STAPLE CROPS PROCESSING ZONEs (SCPZs): Promoting Sustainable Agricultural Value Chains.

FINANCIAL ANALYSIS REPORT OF THE STAPLES CROPS PROCESSING ZONE.

African Development Bank

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1. Introduction.

GCF funding is being requested to enable the Programme Countries take advantage of the AE's financing of the SCPZ to integrate measures that will contribute to meeting their Nationally Determined Contributions (NDCs) targets. GCF funding will also help the Programme Countries to rationalize agricultural value chains in their nations to be more low-carbon and climate resilient. The financing will essentially be linked to assets and practices including:

(i) About 24,577 m^3 biodigesters and accessories to reduce methane emission from the agro and human waste and clean energy to replace diesel fuel for plants and motors for lighting, processing, storage, and packaging facilities;
(ii) About 15 MW of solar to replace diesel fuel for plants and motors for processing, storage and lighting,
(iii) About 2.6MW solar irrigation to replace diesel-based irrigation motors
(iv) About 40,000 hectares of agro-forestry to sequester carbon and
(v) About 39,250 hectares of land with climate resilient agricultural practices.
(vi) Setting up of necessary infrastructure for Climate Information and Early Warning System (CIEWS)

Financing from the GCF for these assets and practices will significantly contribute to the efforts being made by the Programme Countries to meet their NDC commitments under the Paris Agreement. For example, the conversion of human waste and agro-waste especially from post-harvest losses and processing that could have emitted methane and generate over 477,867tCO2eq every year could be avoided. The availability of biogas will also help generate over 44 million kWh/yr clean power to replace diesel fuel for generators, motors and other plant systems that will help reduce atmospheric emission of over 28 thousand tCO_2eq. GCF financing will also help reduce about 36 thousand tCO_2eq of emissions every year by replacing diesel-based irrigation and energy systems with solar (taking advantage of the great solar PV conditions in these countries). The integration of agro-forestry activities in the SCPZ programme will help sequester over 183 thousand tCO2eq every year. The financial analyses focus essentially on these assets and practices.

2. Energy Demand Analysis.

Energy demand for GCF related activities focused essentially on processing as the base activity. The staple crops were grouped into (i) Cereals; (ii) Roots and Tubers; (iii) Legumes and nuts and (iv) vegetables and fruits to determine the estimated yield by linking the total area (ha) that will be allocated for each crop clusters with the average yield per hectare of the crop clusters. Data on yield per hectare from the Food and Agriculture Organization of the United Nations[1] were averaged across crop clusters. The results are designated as Crop Yields for Guinea, Senegal and Togo in Annex 3A. Studies by Ukoba et. al[2] (2018) indicates how solar energy could contribute to the reduction of post-harvest loss of especially roots and tubers. Their studies referenced post-harvest losses in South Africa to be 44% for fruit and vegetables, 26% for grains, 15 % for meat, and 13% for

[1]http://www.fao.org/faostat/en/#data
[2] Kingsley O. Ukoba, Freddie L. Inambao, and Prudence Njiru. Solar Energy and Post-Harvest Loss Reduction in Roots and Tubers in Africa Proceedings of the World Congress on Engineering and Computer Science 2018 Vol I. http://www.iaeng.org/ publication/ WCECS2018/WCECS2018_pp244-248.pdf"

roots, tubers and oilseeds at the upstream production side. At the processing, packaging, distribution and retail and consumption levels, post-harvest lost was estimated as 50%, 25%, 20% and 5 % respectively. Such detailed data and information for the countries is not available. However, report by the World Bank[3] referenced estimates from African Post-harvest Losses Information System (APHLIS) of post-harvest handling and storage loss to be between 10-12%. In the World Bank report, FAO estimates was as much as 37% for Sub-Saharan Africa while countries self-reporting of on-farm post-harvest loss for maize harvest for example was estimated to be between 1.4 and 5.9%. There is therefore very marked disparities between estimates not only at the country and particular studies but also at the different value chains. With the expectation of value addition and improved harvesting and handling practices envisaged at the Agro-industrial Parks (AIPS) and the Agricultural Transformation Centres (ATCs), the analysis used the upper limit or this range. Data and information on energy usage for processing cereals[4],tubers[5], legumes[6], fruits and vegetable[7] were standardized (some data were in tonnes for weight and MJ for energy consumption) into Wh/kg/yr and used as surrogates for the crop clusters. The Annual Energy Usage for Processing (KWh/kg/year) was estimated for each Programme Country.

3. Analysis of Energy Consumption for Irrigation.

Picazo et. al (2018)[8] emphasized the significance of powering irrigation systems with solar energy that are relatively cost-effective and has minimal impacts on climate change and the environment. The results of a case study indicate energy consumption based on PV system with 651 solar panels and energy consumption of 428.74 kWh per day, that irrigates an orchards of about 168 ha translating into about 2.6 kWh per day/ha. Another case study by Guzman et. al (2018)[9] indicates that although on-grid PV systems for irrigation are more financially viable in terms of shorter payback period (12 years) compared to off-grid systems, (over 30 years), off-grid systems may provide greater opportunity for promoting growth and development at the local level especially when on-grid alternative is not reliable or not available. The financial analysis used as benchmark energy consumption data for an off-grid system that Wazed et al (2018)[10]cited from a study by Deveci et al (2015)[11] which utilized 2 x10W PV panels as off-grid system with 132Wh/day to provide 2 hours a day irrigation for an area of about 1000 m^2 with 100 trees. covering 1000 m2 and

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[3]World Bank. Agriculture in Africa : Telling Myths from Facts; Editors. Christiansen, Luc, Demery, Lionel. Is Post-Harvest Loss Significant in Sub-Saharan Africa? https://www.worldbank.org/en/programs/africa-myths-and-facts/publication/is-post-harvest-loss-significant-in-sub-saharan-africa

[4]L. Chladek, P. Vaculik and A. Vagova. The measurement of energy consumption during milling different cereals using the sieve analyses. https://agronomy.emu.ee/wp-content/uploads/2018/05/Vol16S2_5.pdf

[5] Simeon Jekayinfa. Analysis of energy usage in the production of three selected cassava-based foods in Nigeria, Journal of Food Engineering, 2007. https://www.academia.edu/11919866/Analysis_of_energy_usage_in_the_production_of_three_selected_cassava-based_foods_in_Nigeria

[6]SubuolaFasoyiro, Yudi Widodo, and Kehinde Adekunbi Taiwo. Processing and Utilization of Legumes in the Tropics. https://www.researchgate.net/publication/224829993_Processing_and_Utilization_of_Legumes_in_the_Tropics.

[7] Alia Ladha-Sabura, SerafimBakalis, Peter J.Fryer, and Estefania Lopez-Quirogaa. Mapping energy consumption in food manufacturing, https://www.sciencedirect.com/science/article/pii/S0924224417303394

[8] Miguel Ángel Pardo Picazo1,* , Juan Manzano Juárez 2 and Diego García-Márquez 1. A Cost-Effective Methodology for Sizing Solar PV Systems for Existing Irrigation Facilities in Chile https://www.mdpi.com/2071-1050/10/11/4203

[9] Aldo Barrueto Guzmán, Rodrigo Barraza Vicencio, Jorge Alfredo Ardila-Rey, Eduardo NúñezAhumada, Arturo González Araya 2 and Gerardo Arancibia Moreno. A Cost-Effective Methodology for Sizing Solar PV Systems for Existing Irrigation Facilities in Chile. https://www.mdpi.com/1996-1073/11/7/1853

[10]Saeed Mohammed Wazeda,Ben Richard Hughesa, Dominic O'Connora, John Kaiser Calautit. A review of sustainable solar irrigation systems for Sub-Saharan Africa. https://www.researchgate.net/publication/319666224_A_review_of_sustainable_solar_irrigation_systems_for_Sub-Saharan_Africa.

[11]Deveci O, Onkol M, Unver HO, Ozturk Z. Design and development of a low-cost solar powered drip irrigation system using Systems Modeling Language. J Clean. Prod 2015;102:529–44. http://dx.doi.org/10.1016/j.jclepro.2015.04.124.

containing over 100 trees, it was considered that it would require. The energy consumption of 132 Wh/day covering 1000 (1 m² = 0.0001 ha)[12] for 5hrs/day (1825 hours/yr) irrigation translates into installed capacity of 0.264 kW/ha/yr. The installed capacity based on the area allocated by each Programme Country is estimated. The total installed capacity is estimated at 2.59 MW. With 80% adjustment for efficiency of the PV equipment to generate electricity, the annual generation was estimated at 3,775MWh/yr. It is important to recognize that efficiency is different from capacity factor. Efficiency relates to the measure of the ability of the solar PV system to convert solar radiation to electrical energy. Capacity factor relates to the measure of how much energy is actually produced over a period of time compared to how much could have been produced if the facility ran at full output all the time[13]. Table 1 shows the solar PV capacity to be installed and the expected energy output for the Programme Countries.

Table 1. Sizing of solar PVs to replace diesel-based irrigation systems

Solar Irrigation				**Solar Irrigation**
	SCPZs Countries	**Farm Land Covered (ha)**	**Solar energy generation per year (kWh/year)**	**Solar Capacity Required (kW)**
	Guinea	2,952.5	1,138,011.60	779.46
	Senegal	2,985.0	1,150,538.40	788.04
	Togo	3,857.0	1,486,642.08	1,018.25
	Total	**9,794.5**	**3,775,192.1**	**2,585.7**
Solar Irrigation Total				
	Installed Capacity per hectare (kW/ha)		0.264	
	Solar energy generation per year (kWh/year)		3,775,192	
	Total kW capacity needed		2,585.75	
	Costs per watts	**$1.5/watts**	**$3,878.6**	

[12]Reference conversions. https://www.bing.com/search?q=how+many+square+meters+in+one+hectare&form=ANNH01&refig=5e9c961ba0494f229c50f113b3ca2249&sp=2&pq=how+many+squar+meters+in+&sc=8-25&qs=SC&sk=PRES1SC1&cvid=5e9c961ba0494f229c50f113b3ca2249

[13]http://www.lifebynumbers.ca/the-solar-solution/solar-capacity-and-capacity-factor/#:~:text=%20What%20impacts%20solar%20capacity%20factor?%20%201,with%20sufficient%20intensity%20to%20produce%20electricity%20More

4. Analysis of Biogas Energy Generation.

The analysis of the biogas energy generation is at two levels. At the level of the biodigester plants and at the level of the use of the biogas directly for transport, cooking, cooling or for electricity generation. According to Ammenberg et al (2017)[14] due to differences in for example, geographical scope, time perspectives, feedstock, ecological aspects, impacts on climate change and energy potential, there are several and divergent methodological approaches for estimating biogas potential and result. Cuellar et al (2008)[15] offered a very simplified approach for calculating biogas potential by multiplying the values of for the amount of biogas energy that can be produced per animal unit (defined as 1000 pounds of animal) or the biomethane yield per dry matter content on total solids (TS) per day and the number of animal units generating the feedstock. This analysis refined this methodology by introducing discharge rate since the livestock have different discharge rates (tonne/yr) and available manure as feedstock for the digester.

4.1 Assumptions:

For the evaluation of potential feedstock, official livestock data from each country was gathered during a field mission in March 2022. Following discussion with representatives of the agricultural and farming communities, the percentage of livestock headcount that can be used for production of organic matter for biodigester was estimated. The average 2.5% of feedstock that could be obtained from the official livestock data in the SCPZ area is very conservative. Moreover, there are other sources of feedstock such as agro-residues from post-harvest losses and processing, human waste and the sewage systems which points to the availability of feedstock for the installed capacity of biodigesters for each country.

4.2 Estimation of Biogas Potential:

The biogas energy potential was calculated using values for the amount of biogas energy that can be produced per animal unit (defined as 1000 pounds of animal) per day and the number of animal units in the US Information from Ammenberg (2017)[16] on biomethane yield and suitability for anaerobic digestion for each feedstock was averaged and multiplied by the average discharge and the estimated number of livestock or human beings available per year for the annual biogas generation. Estimated annual biogas production from food waste and agricultural residues were estimated based on biomethane yield information from SGC (2012)[17] and that of human discharge was from LGED (2019)[18]. Several biogas designs have specific volume measurement as indicated in IRENA (2016)[19] with for example, volume estimation for (i) Fixed dome plant (hemisphere design), (ii) Fixed dome plant (Deenbandhu design); (iii) Fixed dome plant (Chinese design); and (iv) Floating drum plant. Due to the competitive

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[14]Ammenberg, J et al (2017). Systematic assessment of feedstock for an expanded biogas production —A multi-criteria approach. https://www.diva-portal.org/smash/get/diva2:1156008/FULLTEXT01.pdf

[15]Amanda D Cuellar ´ 1 and Michael E Webber, Cow power: the energy and emissions benefits of converting manure to biogas. stacks.iop.org/ERL/3/034002 or https://iopscience.iop.org/article/10.1088/1748-9326/3/3/034002

[16]Ammenberg, J et al (2017). Systematic assessment of feedstock for an expanded biogas production —A multi-criteria approach. https://www.diva-portal.org/smash/get/diva2:1156008/FULLTEXT01.pdf

[17]Swedish Gas Technology Centre Ltd (SGC) 2012.. Basic Data on Biogas. http://www.sgc.se/ckfinder/userfiles/files/BasicDataonBiogas2012.pdf

[18]LGED (2019) https://sswm.info/sites/default/files/reference_attachments/BRC%20ny%20Design%20Biogas%20Plant.pdf

[19]IRENA (2016). Measuring small-scale biogas capacity and production. https://www.irena.org/publications/2016/Dec/Measuring-small-scale-biogas-capacity-and-production

bidding process for the AE procurement procedures, no single design is to be preferred to provide opportunity for the private developers to present the most technically and commercially efficient and financially viable options depending on the local conditions of the SCPZ area.

An average digester volume per cubic meter of biogas generation estimated from IRENA (2016) ranged from about digester volume of 2 m^3 to 3 m^3 per 1 m^3/day of biogas generation. Following volume estimation by Idan (2012)[20]. Without any specific choice of biodigester designs, the estimated digester volume for this project was conservatively done by annualizing a 5.2 m^3 biogas generation per 1 m^3 of digester volume and dividing it by the annual potential generation. The biogas generation potential and the estimated digester volume is shown in Table 2.

Table 2. Estimation of biogas potential and digester volume

Feedstock	Average Discharge (tonne/yr)	Yield of Biogas (m3/tonne TS)	Annual Biogas Generation (m3/yr)
Cattle manure	3.65	42	14,310,054.26
Sheep & Goat manure	1.825	108	29,002,555.44
Pigs/Swine	1.825	47	1,841,132.22
Poultry/Chicken	0.0365	90	1,492,762.29
Fish/aquaculture	0.0365	90	-
agrowaste	0.000	191	-
foodwaste	0.000	101	-
human waste/sewage	0.1825	64	-
Total (m3/yr)			46,646,504
Volume of Digester (m3)			24,576.66

4.3. Estimation of Net CO_2 Equivalent Emission Reduction (tCo_2eq/Yr)

For the estimation of the net equivalent carbon, the annual biogas generation were a model uncertainty factor of 94% and methane conversion factor for each feedstock following SGC (2012) was used to estimate the methane gas available each year as 40,217,160.21m^3/yr. Following IPCC[21] conversion methodology of methane from m^3 to kg the conversion factor converts the volume of CH_4 to a weight measure and is the density of methane at 20°C and 1 atmosphere, where 0.67 Gg/10^6 m^3 (1 Gg = 10^6 or 670000 kg/1,000,000 m^3 or 0.67 kg/1 m^3). This results in 26,945,497.34 kg/yr and conversion of the kg to tonne (1 kg = 0.001 tonne) results in avoided atmospheric methane emission of 77,688.73 tCH_4. Biogas is a low-carbon, climate mitigation technology. According to the Fourth Assessment Report (AR4) of the Intergovernmental Panel on Climate Change (IPCC),

[20] Idan, J.A . 2012. "Financing Waste to Energy in Africa". United Nations University-Institute for Natural Resources in Africa (UNU-INRA) Visiting Research Seminar Series. June 28, 2012. UNU-INRA.

[21] ENERGY 1.96 - IPCC - Task Force on National Greenhouse. https://www.ipcc-nggip.iges.or.jp/public/gl/guidelin/ch1ref7.pdf

the global warming potential (GWP) of methane over 100 years period of time is 25 times that of CO2 (IPCC, 2007)[22]. Based on this, the CO_2eq equivalent emissions from direct discharge into atmosphere is 673,637.43 tCo_{2eq}.

Methane is the combustible component of biogas. This is expressed by Equations (1) as

$CH4 + 2O_2 \rightarrow CO_2 + 2H_2O$. (1)

That is to say burning CH_4 results in CO_2: $CH_4 + 2O_2 \rightarrow CO_2 + 2\ H_2O$. This illustrates that the combustion of one mole of methane produces one mole of carbon dioxide. Expressing the conversion in mass basis using molecular weights shows that 16 g of methane produce 44 g of CO_2 (Cuellar et al., 2018). Expressing the conversion in tonnes[23] indicates that burning 16 tonnes of CH_4 yields 44 tonnes of CO_2 and burning 100 tonnes of CH_4 yields 100 tonnes x 44/16 = 275 tonnes of CO_2; and burning 1 tonne CH_4 yields 2.75 tonnes CO_2. The carbon equivalent emission (tCO_{2eq}) from conversion of methane to CO_2 during end-use (gas-to-energy) is therefore 74,100.12 tCO_{2eq}. With that adjustment, the net carbon equivalent emission reduction/Yr from this programme is 673,637 tCo2eq.

4.4 Analysis of Direct Utilization of biogas.

Investments in anaerobic digestion technology for biogas are not financially viable when high interest rates and implicit discount rates are used. This is due to the high externalities of incremental costs to the developer and high externalized benefits to global climate change considering the relative GWP potential of the methane emission that is avoided as indicated above.

Kerosene and biomass including wood fuel and charcoal are the most economical options for lighting and cooking and diesel is the cost-effective alternative for transportation in the Programme Countries. For example, according to the energy outlook report by the IEA (2019)[24], 19% of the population in Senegal depends on charcoal for cooking, 52% on other solid biomass such as wood fuel and agro residues, and 29% of LPG. Apart from the significant contributions to climate change, deforestation and land degradation of these biomass-based and fossil-based energy systems for cooking, they also have tremendous health impacts on the especially the vulnerable communities in the Programme Countries.

Meanwhile, biogas technology presents great opportunities for decentralized (off-grid) and diversified uses. Biogas has multiple direct uses such as for stoves, lamps, incubators/radiant heaters for poultry/piggery and other livestock businesses, refrigerators, air-conditioners and transportation. Advanced technologies (appliances, equipment and other facilities) being powered biogas are wide spread not only in developed countries such as Germany and Denmark but in emerging countries such as China, India, Malaysia and Thailand (Amigun 2012)[25], Energypedia[26]

[22]Fourth Assessment Report of the IPCC. https://www.ipcc.ch/site/assets/uploads/2018/03/ar4_wg2_full_report.pdf

[23]GAS IS DIRTY ENERGY. burning methane (CH4) generates carbon dioxide (CO2), CH4 leaks & CH4 is 105 times worse than CO2 as a greenhouse gas (GHG). https://sites.google.com/site/gasisnotcleanenergy/gas-is-dirty-energy

[24]International Energy Agency (IEA). 2019. Senegal Energy Outlook. Analysis from Africa Energy Outlook 2019. https://www.iea.org/articles/senegal-energy-outlook. k

[25]Amigun, B. et al., 2012. "Anaerobic Biogas Generation for Rural Area Energy Provision in Africa". http://cdn.intechopen.com/pdfs/31319/InTech-Anaerobic_biogas_generation_for_rural_area_energy _provision_in_africa.pdf.

[26]https://energypedia.info/wiki/Biogas_Appliances

and Biogas for Better Life (2007)[27]. Biogas use in the Programme Countries will also provide innovative ways for improving resource use efficiency as part of green growth initiatives. Biogas technology could transform "waste" to resources for diversified and decentralized energy use. It could maximize the value and unit output from the reuse of resources and contribute to reduced water usage, recycle and reuse of water for flushing toilets and the application of the bio slurry as fertilizer in the AIPS and ACTs. Biogas technology is also the only renewable energy technology that promotes the 4Rs of waste management (reduce, reuse, recycle and regenerate/recover). It promotes the use of resources in a way that mitigates the negative ecological impacts of waste disposal on the environment. It also offers additional benefits such as improved sanitation and environmental health that are critical for socially-inclusive growth and for meeting the Millennium Development Goals (MDGs). Moreover, the technology depends largely on the use of local materials for feedstock and the biodigester as indicated by Amigun et al (2012) and Biogas for Better Life (20017) and could provide great opportunities for green jobs particularly for carpenters, masons and other artisanal workers including youth and women.

Amigun and Blottnitz (2010)[28] presented a wide variety of costs even with a particular country for biodigester installations in several African countries as indicated in Table 3. The estimated costs of installation for a cubic meter (m^3) of biodigester volume ranges from $145/$m^3$ in Nigeria to $445/$m^3$ in Ghana. This publication was done in 2010. However, using an average rate of inflation for Sub Saharan Africa of about 8% from 2015 to 2021[29] as surrogate for (2010 to 2021) translates into about $345/$m^3$ for Nigeria and $1,060/$m^3$ for Ghana.

[27]Biogas for Better Life—An African Initiative; 2007, www.biogasafrica.org

[28]B. Amigun and H. von Blottnitz (2010). Capacity-cost and location-cost analyses for biogas plants in Africa. Resources Conservation and Recycling 55(1):63-73. https://www.researchgate.net/publication/222906720_Capacity-cost_and_location-cost_analyses_for_biogas_plants_in_Africa

[29]https://www.statista.com/statistics/805570/inflation-rate-in-sub-saharan-africa/

Table 3. Fixed capital investment cost for biogas installations in some African countries

S/N	Plant location	Capacity (m^3)	Year built	Original cost	Original cost (normalised to ENR index 2004) US$
1	Namibia	4	1999	750 US$	860
2	Ethiopia	4	2000	554 US$	618
3	South Africa	5	2002	5000 Rand	504
4	South Africa	5	2003	5000 Rand	685
5	Nigeria	6	1999	763 US$	874
6	Rwanda	6	2004	1016 US$	1016
7	Ghana	6	2004	1358 US$	1358
8	Uganda	6	2004	1005 US$	1005
9	Burkina Faso	6	2004	1029 US$	1029
10	Kenya	8	2004	1535 US$	1535
11	Nigeria	10	2005	4,92,100 Naira	3565
12	South Africa	10	2001	20,000 Rand	2541
13	South Africa	11	2004	23,000 Rand	3487
14	South Africa	11	2004	23,000 Rand	3487
15	South Africa	11	2004	23,000 Rand	3487
16	South Africa	11	2004	23,000 Rand	3487
17	Rwanda	16	2004	2000 US$	2000
18	Rwanda	16	2004	25,000 US$	2500
19	Zimbabwe	16	2004	2,212,804 Zim$	3173
20	Kenya	16	2004	2198 US$	2918
21	Kenya	16	2004	2793 US$	2793
22	Ghana	20	2000	7974 US$	8901
23	Ghana	20	1996	750 US$	6334
24	Lesotho	31	2004	7132 US$	7132
25	South Africa	40	2002	97,000 Rand	9784
26	Burundi	50	2002	18,000 US$	19118
27	Kenya	54	2004	12,176 US$	12176
28	Rwanda	74	2002	7150,000 RWF	15943
29	Rwanda	74	2003	7,800,200 RWF	15050
31	Rwanda	84	2004	9,188,010 RWF	15,990
30	Ghana	100	1999	39,120 US$	44,835
32	Kenya	124	2004	26,090 US$	38,090
33	Rwanda	650	2002	50,870,000 RWF	127,318
34	Rwanda	830	2003	58,086,270 RWF	112,073
35	Rwanda	1000	2004	220,000 US$	220,000
36	Rwanda	1430	2005	96,466,000 RWF	173,835
37	South Africa	4500	2004	1,671,429 US$	1,671,429
38	Nigeria	5000	2004	420,000 US$	420,000

Source: Amigun and Blottnitz (2010)

Greater percentage of the costs component for biodigester usually relates to the construction of the biodigester. As indicated in Table 4, the construction of biodigesters rely extensively on local materials such as cement, sand, lime, stones and gravel and wires. This provides significant jobs opportunity for masons and other artisanal workers. There are significant difference between the total costs including biogas accessories in Rwanda and South Africa. The $859 for Rwanda in 2007 translates into about $2,623 with 8% inflation as surrogate and that of the $1149 for South

Africa translates into \$3508 for the $6m^3$ digester (\$437/m^3 in Rwanda and \$585/m^3 in South Africa). The analysis used a conservative cost estimate of \$300/m^3 for the biodigesters. The analysis used NRREP (2014)[30] O&M information for guidance. Based on a project in Nepal, the fixed costs for a $50m^3$ biogas plant were about 570,000 Nepalese Rupee and the O&M costs was 5,000 Nepalese Rupee which represents about 1% of the fixed costs. This analysis used 5% O&M costs.

Table 4. Rwanda and South Africa-6 m3 GGC 2047 fixed-dome digester cost comparison (on the basis of costs for wide-scale implementation)

	Item	Rwanda (US\$)	South Africa (US\$)
A	Construction materials		
	Cement	160.70	76.00
	Lime	6.50	
	Waterproof cement	49.10	
	Sand	40.00	Owner provided
	Stone	54.50	162 (900 bricks)
	Gravel (3/4)	21.80	Owner provided
	Reinforcement (6 mm)	10.90	49.50
	Binding wire (2 mm)	0.90	
	Smaller items	25.45	
	Mixer		28.50
	Paint		9.65
	Sub-total construction materials	370.00	325.65
B	Pipes and fittings		
	GI pipe (21 mm diameter)	65.50	125.00
	PVC pipe (110 mm)-outlet	27.30	15.40
	GI pipe fitting 21 mm	16.40	16.80
	Sub-total pipe and fitting	109.00	157.20
C	Appliances cost		
	Stove	27.30	65.00
	Main valve	5.00	
	Water drain	2.20	
	Gas tap	3.30	19.30
	Inlet, dome gas + rubber		71.50
	Sub-total appliances	33.80	155.80
D	Labour cost		
	Skilled labour	45.50	228.80
	Unskilled labour	43.60	188.65
	Sub-total labour	89.00[a]	418.05
E	Construction charge		
	Transport cost	98.18	100.00
	Entrepreneur overhead	154.55	120.00
	Company profit		150.00
	Sub-total construction	253.00	370.00
Total	859.00	1008.65	
F	VAT (14%)		141.20
	Grand total	859.00	1149.86

[30]Alternative Energy Promotion Center – NRREP. BIOGAS CALCULATION TOOL USER´S GUIDE. 2017. https://www.aepc.gov.np/uploads/docs/2018-06-19_Biogas%20calculation%20Tool%20User's%20Guide,%202014.pdf

Source: Biogas for Better Life (2007) cited in Source: Amigun and Blottnitz (2010)

Data on price of cubic volume of biogas varies widely depending on the country and specific system of collection, packaging, delivery and utilization. It's therefore useful to rely on benchmark price so for expected revenue, the analysis used price of biogas production in the form of methane for the transport sector based on IRENA (2017)[31] report as the surrogate to calculate the expected revenue. IRENA (2017) indicate that the price of producing biogas typically ranges between USD 0.22 and USD 0.39 per cubic meter of methane for manure-based biogas production, and USD 0.11 to USD 0.50 per cubic meter of methane for industrial waste-based biogas production. IRENA also note that the byproduct of a biogas is the bio-slurry which is usually used to replace commercial agriculture. According to Smith (2011[32]), the bio-slurry is an effective organic fertilizer. The emission impacts from GHGs such as nitrous oxide, were significantly lower from crops treated with bio-slurry than from those treated with urea. Furthermore, using bio-slurry as a fertilizer can increase crops yield by 25% and save the farmers more than 50 US$ on the cost of chemical fertilizers. The expected annual revenue were discounted to reflect the time value of money.

The analysis also considered the potential costs savings from replacing kerosene and wood charcoal that are fossil- and biomass-based systems with significant climate and deforestation impacts with biogas for cooking and lighting. Biogas based cookstoves and lamps are very efficient. Data on 2019 export quantity (tonnes/yr) and value for wood charcoal was obtained from FAOSTAT[33]. The estimated value was $278/tonne. For kerosene, Tracy and Jacobson (2012)[34] provided in their study the average price of kerosene for rural areas of Senegal that was used for the analysis. As indicated in Table 5, by switching to biogas from kerosene and wood charcoal could result in saving about $2.3 million every year and over $35.5 million even at the high ESCO discount rate.

[31]IRENA 2017. Biogas Cost Reductions to Boost Sustainable Transport. https://irena.org/newsroom/articles/2017/Mar/Biogas-Cost-Reductions-to-Boost-Sustainable-Transport#:~:text=Typically%20the%20price%20of%20producing,industrial%20waste%2Dbased%20biogas%20production.

[32]Smith, J. U. 2011. The Potential of Small-Scale Biogas Digesters to Alleviate Poverty and Improve Long Term Sustainability of Ecosystem Services in Sub-Saharan Africa. DFID NET-RCA06502. https://assets.publishing.service.gov.uk/media/57a08ad9e5274a31e00007ec/FinalReport_Biogas-Digesters-in-Sub-Saharan-Africa.pdf

[33]FAOSTAT. http://www.fao.org/faostat/en/#data/FO

[34]Jennifer Tracy and Arne Jacobson. The True Cost of Kerosene in Rural Africa https://www.lightingglobal.org/wp-content/uploads/2012/04/40_kerosene_pricing_Lighting_Africa_Report.pdf

Table 5. Summary Results of financial Analysis of biodigester system and direct use of biogas

Summary.	Values
Annual Cost Savings from Replacement of Kerosene and Wood Charcoal with biogas ($)	**1,655,154.75**
Total Discounted (Soc Disc) Cost Savings from Replacement of Kerosene and Wood Charcoal with biogas ($) over project lifespan	**14,539,402.02**
Total Discounted (ESCO Disc) Cost Savings from Replacement of Kerosene and Wood Charcoal with biogas ($) over project lifespan	**9,826,826.58**

The financial analysis also indicated a negative NPV at the social discount rate of 12% and ESCO discount rate of 20%. The NPV is only positive with a discount rate representing the implicit costs of capital.

4.5.Generation of electricity from biogas.

The most simplified way of estimating the potential electricity generation from biogas is to use the calorific value of biogas which is 6 kWh/m3 and corresponds to about half a liter of diesel oil (SSWM, 2017)[35].

Including unit conversions, the total electricity in kWh that can be produced from biogas can be found with the following equation.

$$Genset\ Electricity\ Output\ (kWh) = Biogas\ (m3) * [21MJ\ energy\ value\ of\ biogas *\ [efficiency\ factor] * [\frac{1}{3.6} Conversion\ Factor\ of\ MJ\ to\ kWh]$$

As shown in Figure 1, using, this formula, Murphy et al (2004) calculated the electricity output using two efficiency factors of 35% and 40%. The analysis used a conservative value of 30%.

[35] Sustainable Sanitation and Water Management (SSWM). 2017. Biogas Electricity (Smallscale). http://www.sswm.info/content/biogas-electricity-small-scale

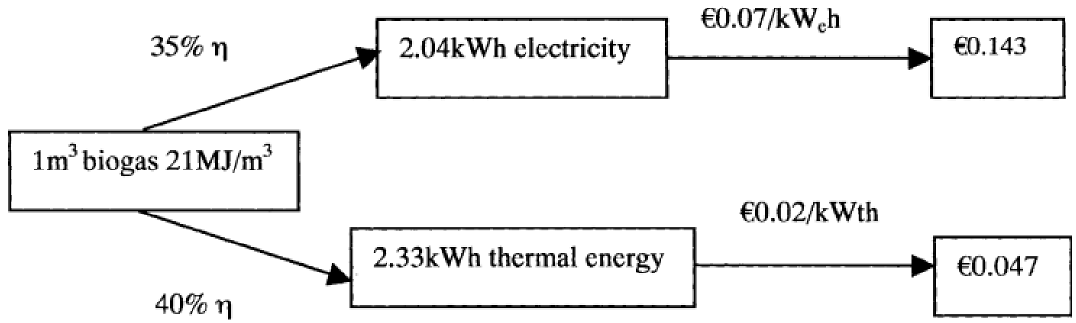

Figure 1. Illustration of electricity generation potential from a cubic meter of biogas with different efficiency assumptions

Source: Murphy et al (2004)[36]

The assumption for capital costs was based on IRENA (2012)[37]. The analysis of electricity from biogas used the same assumptions of diesel emission factor, diesel and grid price as solar because they are all replacing solar and are off-grid solutions. The Levelized Costs of Energy (LCOE) was calculated with the net system cost represented by present value of costs and net generation represented by net energy generation. Avoided Electricity grid costs is costs of grid electricity price minus LCOE of biogas or solar multiplied by annual generation. Avoided social costs of carbon was estimated as annual emission from grid electricity multiplied by the social costs of carbon (SCC) per ton. The SCC is an estimate usually in dollars, to represent the economic damages that would result from emitting one additional ton of greenhouse gases into the atmosphere. Although the Biden Administration has raised the social costs of carbon to $51[38] the analysis uses a conservative figure of $31.

The incremental costs of replacing diesel with biogas and is a cost to the developer that is usually externalized. However, the benefit is enjoyed by the global society and in the absence of reliable carbon market these incremental costs should justify the level of concessionality being requested from the GCF. As shown in Table 6, the use of biogas for gas generation is financially viable only at the implicit costs of capital with GCF financing both with externalities and without externalities.

[36]Murphy, J.D., McKeogh, E. and Kiely, G. (2004) Technical/Economic/Environmental Analysis of Biogas Utilisation. Applied Energy, 77, 407-427. https://www.ucc.ie/en/media/research/hydromet/MurphyPaper.2004.pdf

[37] "IRENA 2012. RENEWABLE ENERGY TECHNOLOGIES: COST ANALYSIS SERIES. Volume 1: Power Sector. Issue 5/. Biomass for Power Generation. . https://www.irena.org/publications/2012/Jun/Renewable-Energy-Cost-Analysis---Biomass-for-Power-Generation"

[38] https://www.cbsnews.com/news/carbon-social-cost-raised-by-biden/

Table 6. Summary Results from Financial Analysis of Electricity Generation with Biogas

IRR (20X0-25)	7.6%	
IRR with externalities (20X0-25)	1.8%	
NPV (20X0-25)	Cost of Capital Imp Rate	$23,363,229.07
	Social Discount	-$5,839,611.33
	ESCO Discount Rate	-$10,510,080.77
NPV with externalities (20X0-25)	Cost of Capital Imp Rate	$3,139,827.27
	Social Discount	-$12,821,285.74
	ESCO Discount Rate	-$14,914,241.04

5. Solar Generation Analysis.

The analysis for solar generation for irrigation, lighting and processing relied on benchmark costs of $1.5/watts (including accessories) for solar irrigation systems and $1/watts for solar PV for lighting and processing. Assumption based on capacity factor was based on information from SunMetrix[39]. As with the analysis for the biogas for electricity, the grid emission factor was an average calculated IFI Dataset[40] on grid emission factors for the Programme Countries. The figure of 640 g/kWh was equivalent to the average of the grid EF for the 3 Programme Countries. The assumptions for electricity tariff and price of diesel were based on Trimble et al/World Bank (2016)[41] and IEA (2020)[42] respectively just as was used for the biogas electricity generation analysis.

The annual grid cost savings by undertaking this off-grid solar option is over $3million with annual emission avoided at 51,475 tCO_{2eq}. Annual avoided social costs of carbon by switching from diesel and grid to solar plants for electricity is over $1 million. The incremental costs of replacing diesel with solar PV and is a cost to the developer that is usually externalized. However, the benefit is enjoyed by the global society. As shown in Table 7, the use of solar generation is financially viable only at the implicit costs of capital with GCF financing both with externalities and without externalities.

[39] SunMetrix. What is capacity factor and how do solar and wind energy compare?. https://sunmetrix.com/what-is-capacity-factor-and-how-does-solar-energy-compare/#:~:text=What%20is%20capacity%20factor%20and%20how%20do%20solar,%20%2070%25%20%202%20more%20rows%20

[40] The IFI Dataset of Default Grid Factors v.2.0. https://unfccc.int/sites/default/files/resource/Harmonized_Grid_Emission_factor_data_set.pdf

[41] "Chris Trimble, Masami Kojima, Ines Perez Arroyo, Farah Mohammadzadeh. Financial Viability of Electricity Sectors in Sub-Saharan Africa. Quasi-Fiscal Deficits and Hidden Costs. World Bank publication. https://documents.worldbank.org/en/publication/documents-reports/documentdetail/182071470748085038/financial-viability-of-electricity-sectors-in-sub-saharan-africa-quasi-fiscal-deficits-and-hidden-costs"

[42] IEA. Energy Prices. May 2020. https://www.iea.org/reports/energy-prices-2020

Table 7. Summary Results from Financial Analysis of replacement of diesel-based systems with solar

IRR (2XX0-2X25)	11.3%	
IRR with externalities (2XX0-2X25)	1.6%	
NPV (2XX0-2X25)	Cost of Capital Imp Rate	$26,599,823.96
	Social Discount	-$624,940.31
	ESCO Discount Rate	-$5,209,127.55
NPV with externalities (2XX0-2X25)	Cost of Capital Imp Rate	$1,696,483.86
	Social Discount	-$9,222,258.11
	ESCO Discount Rate	-$10,632,463.45

Besides the global benefits from using this low carbon energy, investing in solar energy and biogas also reduces the risk of capacity outages and makes the SCPZ countries power generation more secured hence increasing the economic resilience of farmers through reducing the economic risks they could face in the long run as a result of climate change. In addition, by reducing the reliance on fossil fuels and global oil prices, using solar power leads to more stable and predictable electricity costs in the longer run. In addition to the economic and environmental benefits described above, renewable energy is more labor intensive and would hence generate more jobs in production, construction and operations and maintenance. Particularly for biogas energy systems, the reliance on local materials for construction of biodigesters provide significant opportunities for green jobs in the Programme Countries.

6. Drip Irrigation Distribution System (DIDs)

Even though drought and other climate-related extremes requiring better water management for agricultural production are well-known phenomenon in these countries, the use of water efficient techniques such as irrigation among smallholder farmers is still very low. According to FAO (2002)[43], expanded irrigation development and improved water management are keys to increasing agricultural production, under water scarcity conditions. In Togo, the figure is slightly lower with only 0.8 percent of the arable land of a smallholder is under irrigation. The figure is slightly higher for Senegal, with about 5 percent of land under irrigation (Word Bank (2017)[44].

Tables 8, 9, 10 and 11 all indicate that groundwater resources are in general abundant in each of the region and most of the physicochemical properties are within acceptable ranges (only few parameters, for some regions, must be monitored when using these resources for irrigation purposes). The same can be said for surface water resources- there are major rivers in each region, implying important surface water potential.

[43]FAO (2002): www.fao.org/3/ai590e/ai590e.pdf.
[44] Word Bank (2017): World Development Indicator

For drip irrigation purposes, this surface water could complement the groundwater resource in each region. A research by Bajwa et al.(2018)[45] on Design and Implementation of an IoT System for Smart Energy Consumption and Smart Irrigation in Tunnel Farming, indicate that drip irrigation has between 80 to 90% water efficiency compared with sprinkler irrigation, overhead irrigation, sub irrigation, level basin and surface irrigation that have relatively lower water efficiency. Drip irrigation also has higher energy efficiency than these systems. Drip irrigation is also noted to "save water by reducing the size of the wet soil surface, thus decreasing the amount of direct evaporation and excess percolation through the root zone. Unlike sprinklers, drip irrigation is practically unaffected by wind conditions, nor is it affected by soil surface conditions. Soil is maintained in a continuously moist condition. Nutrients can be applied through the drip systems, thus reducing use of fertilizers and improving quality of returned water. Increases in water use efficiency in drip irrigation, compared to conventional basin/furrow irrigation, are attributed to both water savings and the increase in yields resulting from favorable soil moisture and nutrient regimes. Due to the relative suitability to drought conditions that are typical of these countries, applicability on small-scale and complementarity with solar systems, drip irrigation is gaining widespread use in Africa.

Table 8. Groundwater availability, properties and degree of restriction for irrigation at project-specific levels

		Togo	**Senegal**	**Guinea**	
		Kara	**Casamance**	**Boké**	**Kankan**
Groundwater (GW) potential		Moderate [o]	High to very high[n]	Probably low to high[p]	Low to moderate[p]
Depth to GW (mbgl)		0-25[l]	0-25[l]	0-25[l]	0-25[l]
Groundwater property	**Temp. (°C)**	26-32[k]			
	pH	5.4-7.9 [k]	3.8-8.3[m]	6.31-6.39[r]	6.31-6.39[r]
	Electrical conductivity (µS/cm or µmho/cm)	42-982[k]	38.7-7160[m]		
	Total alkalinity (mg/l)				
	Total dissolved solids (ppm or mg/l))		20.6-3900[m]		
	Turbidity (NTU)			0.40-050[r]	0.40-050[r]
	Nitrogen (mg/l)	0[k]	0.0[m]	3.34-4.01[r]	3.34-4.01[r]
		10[k]	342.0[m]		
	Na+ (mg/l)	1.8-96 [k]	4.5[m]		
			1726[m]		
	Sodium adsorption ratio				

Note: Degree of restriction expressed following Ayers and Westcot 1985; and Müller and Cornel 2017.Blue box represents no restriction, Green box is for slight to severe (i.e., use on sensitive crops must be cautioned.)

[45]Bajwa (2018). https://www.researchgate.net/project/http-wwwmdpicom-1996-1073-11-12-3427-pdf.

Table 9. Potential Groundwater Recharge in the SCPZs for the baseline and 2011-2040 Period

	Baseline	RCP 2.6	RCP 4.5	RCP8.5
	MCM/yr	MCM/yr	MCM/yr	MCM/yr
Kankan	46.177	50.777	48.127	46.103
Boke	47.023	47.233	46.292	53.598
Kara	20.366	18.176	17.786	17.786
Cassamance	3.562	2.216	2.051	2.051

Table 10. Surface water availability, properties and degree of restriction for irrigation at the regional levels

		Togo	Senegal	Guinea	
		Kara	Casamance	Boké	Kankan
Surface water potential (River)		Sufficient[u] (Kara)	Significant[v] (Casamance river)	Importante[r] (Nunez)	Importante[r](Milo, Bafing)
Surface water property	**pH**	5.5-8.5[z]			
	Electrical conductivity (µS/cm or µmho/cm)	20-240[z]			
	Total dissolved solids (ppm or mg/l))				
	Sodium adsorption ratio				

Note: Degree of restriction expressed following Ayers and Westcot 1985. Blue color represents no restriction while green stands for slight to severe (i.e., use on sensitive crops must be cautioned.)

Table 11. Surface Water availability in the SCPZs for the baseline and 2011-2040 Period

		Baseline		rcp2.6		rcp4.5		rcp8.5	
SCPZ	**Basin**	**m3/s**	**BCM/yr**	**m3/s**	**BCM/yr**	**m3/s**	**BCM/yr**	**m3/s**	**BCM/yr**
Kankan	Niger	1271	40.1	1396	44.1	1326	41.8	1273	40.2
	Cogon	312	9.8	317	10.0	311	9.8	444	14.0
Boke	Tingulinta	226	7.1	231	7.3	229	7.2	285	9.0
Kara	Kara	54	1.7	48	1.5	47	1.5	152	4.8
Cassamance	Cassamance	21	0.7	13	0.4	12	0.4	13	0.4

The impact of projected climate on the SCPZs water availability was recently assessed using the RCA4 with three RCPs (RCP2.6, 4.5 and 8.5) and compared the changes that area likely to occur in these zones with the baseline conditions of 1981-2010 (See Section 5 of Annex 2 for details). The study used a combined surface-groundwater model named Mike Hydro model which has both a rainfall-runoff, water resources and groundwater modules which exchange data seamlessly. Rainfall runoff model was set up for the basins within the SCPZs and calibrated against observed stream flow data for the baseline period of 1981-2010 (Table 12). Potential groundwater recharge was used as an indicator for groundwater resource. The baseline model was forced with CHIRPS and Terra Climate PET. A total of 8 river gauging stations were used to calibrate the models and as indicated in Table below. Good calibration results were obtained using the three selected criteria.

Table 12. Models Calibration and Validation Results

SCPZ	Gauge	Criteria	Daily		Monthly	
			Calibration	Validation	Calibration	Validation
Cassamance	Kolda	R^2	0.26	0.24		
		NSE	-0.85	-3.09		
		WBE (%)	7.4	-56.59		
Boke	Tingulinta	R^2	0.68	0.5		
		NSE	0.4	0.38		
		WBE (%)	-51.9	-20.3		
Boke	Cogon-Pont	R^2	0.6	0.47		
		NSE	0.48	0.42		
		WBE (%)	33.4	29.28		
Kankan	Dailakora	R^2	0.86	0.8		
		NSE	0.84	0.52		
		WBE (%)	11.4	-37.9		

Kara	Nnaboupi	R^2	0.36	0.65		
		NSE	0.14	0.61		
		WBE (%)	-49.7	-25.37		

The results revealed that most SCPZs currently have abundant water resources. However, there will be a reduction in future water availability for both surface and potential groundwater recharge particularly for the Casamance and Kara SCPZ. The net potential PET is also projected to increase in all the SCPZs compared to the baseline conditions which means more water will be required to meet crop water demands. It will thus be necessary for efficient water conveyance and distribution systems such as drip irrigation to meet crop water requirements, encourage on-farm water storage and monitor both surface and groundwater for sustainable utilization.

To assess the potential impact of the support provided by the GCF for the implementation of drip irrigation technology in the four pilot countries, we have carried out the following analysis based on previous experience and existing studies. The initial investment for drip irrigation technology is based on a proposed budget of $1,500 on a per hectare basis (covering climate resilient activities for women engaged in off season farming of vegetables including purchase of drip irrigation tool kits).
The underlying assumptions are:

- A sample plot with a total surface area of 2,278 m^2 including 1,400 m^2 of vegetable plots and 200m^2 reserved for nursery as shown in the Figure 2.

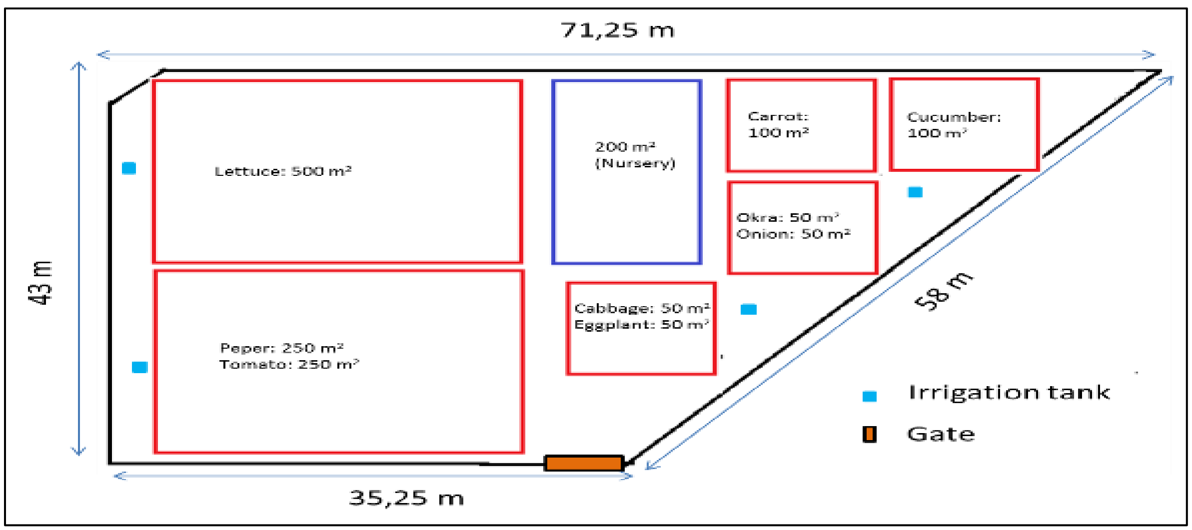

Figure 2. Ground plane for irrigation.

- The suggested irrigation system used is composed of drip irrigation kits (iDE technology)[46] adapted to the water requirements of vegetable crops in most parts of the Sahel and SSA (Togo, Senegal and Guinea)[47] (Figure 3). These include: (1) water tanks; (2) two kits of 500 m2 for a total of 1000 m2; (3) four kits of 100 m2 for a total of 400 m2; and, (4) a water tower of up to 5,000 liters of capacity, which must be supplied by a regular water supply such as a borehole initially expected to have a discharge potential of at least 5 m^3 $h^{-1.}$ The so-called kits are new generation kits (with 40 cm density of drippers,) recently tested under the agro-climate conditions of the Sahel and showing a higher performance compared to the old technology with 1m density of drippers (Venotet al. (2014)[48]. The advantages of such an irrigation system are multiples: (1) significant decreases in crop water requirement of up to 30% since water is supplied directly to the root zone, with no erosion and no soil washing; (2) increases in yield production due to continuous and adequate water/fertilizer supply in function of the needs and depending strictly on the development stages; (3) decrease in labor and energy costs; (4) significant decrease in disease attacks since water is not applied to the foliar system.

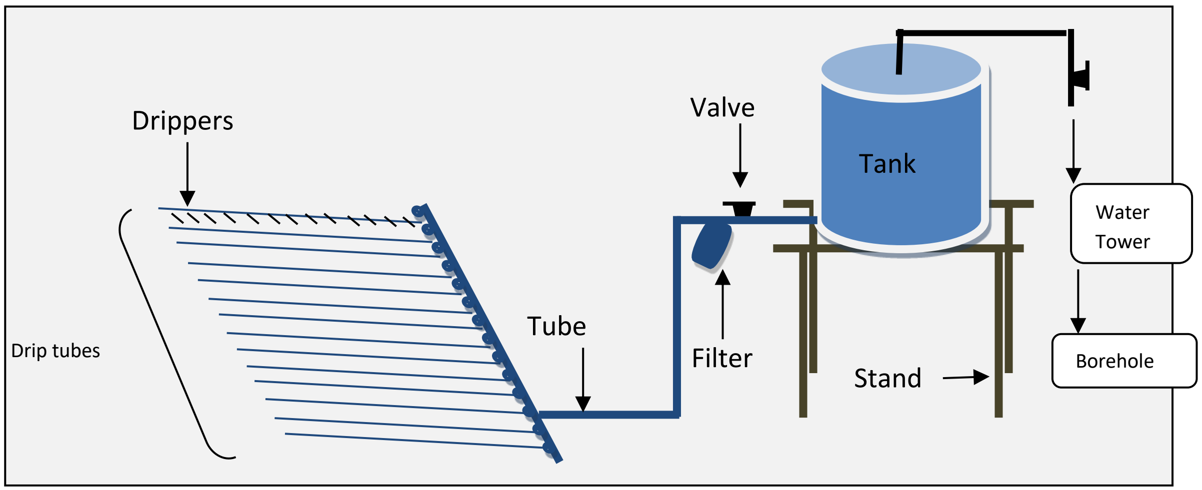

Figure 3. iDE's drip kit schematic layout with 40 cm density of drippers.

As previously mentioned, a borehole equipped with a water tower is needed to supply the irrigation tanks at regular intervals. The borehole has a characteristic discharge of 10 m^3 h-1, while the reservoir chosen for the tower has a capacity of 5 m^3. It has to be stressed that these characteristics

[46] International Development Enterprises: iDE | Drip Alliance (ideglobal.org)
[47]IFPRI Discussion Paper 00993: What Is the Irrigation Potential for Africa? A Combined Biophysical and Socioeconomic Approach
[48]Venotet al. (2014). BeYondthe Promises of Technology: A Review of the Discourses and Actors Who Make Drip Irrigation. Irrigation and Drainage, https://doi.org/10.1002/ird.1839

are largely sufficient to permanently supply the irrigation tanks and then meet the water requirement of the whole site. The discussions conducted with the technical partners (iDE) has pointed out the fact that an irrigation tank of 1,000 liters (used on the site) is emptied in approximately 15 mn for a plot of 250 m^2. The calculation of the daily water requirements was carried out for the selected crops taking into account their water consumption coefficients. Onion has been pointed out as the most demanding with up to 130 $l\ m^2\ d^{-1}$, leading to a total irrigation time of up to 75 mn d^{-1} for a plot size of 500 m^2. Based on this investigation it was suggested an irrigation time of 30 mn twice a day (morning and evening) over a plot of 500 m^2. A more detailed irrigation plan for the different plots implemented on the site is shown in Table 13.

Table 13. **Detailed irrigation plan for different plot sizes**

Tank	Plot	Volume of water and irrigation time		Total number of filling	
		Morning	Evening	Morning	Evening
Tank 1	Plot 1 (250 m^2)	1 m^3 in 15 mn	1 m^3 in 15 mn	1	1
	Plot 2 (250 m^2)	1 m^3 in 15 mn	1 m^3 in 15 mn	1	1
Tank 2	Plot 3 (250 m^2)	1 m^3 in 15 mn	1 m^3 in 15 mn	1	1
	Plot 4 (250 m^2)	1 m^3 in 15 mn	1 m^3 in 15 mn	1	1
Tank 3	Plot 5 (100 m^2)	0.5 m^3 in 7 mn	0.5 m^3 in 7 mn	1/2	1/2
	Plot 6 (100 m^2)	0.5 m^3 in 7 mn	0.5 m^3 in 7 mn	1/2	1/2
Tank 4	Plot 7 (100 m^2)	0.5 m^3 in 7 mn	0.5 m^3 in 7 mn	1/2	1/2
	Plot 8 (100 m^2)	0.5 m^3 in 7 mn	0.5 m^3 in 7 mn	1/2	1/2

- The following vegetable crops are irrigated during the dry season (onion, tomato, local eggplant, cabbage, pepper, carrot, lettuce, cucumber and okra), all widely cultivated by small farm households in the four pilot countries.
- Variable costs include; drip irrigation kits, solar powered pumps with capacity of 66 kW/ha, water storage tank and small reservoir of with capacity of 5 m3, small agricultural tool kids, labor (plot installation), cost of site clearing and preparations, fencing of plot, seeds costs, fertilizer, pesticides and disease control, permanent labor (daily labor and follow-up during harvesting), cost of transportation and procurement of supplies for marketing, and a seasonal interest rate of 6% on total variable cost.
- Fixed cost includes interest payment on part of variable costs incurred (6%), and non-fixed cost includes a flexible maximal annual depreciation charge of 5% and total intermediate consumption by households.

Annual Gross Operating Incomes

In order to assess the agricultural and economic potential of the sample plot size and therefore decide on the types of crops to put in place (as previously indicated in the ground plane) and beyond provide reliable input data for the economic and profitability analysis exercise, it was appropriate to pay visits to existing vegetable farming sites, especially production sites under drip irrigation systems. Drip irrigation sites were visited in Togo, Senegal and Guinea. Group-based interviews and discussions were held to help compile very useful farm and market information (main crop types, crop duration, yields, market prices, possible number of crop cycle during the year). These field information were analyzed and compared with the online resources titled: Agboyi (2015)[49], WMS (2021)[50], World Bank (2019)[51], FAO-FOASTAT[52], USAID (2015)[53]:David-Benz et al. [54], Bezabih et al. (2015)[55] and Meissa Diouf (n.d)[56].

Table 14. Gross Operating Income for the Selected Crops

Ref.	Crop	Crop Duration (Day)	Yield Per Hectare (Ton)	Average Price Per Kg during the Rainy Season -RS (FCFA)	Average Price Per Kg during the Dry Season-DS (FCFA)	Possible Number of Cycles over the RS or DS and under Irrigation	Annual Gross Income Per Hectare under Irrigation (FCFA)	Annual Gross Income Per Hectare under Irrigation (USD)	Planned Plot Size (m²)	Expected Yield Per Plot (Kg)	Annual Gross Income Per Plot under Irrigation (FCFA)	Annual Gross Income Per Plot under Irrigation (USD)
1	Onion	90-120	20	500	1,000	2	30,000,000	50,000	50	70	150,000	$250.00
2	Tomato	100-110	40	600	1,200	3	108,000,000	180,000	250	700	2,700,000	$4,500.00
3	Local Eggplant	130	40	300	600	2	36,000,000	60,000	50	140	180,000	$300.00
4	Cabbage	80-90	40	200	400	4	48,000,000	80,000	50	140	240,000	$400.00
5	pepper	180	30	800	1,200	2	60,000,000	100,000	250	525	1,500,000	$2,500.00
6	Carrot	90	40	300	600	3	54,000,000	90,000	100	280	540,000	$900.00
7	Lettuce	45	*	**	***	7	63,700,000	106,167	500	****	3,185,000	$5,308.33
8	Cucumber	60-70	45	300	500	4	72,000,000	120,000	100	315	720,000	$1,200.00
9	Okra	110	15	600	600	3	27,000,000	45,000	50	52.5	135,000	$225.00
	Total		270				498,700,000	831,167	1,400	2,223	9,350,000	$15,583.33

[49] Agboyi, K.L. (2015). Vegetable production in Togo and potential impact of pesticide use practices on the environment. International Journal of Biological and Chemical Sciences 9(2):723. DOI: 10.4314/ijbcs.v9i2.13.

[50] WMS (2021). Togo: Vegetables Industry. Togo: Vegetables Industry Research Report (wm-strategy.com).

[51] World Bank (2019). Togo: Future SOURCES OF GROWTH, Report No. Report No: AUS0000520, World Bank, Washington DC.

[52] FAO: FAOSTAT (1991 – 2019): Producer Prices. www.fao.org/faostat/en/#data/PP.

[53] *USAID (2015): Rapid assessment of the horticulture sector in Guinea. https://horticulture.ucdavis.edu/sites/g/files/dgvnsk1816/files/extension_material_files/guinea-horticulture-assessment-usaid-report.pdf.*

[54] *David-Benz et al. (2005): Market Information and Price Instability : An Insight into Vegetable Markets in Senegal . ISHS Acta Horticulturae 699, DOI: 10.17660/ActaHortic.2006.699.14.*

[55] *Meissa Diouf : Research on African vegetables at the Horticultural Development Centre (CDH), Senegal https://www.bioversityinternational.org/fileadmin/bioversity/publications/Web_version/500/ch05.htm.*

[56] *Bezabih et al. (2015): Characterization and Assessment of Vegetable Production and Marketing Systems in the Humid Tropics. http://dx.doi.org/10.22004/ag.econ.210313.*

The Table 14 shows that the sale prices are almost double during the dry seasons. Lettuce has been pointed out as the crop with the shortest growing cycle with a total of 7 possible cycle of cultivation over the year under adequate irrigation systems. With 3 possible growing cycles over the year, tomato has shown the highest annual income per hectare (180,000USD/hectare) followed by cucumber (120,000 USD/hectare), lettuce (106,000SD/hectare) and pepper (100,000 USD/hectare). This analysis has mainly supported the crop distribution as shown on the ground plane (cf. section 1): 250 m2 for tomato, 250 for pepper, 500 m2 for lettuce, etc. The highest plot size was attributed to lettuce since it's required almost no management in terms of diseases and pests' control. Overall, based on the implemented ground plane, lettuce is associated with the highest annual gross income ($5,308 over 500 m2) followed by tomato ($4,500 over 250 m2), pepper ($2,500 over 250 m2), etc. A total gross income of $15,583 (over 1400 m2) is expected annually from the ground plane put in place. This amount may be optimized while going for a single crop cultivation (such as tomato) but does not meet the requirements for a sustainable agriculture.

6.1 Economic and Financial Profitability Analysis

The economic and financial profitability of the investment is assessed throughout a series of analytical indicators such as the added value (AV), the gross operating surplus (GOS), the net operating surplus before taxes (NOS), the net profit and cash-flow.

AV means the wealth created by the activity. It is obtained by subtracting from the total raw product (sum of the gross operating income per crop) the total intermediate consumption such as procurements of supplies for marketing or transportation and delivery services. The added value is given by the equation (1):

$$AV = \sum_i RP_i - \sum_k IC_k \qquad (1)$$

where RP_i is the row product or the gross income per sold vegetable *i*, $IC_k$is the expense associated with the intermediate consumption *k*.

GOS expresses the gain (or loss) of the economic agent once acquitted of all current operating expenses so it's the difference between the added value and the operating costs taking into account all goods and services that are destroyed or transformed during the production process or are incorporated into the product. The operating costs are mainly personnel costs (labor), seed costs, fertilization costs, costs for diseases and pests' controls and other unexpected costs. GOS is given by the equation (2):

$$GOS = AV - \sum_i OC_i \qquad (2)$$

where OC_i is the operating charge *i*.

NOS expresses the economic gain (or loss) given by the investments made so is the profit before the income tax expense is applied and is obtained by subtracting the depreciation of equipment and financials costs from the gross operating surplus. NOS is given by the equation (3):

$$NOS = GOS - \sum_i DC_i \qquad (3)$$

where DC_i is the depreciation charge *i*.

The net profit is calculated by deducting the income tax expense from the net operating surplus. These taxes are calculated on the profit generated by the business and represent 7% of profit before tax (NOS). The net profit is given by the equation (4):

$$Net\ profit = NOS - Income\ tax\ expense \qquad (4)$$

The cash flow is calculated as the sum of net income and amortization. It's primarily used to evaluate companies through the "discounted cash flow method DCF" and given by the equation (5):

$$Cash\ flow = Net\ profit + \sum_i DC_i \qquad (5)$$

where DC_i is the depreciation charge *i*.

The above-described analytical indicators were calculated and shown in the table below based on the data presented in the Excel spreadsheet (annex 3b).

Table 15. Analysis of profitability for years of exploitation (10 years)

Years	01/10/2021	31/12/2022	31/12/2023	31/12/2024	31/12/2025	31/12/2026	31/12/2027	31/12/2028	31/12/2029	31/12/2030
Gross Operating Income (GOI)	600,000	150,000	150,000	9,350,000	9,350,000	9,350,000	9,350,000	9,350,000	9,350,000	9,350,000
Total raw product* (1)	600,000	**150,000**	**150,000**	**9,350,000**	**9,350,000**	**9,350,000**	**9,350,000**	**9,350,000**	**9,350,000**	**9,350,000**
Procurement of supplies for marketing	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000
Services: transportation and deliveries	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000
Total Intermediate Consumption -TIC (2)	**150,000**	**150,000**	**150,000**	**150,000**	**150,000**	**150,000**	**150,000**	**150,000**	**150,000**	**150,000**
Added value (3) = (1) - (2)	**450,000**	**0**	**0**	**9,200,000**	**9,200,000**	**9,200,000**	**9,200,000**	**9,200,000**	**9,200,000**	**9,200,000**
Per ha initial investment	1,777,790									
Total Initial Investment (TINV)	1,777,790									
Seed costs	19,754	19,754	19,754	19,754	19,754	19,754	19,754	19,754	19,754	19,754
Fertilization costs	444,418	444,418	444,418	444,418	444,418	444,418	444,418	444,418	444,418	444,418
Costs for disease and pest control	73,991	73,991	73,991	73,991	73,991	73,991	73,991	73,991	73,991	73,991
Land preparation	0	20,700	20,700	20,700	20,700	20,700	20,700	20,700	20,700	20,700
Permanent labor (daily labor and follow-up)	504,000	504,000	504,000	504,000	504,000	504,000	504,000	504,000	504,000	504,000
Season interest rate (6% per season)	63,772	63,772	63,772	0	0	0	0	0	0	0
Contigencies (10% of OC)	0	112,663	112,663	112,663	112,663	112,663	112,663	112,663	112,663	112,663
Total Operating Charges-TOC (4)	**1,105,935**	**1,239,298**	**1,239,298**	**1,175,527**	**1,175,527**	**1,175,527**	**1,175,527**	**1,175,527**	**1,175,527**	**1,175,527**
Gross Operating Surplus GOS (5) = (3) - (4)	**-2,433,725**	**-1,239,298**	**-1,239,298**	**8,024,473**	**8,024,473**	**8,024,473**	**8,024,473**	**8,024,473**	**8,024,473**	**8,024,473**
Depreciation charges	105,558	105,558	105,558	105,558	105,558	105,558	88,358	88,358	88,358	88,358
Charges after GOS (6)	**105,558**	**105,558**	**105,558**	**105,558**	**105,558**	**105,558**	**88,358**	**88,358**	**88,358**	**88,358**
Net Operating Surplus (NOS) before taxes (7) = (5) - (6)	**-2,539,283**	**-1,344,856**	**-1,344,856**	**7,918,915**	**7,918,915**	**7,918,915**	**7,936,115**	**7,936,115**	**7,936,115**	**7,936,115**
Income tax expense (8) = X%* (7)	-	-	-	-	-	-	-	-	-	-
Net profit (9) = (7) - (8)	-2,539,283	-1,344,856	-1,344,856	7,918,915	7,918,915	7,918,915	7,936,115	7,936,115	7,936,115	7,936,115
Cumulated net profit	-2,539,283	-3,884,139	-5,228,996	2,689,920	10,608,835	18,527,751	26,463,866	34,399,982	42,336,097	50,272,213
Cash Flow (10) = (9) + (6)	-2,433,725	-1,239,298	-1,239,298	8,024,473	8,024,473	8,024,473	8,024,473	8,024,473	8,024,473	8,024,473

Cumulated cash Flow	-2,433,725	-3,673,023	-4,912,322	3,112,152	11,136,625	19,161,099	27,185,572	35,210,046	43,234,519	51,258,993
Cash Flow (USD)	**-$4,056**	**-$2,065**	**-$2,065**	**$13,374**	**$13,374**	**$13,374**	**$13,374**	**$13,374**	**$13,374**	**$13,374**

*** In the first 3-year, initial investment of $1000 is assumed per/Ha for year 1, and $250 each foe years 2 & 3.**

Economic Analysis: Based on the above analysis, a cost-benefit analysis (CBA) was carried out to assess the profitability of investing in drip irrigation technology under the programme (2021 - 2030). The cash flow outlay was used to calculate the Extended Internal Rate of Return (XIRR) and the Net Present Value (NPV), using a discount rate of 12% common to all AfDB's investments. This is the rate usually used by other MDBs such as the World Bank when evaluating projects in developing countries[57][58]. The AE has been applying this discount rate as a practice which is also consistent with the results of survey of PWC of the range of discount rates used on the continent[59] and for renewable energy projects in Africa[60]. The results are presented in the Table 15. As observed in the Table 15, results from the CBA indicate a moderate XIRR of 68% for the investment with an XNPV values of **$81,221** assuming a 0.75% interest rate from the GCF (cost of borrowing from GCF). However, when the interest rates are alternated (i.e., using 12% social discount rate and 20% ESCO Discount rate (private sector), the XNPV values drops to $39,832 and $24,898 respectively, with a payback period of approximately 3.72 years or 44.7 months for the initial investment or $1,500 (Table 16). Even at different discount rates applied for the investment, the results indicate that there is strong potential for investing in drip irrigation technology in the programme in combination with other CRA interventions, and that these are also economically viable investments for farmers especially smallholders' farmers. If support were to be provided to increase access to financing, drip irrigation offers the greatest opportunity for smallholder farmers in these countries. With evidence of recurrent drought and increasing demand for agricultural water, supporting smallholder farmers to invest in drip irrigation technology offers the most promising climate resilient pathway to development. With a minimal investment capital of only $1,500, in five years, women in agriculture in the four pilot countries can earned up to $20,000.0 as shown in the Figure 4.

Table 16. Economic Rate of Return (ERR), DIDS

XIRR (2XX0-2X25)	69%
XNPV (2XX0-2X25) at Discount (0.75% implicit for cost of capital)	$81,221.61
XNPV (2XX0-2X25) at Social Discount	$39,832.81
XNPV (2XX0-2X25) at ESCO Discount	$24,898.19
Payback Period (Years)	3.72

57 https://www.adb.org/sites/default/files/publication/28360/wp094.pdf
58 https://www.federalreserve.gov/econresdata/notes/feds-notes/2014/the-social-discount-rate-in-developing-countries-20141009.html
59 https://www.tralac.org/images/docs/7192/africa-valuation-methodology-survey-2015-pwc.pdf
60 https://www.grantthornton.co.uk/globalassets/1.-member-firms/united-kingdom/pdf/documents/africa-renewable-energy-discount-rate-survey-2018.pdf

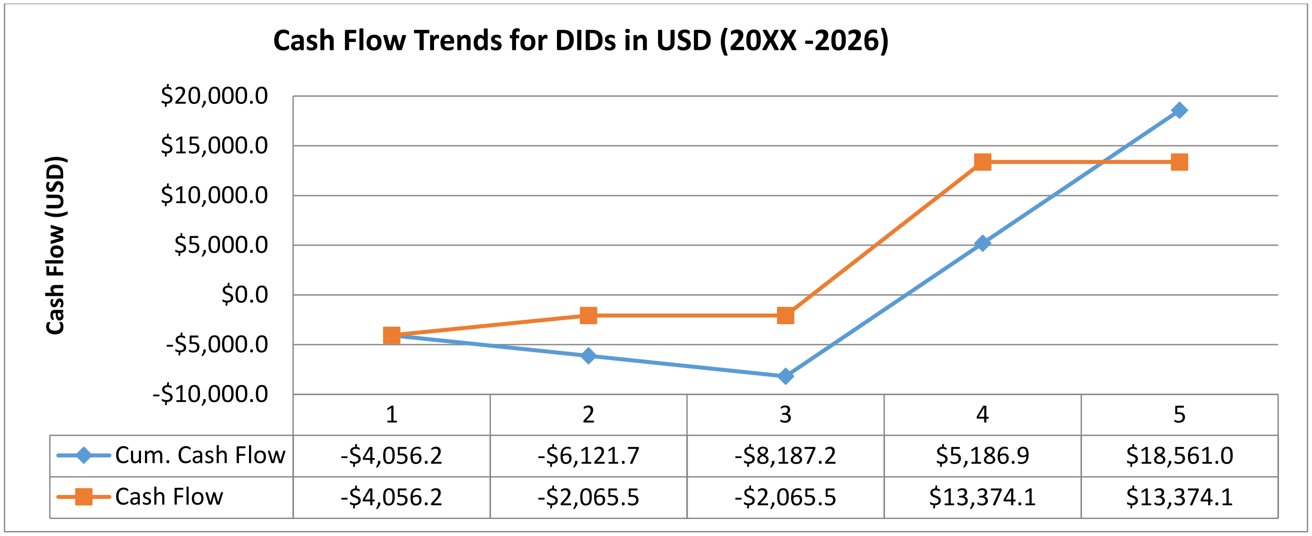

Figure 4. Cashflow trends for DIDs in USD (2021 - 2025)

7. Agroforestry Management Practices

According to Godsey (2006)[61], agroforestry budgeting is a two-step process. The steps are to develop enterprise budgets and combine the enterprise budgets into a cashflow plan. An enterprise budget is a complete, detailed listing of all the costs and revenues expected for each single enterprise, such as cashew, mango, corn, livestock or nut and timber trees. A cashflow plan combines the details from the different enterprise budgets in the agroforestry practice and adds a time dimension. The enterprise budget provides a framework for reporting and monitoring the profitability of each enterprise, and the cashflow plan provides the information necessary to assess and forecast the economic feasibility of the agroforestry practice over time.

The development of an enterprise budget is a three-step process. The first step is to list all possible sources of revenue for an enterprise. For the tree component of an agroforestry practice, it is important to list not only the sources, but also list the timing of those revenues (when fruits are produced if cultivated for their economic potentials as fruit trees). The second step is to list, in detail, all possible sources of variable costs. Variable costs are those costs attributed to the productive use of resources. Variable costs can be grouped into cash and non-cash costs. Variable cash costs include payments for establishment, maintenance, harvesting and marketing. Variable non-cash costs do not require a cash outlay but reflect

[61] Godsey, D.L. (2006). Economic Budgeting for Agroforestry Practices, www.centerforagroforestry.org/pubs/economichandbook.pdf.

opportunity costs. Opportunity cost is simply the value of the next best alternative that is not chosen. For example, labor supplied by family members may not require a cash outlay but could still be considered in the economic analysis.

The third and final step to preparing an enterprise budget and to list all fixed costs. Fixed costs are typically those costs that are attributed to resource ownership. In other words, fixed costs occur regardless of any productive activity being attempted. Fixed cash costs usually include property taxes, insurance, interest on intermediate or long-term debt, and lease agreements. Fixed non-cash costs are important when developing an investment analysis, because these costs have significant influence on taxes. However, these costs are difficult to determine. Depreciation and land costs are the two main areas of fixed non-cash costs. Fixed costs may not change as often as the revenues and variable costs. In fact, any changes may be predictable, such as a 2 percent increase in property taxes every year. When reporting fixed costs, be sure and note the source, the amount and the estimated changes that will occur in the original amount.

Summary steps for developing an agroforestry enterprise budget

- List all possible sources of revenue;
- List all possible sources of variable costs (both cash and non-cash);
- List all possible sources of fixed costs (both cash and non-cash).

Mango (Kent or Keitt mango) - Senegal, Togo and Guinea

Key Assumptions

- The mango plantation lifespan is for 25 years since after 25 years, most mango orchards are no longer very profitable.
- Yield is optimal for 10 to 15 years but starts at year 4
- Average per ha yield of 18.1kg although yields of 20 - 30 tons per ha have ben recorded in Senegal
- The farm gate prices per/kg ranges from 151XAF in Senegal, 130 XAF in Togo and 120 XAF in Guinea
- Can be intercropped with cabbage, okra or onions from year 3
- An initial budget of $1,500 per ha is assumed covering drip irrigation and CRA practices for vegetable farming (if decided).
- Variable costs for per ha production include: site preparations cost (land clearing for liming, digging of holes and fencing the farm); costs of fertilizing holes with MOP and FYM, cost of planting (seedlings -Grafted scion, cost of transplant (July - August), labor cost for planting, and replanting- 1/50th of a hectare each year for first three years); maintenance cost: Fertilizer (October, June - July with Nitrogen, Phosphate & Potash, application of Pesticides/Fungicides, Herbicides, Weed Control (May to September), and pruning (Once every 2 years) and starts at year 3), and labor cost for maintenance, and initial investment in drip irrigation); lastly, labor for harvesting of fruits, which takes place from January to May. In economic prices, the variable cost per hectare under irrigated farming conditions is **$3,288.80** before yield starts at year 3. (Annex 3B).

- Fixed and non-fixed costs per hectare include: interest payment on part of variable costs incurred (6%) and depreciation charges (5%), which is **$348.42** prior to year 3 when yield starts.

Developing a Mango cash flow plan: All figures for the economic budgeting where calibrated based on the following source references [62],[63], [64], [65], [66], [67].[68], [69]. Based on this, the per hectare net profit and cash flow streams of Mango were computed throughout the lifespan of the investment using CBA under irrigated farming conditions. This is because drip irrigation is highly recommended for improved mango yields, schedule cropping, and management of climate change issues. Though mangoes are considered drought resistant, but extended drought periods and more erratic rainfall patterns can create stress for the trees and diminish fruit quantity and quality. The use of drip irrigation will ensure that the mango trees have adequate moisture throughout the year and are not subject to excessive drought stress. Irrigation for mangoes increases yields, improves the overall quality of the fruit produced, and enhances the results of floral manipulation (used to produce fruit out of season).

Economic Analysis: Positive income flows for Mango Orchards start only at year 4 (Annex 3B). The expected cash flows were then used to compute the Extended Internal Rate of Return (XIRR) and the Net Present Value (NPV) for the initial investment of $1,500 per hectare, using three different discount rates (cost of borrowing from GCF - 0.75%, 12% Social Discount rate and Private ESCOs Discount rate of 20%). The CBA shows that investing in Mango production in the programme is the most profitable of the agroforestry management practice for smallholder farmers, ACSs and FBAs (Table 18). The Extended Internal Rate of Return (XIRR) is 81 % with a Net Present Value (XNPV) of $261,346.64 per hectare (0.75% implicit for cost of capital). However, when a Social Discount Rate of 12% is used as in all AfDB investments, the XNPV drops to $77,084.46 and further down to $42,006.83 (at Private ESCOs Discount rate of 20%), and with a payback period of 3.6 years. Of all the agroforestry management practices proposed under the programme, the analysis shows that investing in Mango is most profitable. The Kent or Keitt Mango form Senegal has the highest export value in the whole of the West African region. Recorded yields of 20 - 30 tons per ha have been reported for small farms in Senegal under irrigated farming conditions[70]. This to say that, the per hectare profit may even be higher within this programme with the addition of irrigation and adoption of CRA at the farm level.

Table 17. Economic Rate of Return (ERR) for Mango

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[62] FAO: FAOSTAT (1991 – 2019): Producer Prices. www.fao.org/faostat/en/#data/PP.
[63] https://www.rvo.nl/sites/default/files/2020/12/201204%20SVC%20Export%20Mango%20Farm.pdf.
[64] https://wire.farmradio.fm/farmer-stories/senegal-farmer-develops-method-for-growing-mango-trees-with-little-water/.
[65] (PDF) Mango-based orchards in Senegal: Diversity of design and management patterns (researchgate.net).
[66] https://www.researchgate.net/publication/274626027_Mango-based_orchards_in_Senegal_Diversity_of_design_and_management_patterns.
[67] https://www.togofirst.com/en/agriculture/1601-7101-mango-production-in-togo-latest-figures-show-improved-production.
[68] West African Mango Producers Smiling Again – CORAF.
[69] www.coraf.org/2017/10/16/coraf-takes-on-fruit-flies-to-save-millions-in-mango-losses/.
[70] https://www.rvo.nl/sites/default/files/2020/12/201204%20SVC%20Export%20Mango%20Farm.pdf.

XIRR (2XX0-2X25)	85%
XNPV (2XX0-2X25) at Discount (0.75% implicit for cost of capital)	$261,714.60
XNPV (2XX0-2X25) at Social Discount	$77,270.55
XNPV (2XX0-2X25) at ESCO Discount	$42,159.05
Payback Period (Years)	3.20

Cashew - Togo, Senegal and Guinea

Key Assumptions.

- The plantation lifespan is for 25 years
- Yield starts at year 3 and increases at a rate of 3% starting from year 4 to 10. but productivity declines after 25 years of producing
- An average of 4.5kg of raw nuts is produced per Cashew tree and 1 ha has approximately 625 Cashew trees.
- Minimum government farm gate price per/kg ranges from 450 - 550 XAF in West Africa.
- Can be intercropped with cabbage, or okra from year 3
- Minimum expected yield per hectare is about 2,812.5 kg/ha
- An initial budget of $1,500 per ha is assumed also covering drip irrigation and CRA for vegetable farming.
- Variable costs for per ha production include: site preparations cost (land clearing for liming), digging of holes and fencing the farm); costs of fertilizer (Lime, gypsum and N-P-K); planting cost (seedlings -Grafted scion, cost of transplant, labor cost for planting, and replanting- 1/50th of a hectare each year for first three years); maintenance cost (fertilization (November & December, application of Pesticides/Fungucides, Herbicides, Weed Control (May to September), training (first 4 years) August – September, labor cost for maintenance, and initial investment in irrigation). In economic prices, the variable cost per hectare under irrigated farming conditions is **about** $2,550.05 before yield starts at year 4. (Annex 3B).
- Fixed and non-fixed costs include: interest payment on part of variable costs incurred (6%) and depreciation charges (5% on depreciable assets), which is about **$276** per/ha.

Developing a Cashew cash flow plan: All figures for the economic budgeting where calibrated based on the following source references[71], [72], [73]. Based on this, the per hectare net profit and cash flow streams for Cashew orchards were also computed for the lifespan of the investment using CBA (Annex 3B). Though the first two years recorded net losses, as soon as the Cashew orchard starts producing in year 3, net profit or income starts flowing in steadily. As observed in Table 19, overalll, investing in Cashew is highly profitable and a viable business in West Africa. The Extended Internal Rate of Return (XIRR) is 66 % with a Net Present Value (XNPV) of $52,484.88 per hectare at 0.75% implicit for cost of capital.

[71] FAO: FAOSTAT (1991 – 2019): Producer Prices. www.fao.org/faostat/en/#data/PP.
[72] https://www.cbi.eu/sites/default/files/vca-cashew-west-africa_0.pdf.
[73] https://www.researchgate.net/publication/271743844_Cashew_from_seed_to_market_A_review.

When a Social Discount value 12% is considered, the XNPV falls to $14,958.98 and further down to $7,770.72 (at ESCO Discount Rate of 20%) and with a payback period of 3.78 years. Also note that, these values can be increased if intercropped with more profitable seasonal CRA practices such as tomato farming and carrots (the choice is up to the farmers, however, advisory services will be provided to guide these SHFHs)

Table 18. Economic Rate of Return (ERR), Cashew

XIRR (2XX0-2X25)	66%
XNPV (2XX0-2X25) at Discount (0.75% implicit for cost of capital)	$52,482.99
XNPV (2XX0-2X25) at Social Discount	$14,958.98
XNPV (2XX0-2X25) at ESCO Discount	$7,770.72
Payback Period (Years)	3.78