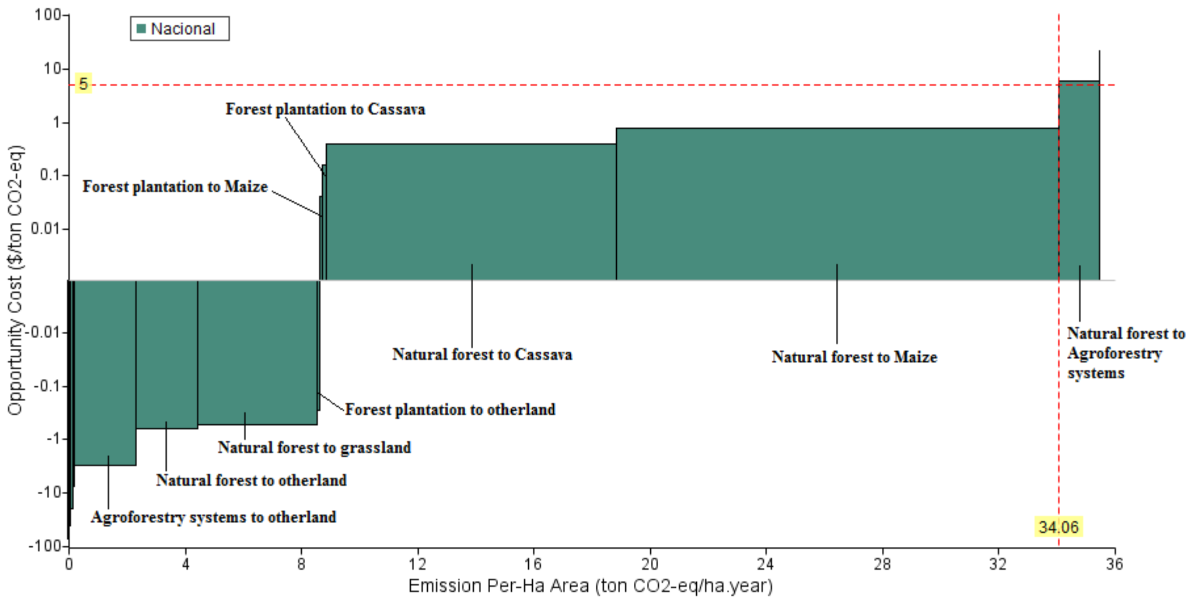


Figure 10: Opportunity cost curve from 2010 to 2014 (emission avoidance from land use systems conversion).

Figure 9 indicates that converting natural forest land to SAB agriculture not only causes emissions, but also represents a high cost; therefore, these are actions to be avoided. Conversion of natural forest to SAB agriculture (maize or cassava) is to be avoided as they will generate higher opportunity costs and higher emissions. Although natural forest to agroforestry land use option has relatively high opportunity cost, this represents emission reductions when compared to the BAU conversion of natural forests to slash-and-burn. Thus, avoiding land use conversion from AFS to other lands, natural forest to grassland would result in net GHG benefits at negative costs, which mean potential benefits in part because the NPV for this land use is lower than that of AFS and natural forests.

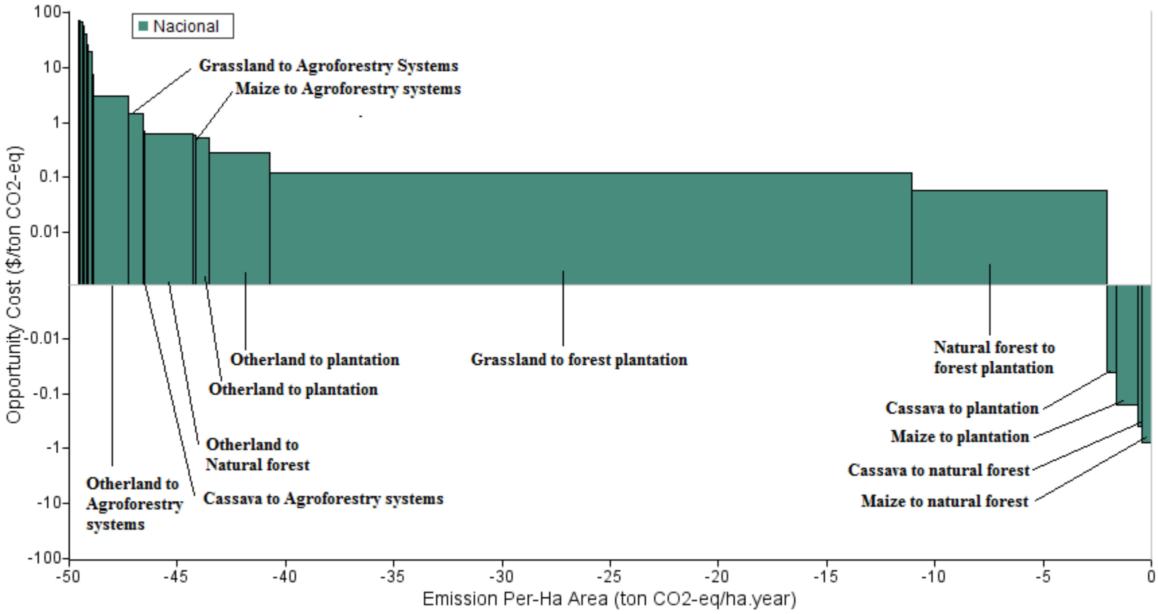


Figure 11: Opportunity cost curve from 2010 to 2014 (sequestration from land use systems conversion).

The main potential sequestering land use changes are the conversion of grassland to forest plantations, natural forest to forest plantations as represented by the larger bars (Figure 10). However, converting natural forest to any other land use system, means that we are promoting deforestation or forest degradation. The conversion of maize to AFS has low sequestration and had relatively high opportunity cost of avoiding conversion. The question of this study in relation to the potential of AFS to replace SAB agriculture (maize and cassava) can be answered by Figure 10, showing that the conversion from maize or cassava to AFS has relatively low potential of sequestration as represented by the narrowness of these bars in that conversion option. However, it should be clear that the narrowness is in relation to other land use options with higher potential like forest plantations, and natural forests which have much higher carbon stocks.

5.3. Scenario to reduce GHG emission from Agriculture and Energy sector (soft-linking approach)

The mitigation scenarios will serve as an outstanding effort involving the activities leading to reduce GHG emission in the energy sector and agriculture sector. The result of comparison between BAU scenario of irrigation and land use and its intervention is presented in Figure 11 (in logarithm scale). The total BAU emission indicated that both land use change and irrigation will reach emissions of about 6 million tCO2eq by 2030. This value is lower than 9.63 million tCO2eq reported by GoM (2012) but comparable to the 6.1 million tCO2eq from the land use component in 2030 reported by *Estratégia de Baixo Carbono*[43]. Data quality and methodology used in both studies can explain the differences. In fact, data employed in this report, mainly matrix transition, were gathered by assumptions and extrapolations using national forest inventory data of Marzoli[44]. Very high emission from land use change were reported by recent national forest inventory (in preparation), estimated in 40.5 million of tCO2eq in 2013. This clearly suggests that the differences in methodology can bring also different results, which need to be discussed with more detail.

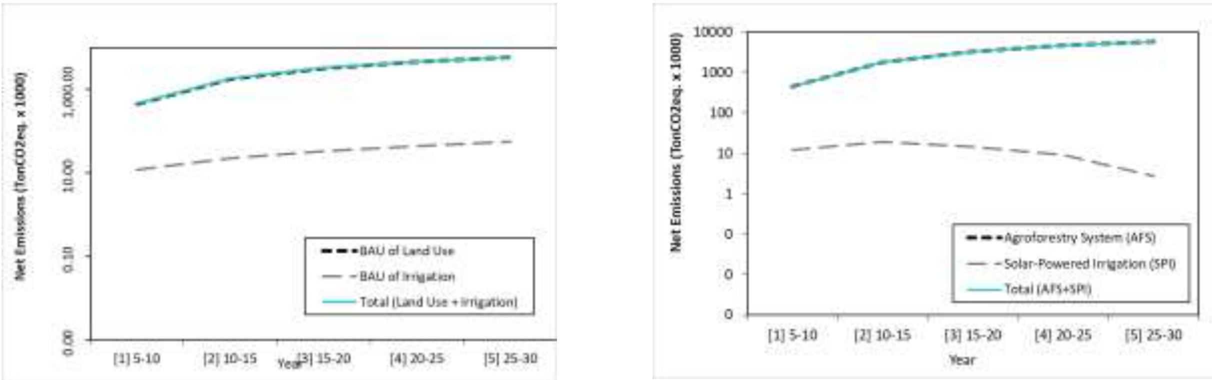


Figure 12: A comparison between BAU scenario (left side) and redution emission intervention scenario (right side).

The reduced emission scenario actions in Figure 11 will be potential to reduce the total cumulative of GHG emission equivalent to 1.9 million tCO2-eq/year from agriculture sector and energy sector by 2030 at national scale. The replacement of SAB agriculture to AFS is expected to reduce 33% of the land use change related emissions and FPI replaced by SPI to reduce in 35% of emission compared to historical baseline emissions (BAU). Here, can be noted that despite of emission reduction of SPI is very lower than from AFS as consequence of small irrigated land throughout the country, the relative value shows that SPI has more potential of emission reduction than AFS (Figure 11).

The soft-linking approach indicated that both SPI and AFS together are responsible for 54% of emission reduction from irrigation and land use change. The total BAU scenario which includes both slash and burn agriculture and FPI compared to total intervention which include AFS and SPI had the same trends as land use scenarios presented in Figure 8 in the preview section. Once again, here the large area of land use showed in Figure 12 overshadowed the impact of SPI impact.

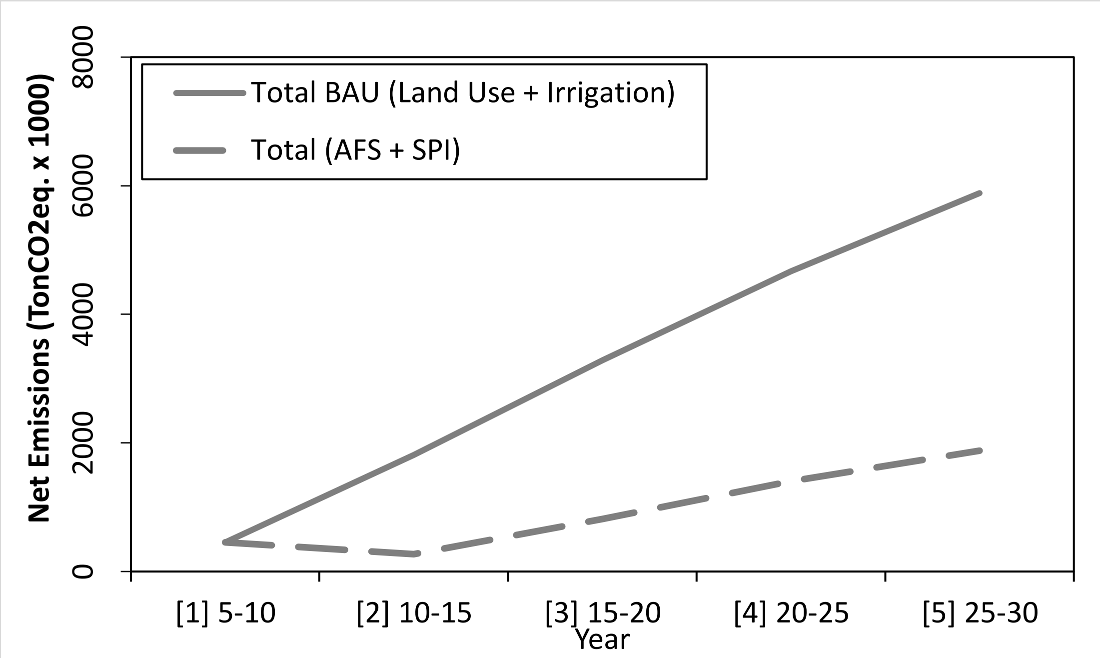


Figure 13: Total net emission of BAU form land use plus irrigation against AFS plus solar powered irrigation system from 2010 to 2030.

5.4. Economic and social benefit of solar powered irrigation system against fuel powered irrigation system

The BAU (FPI) were compared with SPI in terms of net present cost, job creation and emission reduction (Figure 13). The economic analyses were made at net present cost. Mozambique has limited irrigated area (0.5% of the cultivated land), therefore little has also been published in this area in terms of yield per crop, production cost and its disaggregation, and profit at level of smallholder farmer. Thus, in this report we used the net present cost (NPC), (that aggregates capital cost, operation cost, maintenance cost etc.) rather than net present value for both systems FPI and SPI [45],[46]). According to these authors, the NPC of FPI is four time higher than SPI, with 62,494 and 16,472 USD, respectively. The BAU scenario indicates that vegetables had higher CO2eq emissions, but higher employment amongst all crop groups. This result can be explained by the fact that vegetables are among the main activities of smallholder farmers in irrigated systems. Yet, vegetables have high water demand, hence high fuel consumption. On the other hand, if SPI technology is to be implemented, then the emission from fossil fuels can be avoided. In addition, considering the low NPC of SPI, this means that more people will have access to irrigation facilities, increasing job creation almost twice than BAU. The same trend can be seen on other crop groups as roots and tubers and leguminous.

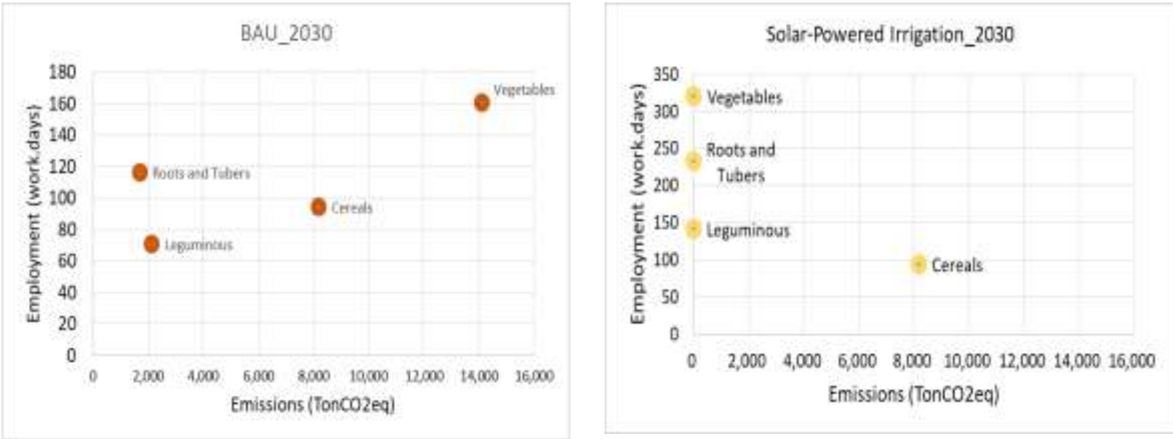


Figure 14: BAU baseline of emission and job creation of each crop in 2030 (left graph); Solar powered irrigation system baseline based on scenario to reduce emissions and increase job creation by irrigated crop in 2030 (right graph).

5.5. Economic and social benefit of Agroforestry against other land use

The land use transitions were analyzed in terms of their economic impacts and social impacts, i.e. return to land and return to labor, and potential for carbon sequestration. Some of these changes represent clear tradeoffs: increases in NPV with decreases in carbon or increases in carbon with decreases in NPV. Others represent win-win outcomes of increased NPV and carbon, while others represent lose-lose outcomes of decreased NPV and decreased carbon. The tradeoff analysis shows (Figure 14 to 16) that there are few easy wins, while most of the existing land use change systems in the study area do not show clear clusters.

Figure 14 below shows that AFS and plantation forest are the only components with clear win-win outcomes, with a “medium carbon – high profits” cluster for AFS and “medium profits – high carbon” cluster for plantation forests. Forest plantations are characterized by monoculture where trees are planted with well-defined spacing and trees grow with the same size that is why plantation forest has relatively high carbon stock. The potential of AFS for carbon sequestration is largely a consequence of carbon sequestration associated with trees growing in cropland[47] making the AFS as medium carbon close to natural forest. AFS has highest profits amongst land use systems given its diversity of annual and perennial crops. The only clear lose-lose land use option outcomes is grassland, with "low carbon – low profits", while SAB agriculture system (maize and cassava) outcomes are "low carbon – medium profits". The analysis of land use changes reveals that a transition from traditional shifting cultivation systems (maize and cassava) towards AFS generates higher profits while reducing emissions.

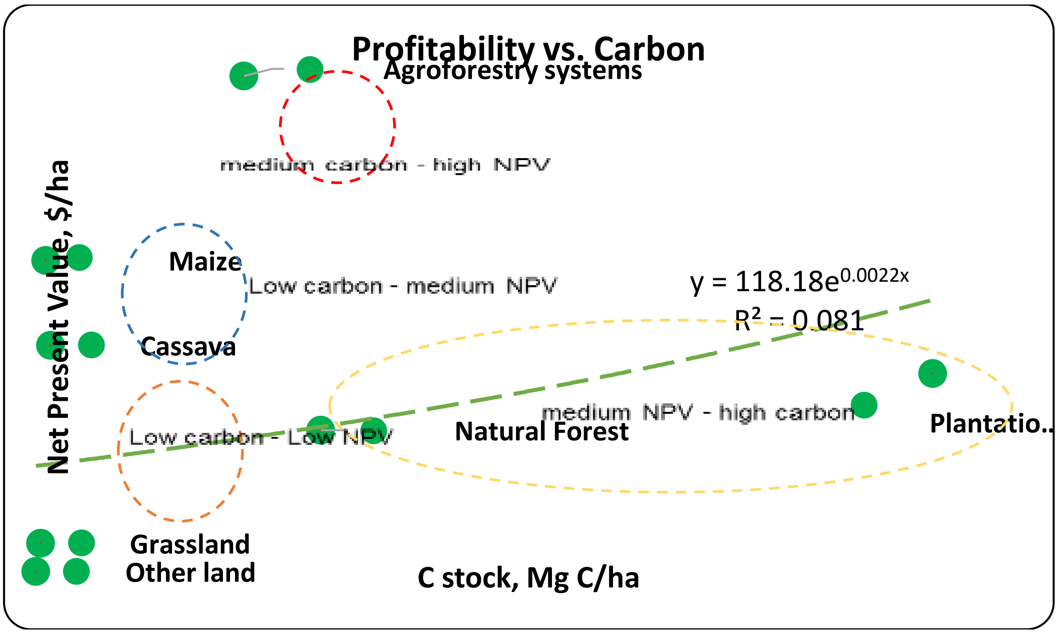


Figure 15: Cluster analysis between profitability and carbon stock amongst land cover.

The tradeoff analyses of carbon and employment (Figure 15) also suggest that there are some achievable win-win solutions, where carbon-sequestering land use changes also increase job creation, this can be seen clearly in AFS the only land use option within "medium-carbon – high jobs" cluster, and plantation forest with "high carbon – high jobs" cluster. Plantation forest and AFS both have a lot of activities from land preparation to harvesting, which require more workers than slash and burn agriculture systems. Cassava and Maize fall into "low carbon – medium jobs" cluster, this is in line with shifting cultivation are characterized by subsistence agriculture with less intensive process of production, with maize and cassava as main crops, and the activity of production usually are made by householder members around 2 or 3 people (father, mother and son).

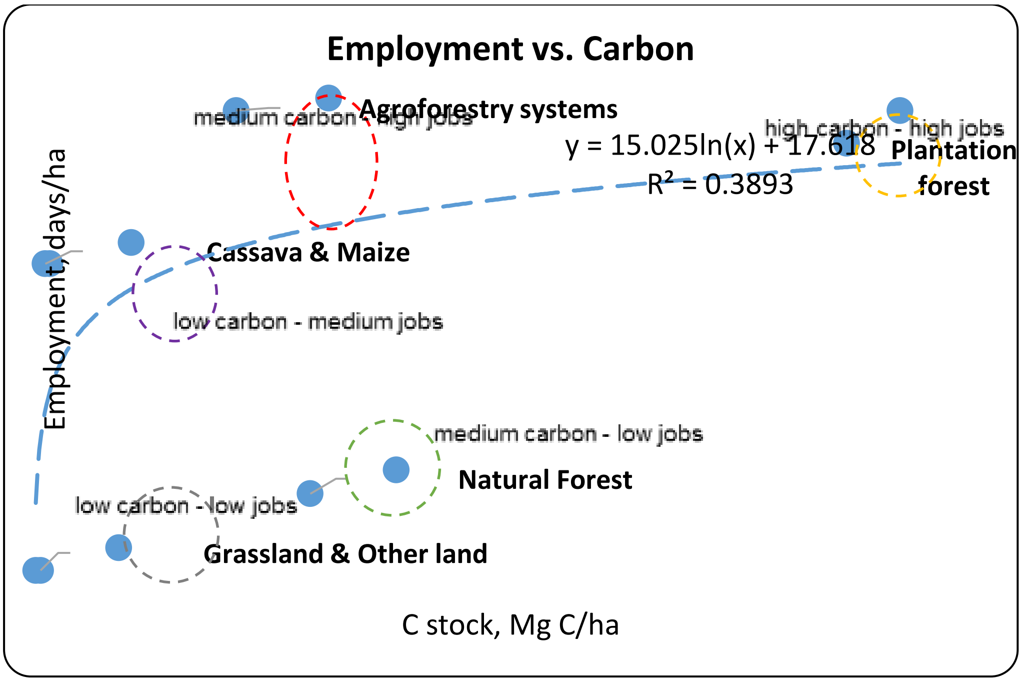


Figure 16: Cluster analysis between carbon stock and employment amongst land cover.

The cluster analysis between profitability and employment among land cover (Figure 16) shows that AFS is the land use option which falls into "high jobs – high profits" cluster following forest plantations with a "high jobs – medium profits" cluster. Regarding shifting cultivation, cassava and maize got win-win outcomes falling into "medium jobs – medium profits", suggesting that these are better land use options when compared to natural forests and grasslands, which at the present situation, do not generate jobs and have little profitability. Overall, these results enfasize that AFS is the only land use systems which generate high profits, high jobs and medium carbon stocks representing the best land use option when compared to the considered alternatives.

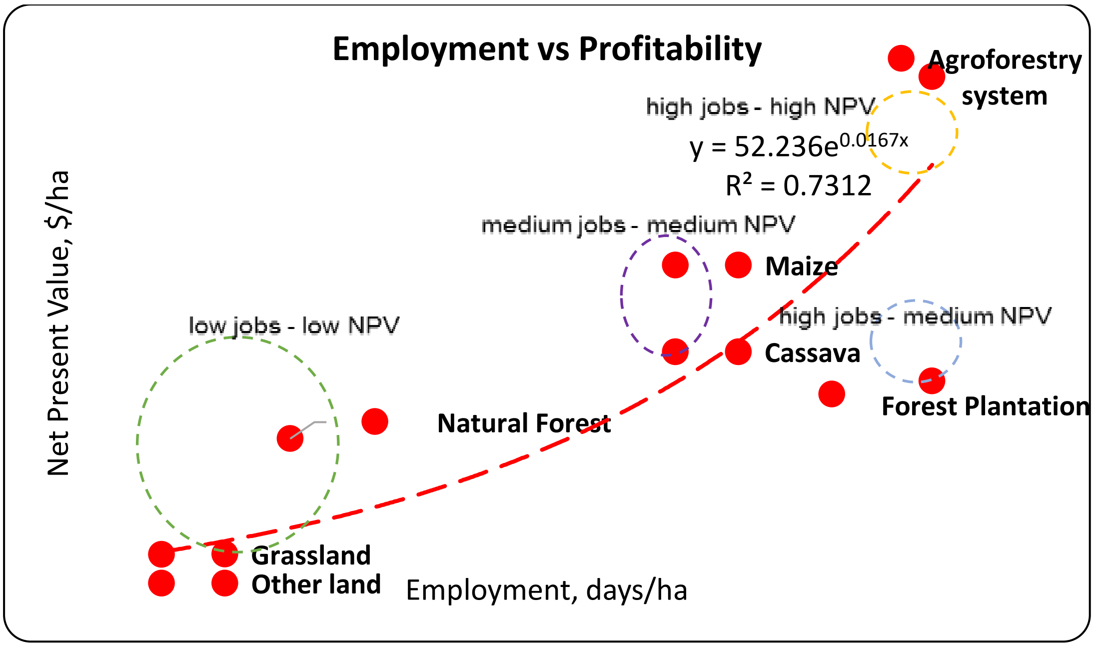
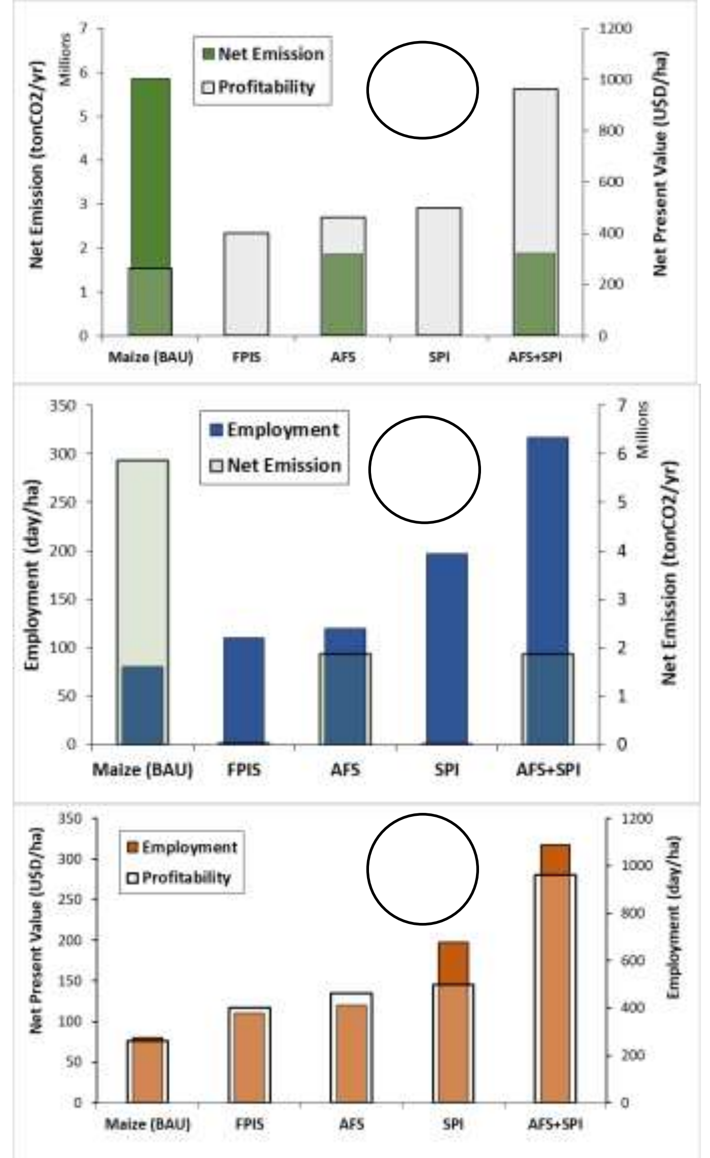


Figure 17: Cluster analysis between profitability and employment amongst land cover.

5.6. *Merging agroforestry systems and solar panel irrigation on maize production*



The evaluation of the joint effect of adopting agroforestry systems and solar panel irrigation was evaluated by combining the AFS and SPI scenarios over the traditional maize production in SAB agriculture. The results are given in Figure 18 where the three main parameters (net carbon emissions, employment, and net present value) are compared across different combinations. The general trend shows that the combination of SPI and AFS represents the best combination as it simultaneously results in lower net carbon emissions (Figure 18 A, B), highest NPV (Figure 18 A, C), and highest employment opportunity (Figure 18, B, C). These findings suggest that where possible, the combination of AFS and SPI should be used to maximize all important parameters of interest. Focus is given to profitability, opportunity of employment, and emission reduction potential. We used maize in this example, however, the other crops with potential use with agroforestry systems may also be considered under these scenarios.

Figure 18. Integrated evaluation of carbon and socioeconomic parameters of maize production

6. Conclusions and Lessons Learnt

The REDD Abacus was found to be relatively easier to implementation than the LEAP model as it was designed to evaluate land use change. The energy component (the FPI and SPI) could be simulated using LEAP, a system designed mainly to evaluate energy options. However, REDD Abacus could handle additional (non related to land use change)[48]. We can´t say much in terms of numerical results presented in this study, but tendencies, and data requirements. The results suggested that there is a great deal of opportunities to reduce CO_2 emissions, and increase CO_2 sequestrations in the agricultural sector with AFS. Moreover, using SPI, apart from reducing emissions, provides increased economic returns, and increase opportunities for more people to engage in irrigated agriculture. The analyses indicated that there is a medium and long-term potential for replacing SBA by AFS, and this has a potential to generate social, economic and environmental benefits. Because of these benefits, AFS should be considered among potential land use options for emission reduction. The combination of AFS and SPI resulted to provide the highest potential for emissions reduction at the same time that provides the highest profitability and employment opportunities.

Technical knowledge and accurate information should be carefully conveyed so that AFS as well as SPI practices can be sustained and to maximize benefits[49]. Moreover, there are remaining challenges to overcome this exercise. Management of such systems may represent an additional challenge for local communities. Net present value is main input for performing opportunity cost analysis, but there is lack of field data for each land use system, this limitation forced us to use international literature to extrapolate to our context. This study, therefore strongly recommends field data gathering, but our experience demonstrated that the smallholder farmers do not keep records of their production and consumption over the value chain. Thus, upcoming surveys will need to cover local stakeholders and should also adjust the choice of control variables for SBA and AFS, FPI, and SPI – e.g. by including ‘income’, ‘revenue’, ‘land ownership and land size’ as well as ‘employment’. This information will help to address transition cost and implementation cost as social costs is usually difficult to address. Although it is recognized that for emission reduction efforts, there are yet more relevant costs to be evaluated, even with the absence of transaction costs, implementation costs and social costs, the analysis of opportunity costs can still be powerful in providing information for decisions-makers for assessing the economic feasibility of emission reductions from land use change or land-based activities[50]. The transition matrix it is another main input for REDD Abacus modelling. However, there is no transition matrix for national scale as yet, and for this report we used deforestation rate from the 2007 national forest inventory[51] to extrapolate to each land use system conversion. The 2017 national forest inventory created a transition matrix but is not yet publicly available.

The main opportunity of this exercise apart from capacity building, we found out that data is needed in order to deal with minimum requirement to run both models LEAP and REDD Abacus. Thus, taking into consideration all earlier listed data limitation we recommend that the results of this report be used with care. However, given that the main objective of this study is country capacity building under LEDS program the results found are a good starting point to discuss agriculture and energy emission reduction options at national level. From the workshop with the stakeholder's discussion and validation we found out that the systematic observations and data collection systems in Mozambique are insufficient. Weak technical and institutional capacity contributes to the poor exploitation of opportunities provided by most of climate change mitigation programs, with emphasis on access to financial and technological resources, including capacity building. The capacity building provided by LEDS is an opportunity for Mozambique to strengthen the technical team in modelling and become engaged in global efforts to reduce GHG emissions by setting voluntary national priorities to promote a low-carbon economy that makes use of these abilities to mobilize financial and technological resources at affordable costs. Thus, to address this we identified some gaps that needs urgently to be addressed which are: (i) institutional coordination; (ii) training local technicians on the use of methodologies and guidelines for inventory and monitoring GHG emissions; (iii) establish a mechanism for systematic observation and collection of data on carbon stock and net present value (NPV) for the most common land use systems at local and national scale. This intent will be achieved through memorandums of understanding between institutions, databases to ease data access and sharing and protocol development for collection of missing data, production of scientific papers to validate the data, and harmonization of methodologies between institutions involved in LEDS program including all mitigation and adaptation to climate change.

7. Way forward and next steps

Ultimately, LEDS measures will only be successfully implemented, if they are understood and supported by local stakeholders. Taking this into consideration, it is necessary to inform policymakers about the economic, social and environmental benefits of available options to promote development while reducing emissions, such as presented in this study.

Data availability revealed to be the most limiting factor for the simulation. In this regard, we suggest that research institutions be engaged and strongly encouraged to include research lines that generate data and information to support LEDS.

Statistics on areas, land use change, irrigated area, characteristics of the fuel powered irrigation, and capacity of the solar powered irrigation systems, among others need to be systematically collected to provide a solid base for estimation of emissions and the potential of emissions reduction. Therefore, national institutions, such as Instituto Nacional de Irrigação (INIR), and the Instituto de Investigação Agrária de Moçambique (IIAM) are encouraged to engage in systematic data collection and provide a platform to facilitate data access.

The Government of Mozambique is in process of preparation of several documents reporting to UNFCCC, such as the National Determined Contribution (NDC), the Biennial Update Report (BUR), National Communication (NC), GHG inventory. The results of this report have potential to inform these processes in term of emissions and emission reduction potential.

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