Comprehensive and Integrated Impact Assessment Framework for Development Policies Evaluation

Supplementary Information

Supplementary Material S1. Detailed Materials and Methods

A1 – Supply Chain Analysis

Initially, a comprehensive literature review is conducted during the preparatory stage of the study, to understand the overall supply chain and to provide insights regarding the main areas to focus on during the primary research. Then the appropriate supply chain strategy is identified for the product/s, as this defines how the supply chain should operate to be competitive and to evaluate the cost benefit trade-offs of operational components. Thus, the patterns of demand, customer requirements and any associated risk which may delay delivery by the supply chain are understood first, as these drive the supply chain strategy. Also, the stability of the supply process is determined, and the supply chain is aligned with uncertainties that revolve around the supply process. Value chain analysis is then used to:

- Understand the characteristics of the actors, flow of goods along the chains, employment characteristics and final products volumes and regions of sale;
- Obtain a better understanding of the connections and interdependencies between the actors and processes;
- Understand how value is distributed along the chain and which actors benefit most and those who need support through improvements;
- Understand the role of both internal and external governance and their impact on the supply chain;
- Assess the profitability of the actors and identify present limitations and governance issues,
- Identify investment opportunities and to determine development strategies for the selected product/s.

Process mapping is used in conjunction with value chain analysis to provide in depth understanding of specific processes along the supply chain and to support in the identification of bottlenecks. Root cause analysis is utilized to look deeper into problems identified to define and pin down their actual cause/s. Finally, SWOT analysis is conducted to help in identifying areas for development for the product/s and its industry and to focus activities into areas of strengths and where the greatest opportunities lie. Also, to create an actionable plan and strategies to improve the industry or businesses (Hussain et al., 2020a).

As a final goal, this approach permits to collect an overall understanding of the supply chain under investigation, with specific focus on the main hotspots and bottlenecks actually decreasing the supply chain efficiency and competitiveness. In such a way, it is possible to identify and design improvement interventions addressing main criticisms of the supply chain.

A2 – Energy Modelling Approach

In order to build a model of the Kenyan National Electricity System the first step is to understand the reference energy system that has to be modelled. That is done according to the accuracy of available data. Figure S1 reports the structure of the reference energy system.

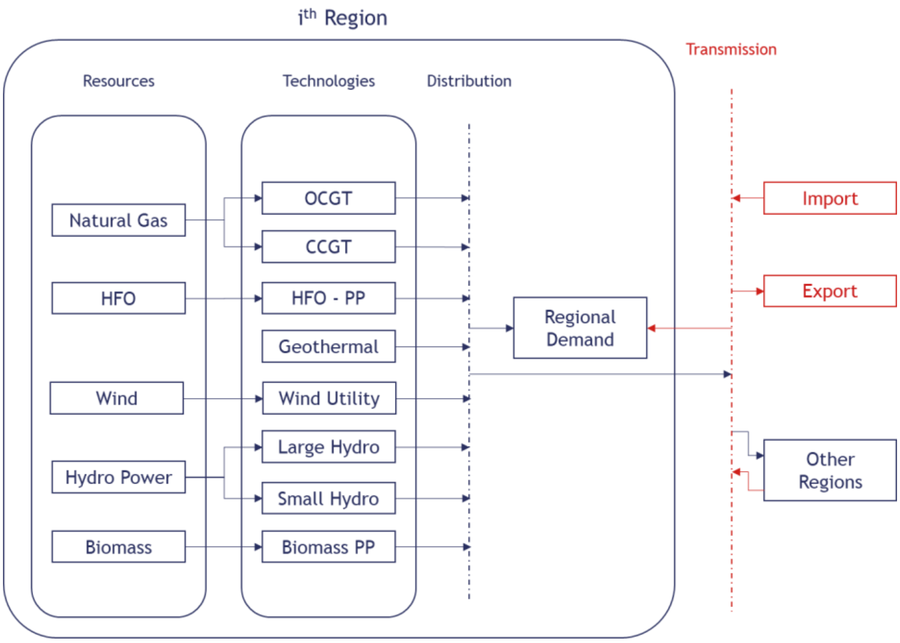


Figure S1. Reference Energy System.

Thanks to a field campaign conducted in 2019, during which several Kenyan stakeholders from the energy sector where interviewed, it was possible to obtain several information keys for the model characterization. A detailed list of the power plants operating in the country and connected to the national grid; a list of the existing transmission lines, their voltage and capacity; and the metered electric demand of the entire year 2015, with a time resolution of 1-hour, and a geographical resolution of the four regions of the energy market, as reported in Figure S2. For the list of modelled power plants, see Additional Data A - Table S1.

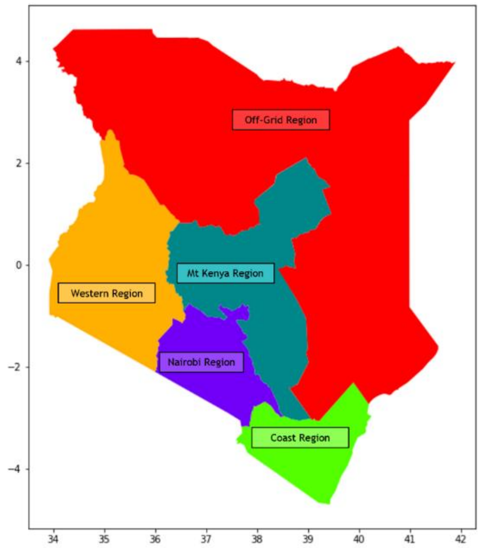


Figure S2. Regions of the electricity market of Kenya. Western Region (WSTR), Mount Kenya Region (MTKR), Nairobi Region (NBOR), Coast Region (CSTR).

Once the model is built, having characterized the power production technologies, the transmission technologies and the load demand curve of the country, the dispatch strategy is optimized per every hour. Figure S3 shows the overall output of the model in form of generated electricity by source over the entire year.

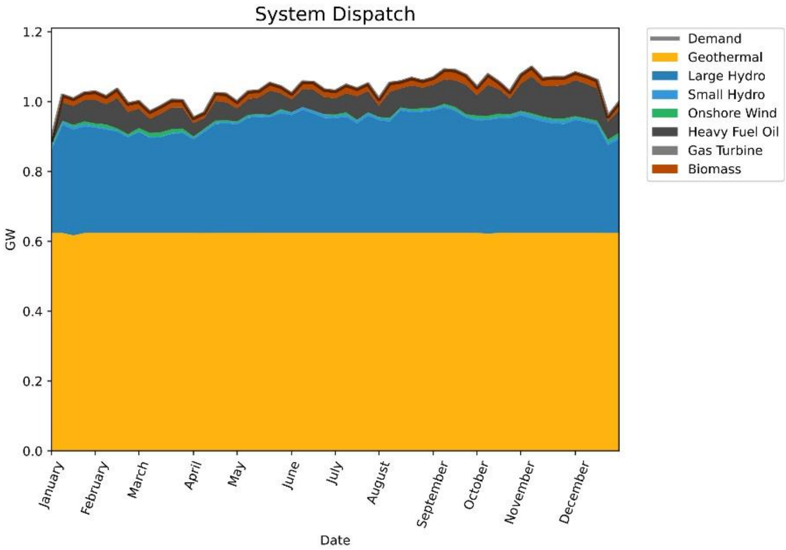
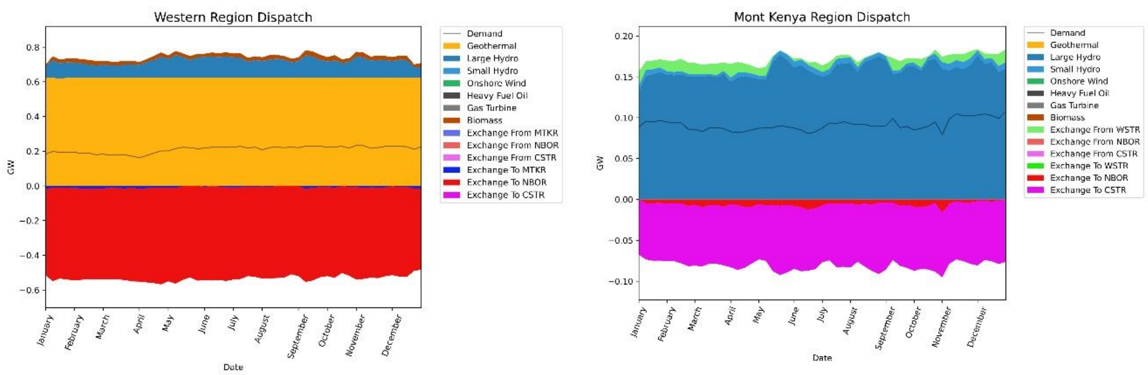


Figure S3. Electricity dispatch by source. Model Output.

The multi-node nature of the model allows for a deeper analysis of the results. In Figure S4 the optimized dispatch strategies are reported for each of the four regions. In addition to the previous representation of the results, is possible to notice that the *Exchange from* and *Exchange to* technologies are now present in the mix. It is in fact possible to plot the electricity interactions between regions. Is possible to observe how Western (WSTR) and Mount Kenya Region (MTKR), are the two regions richer in terms of resource availability, geothermal for the first case and Hydro for the second, but at the same time the regions with the lower electricity demand, being Nairobi (NBOR) and Coast region (CSTR) the most urbanized and industrialized regions. This results in a flow of electricity from WSTR and MTKR to NBOR and CSTR, in red in the WSTR dispatch plot and purple in MTKR. NBOR imports more energy than the amount it actually needs to satisfy its demand, and in fact presents a share of export to CSTR, this is just energy transiting the region, actually produced in WSTR, and then consumed in CSTR, geographically divided by NBOR that only transfers that amount of electricity. In the CSTR plot are visible imports from both NBOR and MTKR, the two neighbouring regions.



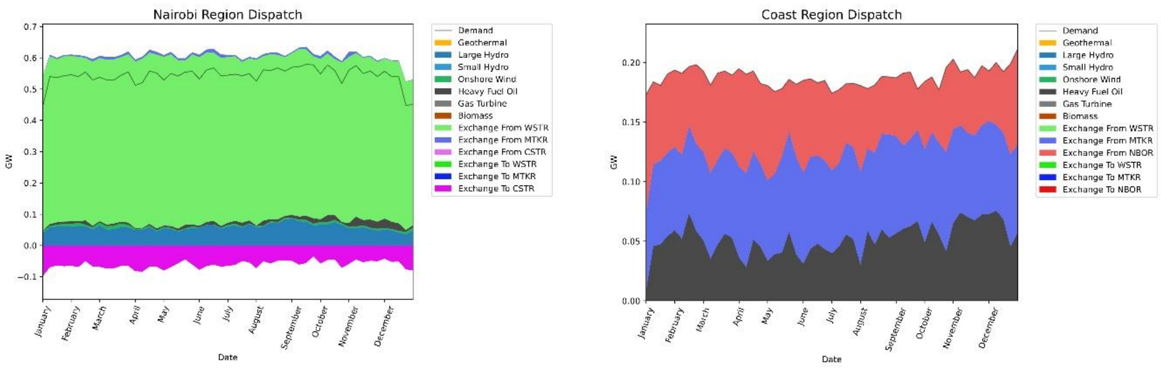


Figure S4. Electricity dispatch by source, per region. Model Output. Western Region (WSTR), Mount Kenya Region (MTKR), Nairobi Region (NBOR), Coast Region (CSTR).

A3 – Input Output Analysis Approach

The present methodology takes advantage of the SUT framework shown in (Lenzen and Rueda-Cantuche, 2012) and (Södersten and Lenzen, 2020). In this case, input-output coefficients have been obtained by simply dividing supply (*V*) and use (*U*) matrices (collectively identifiable as *Z*) by the resulting vector of total outputs of commodities (*Q*) and industrial activities (*G*). In this way, industry related assumption (i.e. input-structure of an industry is invariant irrespective of its product-mix) is implicitly assumed, resulting into the equations S1, here shown:

$$\overbrace{\begin{bmatrix}0 & U\\ V & 0\end{bmatrix}}^{\underline{\underline{Z}}}\begin{bmatrix}1_c\\ 1_a\end{bmatrix}+\overbrace{\begin{bmatrix}Y_c\\ 0\end{bmatrix}}^{\underline{Y}}=\overbrace{\begin{bmatrix}Q\\ G\end{bmatrix}}^{\underline{X}} \qquad \text{S1}$$

$$\underbrace{\begin{bmatrix}0 & U\\ V & 0\end{bmatrix}}_{\underline{\underline{Z}}}\underbrace{inv(diag\left(\begin{bmatrix}Q\\ G\end{bmatrix}\right))}_{\hat{\underline{X}}^{-1}}=\underbrace{\begin{bmatrix}0 & u\\ v & 0\end{bmatrix}}_{\underline{\underline{z}}}$$

Where:

- 1_c and 1_a are two row summation sub-vectors, one for commodity (*c*) and one for activities (*a*);
- Y_c is the demand, which is clearly expressed by means of commodities;
- *u* and *v* form the supply and use coefficient matrices: *u* is called the (product-by-industry) use coefficients matrix (input structures), and *v* is called the (industry-by-product) market share matrix.

In this way it is possible to express the economy by means of coefficients which are showing the following information: from the one hand how much inputs of commodity are required to produce one unit of industrial activity (*u*); from the other hand, how much activity production is needed by each industrial activity for every one unit of a certain commodity (*v*). Getting coefficients from the other matrices is straightforward: all of them are multiplied by the inverse of the same vector of total output (*X*).

Therefore, a deterministic representation of the analysed economy is assumed, so that every time a certain commodity is demanded a fixed endogenous set of technologies, which represent sectoral, economic and environmental interlinkages, are activated. In particular, the model will be identified by one unique technology (*z*) presented as in equation S2, as already anticipated in equation S1.

$$\underline{\underline{z}} = \underline{\underline{Z}}\,\hat{\underline{X}}^{-1} \qquad \text{S2}$$

Note that a variable with one underline identifies a vector, while one with double underline identifies a matrix. A variable in capital letters has absolute units (e.g. M$ or Gg), while one in small letters has output-specific units (e.g. M$/M$ or Gg/M$).

In the case of a change in the use of commodity by an industrial activity (*u*), specific coefficient co-production must be considered. In fact, since the use of input is related to each industrial activity, one should consider that not all the input refers to the production of one commodity. Therefore, it is assumed that the amount of input required by each activity to produce a certain commodity is weighted on the ratio between that commodity output and the total amount of output produced by that activity.

In order to model Kenyan economy, it is required to represent it in such a way that economic agents' transactions could be accounted entirely. In this way it could be possible to characterize sectoral interlinkages and model the economic and natural requirements of each economic activity and commodity. In this research, it was decided to adopt a Social Accounting Matrix (SAM) developed by JRC (Causapé et al., 2014). This SAM have been selected because of its very recently updated data and for the characterization of household's activities as a contribution to the local economy. This is very important when it is required to model agricultural sector in a developing economy such as Kenya. Since the SUT model that is adopted in this research does not require information on factor income distribution and transfers, only a part of the SAM has been used as input.

With reference to Figure S5, which is a modified version of Figure S7 from JRC's report on Kenya SAM (Causapé et al., 2014), accounts highlighted in pink have been included in *final demand*; the green account, which includes the intermediate consumption of commodity by each activity has been used as the *use* matrix of the model; the blue account, representing the production of commodity by domestic activity, has been used as the *supply* matrix of the model; the yellow account represents the use of commodity rest of the world (RoW) commodity and it has been used as the *import* matrix; the grey accounts, which represents both economic factors of production by activity and taxes that may interest both commodities and industrial activities, have been used as the *economic factors* matrices; finally, lighter pink and grey accounts, representing margins, will be respectively included in the *final demand* matrix and in the *economic factors* matrices. Alternative representations, which do not use specific margins accounts and records correspondent amounts directly as transfers between commodities accounts, are possible (Mainar-Causape et al., 2018). In this case, since the interest has been on the physical quantities produced and exchanged within Kenyan economy, it has been decided to include margins only out of the supply and use matrices.

	Commodities	Margins	Activities	Factors	Households	Enterprises / Corporations	Government	Savings-Investment	Rest of the World	*Total*
Commodities (C)		$T_{C,M}$ Transaction costs (trade / transport)	$T_{C,A}$ Intermediate (inputs) consumption		$T_{C,H}$ Household consumption		$T_{C,G}$ Government expenditure	$T_{C,S-I}$ Investment and stock changes	$T_{C,RoW}$ Exports	*Demand*
Margins (M)	$T_{M,C}$ Transaction costs (trade / transport)									*Margins*
Activities (A)	$T_{A,C}$ Domestic production									*Gross output / Production (activity income)*
Factors (F)			$T_{F,A}$ Remuneration of factors / Factor income						$T_{F,RoW}$ Factor income from RoW	*Factor income*
Households (H)				$T_{H,F}$ Factor income distribution to households	*($T_{H,H}$) (Inter Households transfers)*	$T_{H,E}$ Distribution of corporations income to households	$T_{H,G}$ Government transfers to households		$T_{H,RoW}$ Transfers to Households from RoW	*Household income*
Enterprises / Corporations (E)				$T_{E,F}$ Factor income distribution to enterprises			$T_{E,G}$ Government transfers to enterprises		$T_{E,RoW}$ Transfers to Enterprises from RoW	*Enterprise income*
Government (G)	$T_{G,C}$ Net taxes on products		$T_{G,A}$ Net taxes on production	$T_{G,F}$ Factor income to Government / Factor taxes	$T_{G,H}$ Direct Household taxes / Transfers to Government	$T_{G,E}$ Direct Enterprise taxes / Transfers to Government			$T_{G,RoW}$ Transfers to Government from RoW	*Government income*
Savings-Investment (S-I)				*($T_{S-I,F}$) (Depreciation)*	$T_{S-I,H}$ Household savings	$T_{S-I,E}$ Enterprise savings	$T_{S-I,G}$ Government savings	*($T_{S-I,S-I}$) (Capital accounts transfers)*	$T_{S-I,RoW}$ Capital transfers from RoW (Balance of Payments)	*Savings*
Rest of the World (RoW)	$T_{RoW,C}$ Imports			$T_{RoW,F}$ Factor income distribution to RoW	$T_{RoW,H}$ Household transfers to RoW	$T_{RoW,E}$ Corporations income to Row	$T_{RoW,G}$ Government transfers to RoW			*Payments to RoW*
Total	*Supply*	*Margins*	*Costs of production activities*	*Expenditure on factors*	*Household expenditure*	*Enterprise expenditure*	*Government expenditure*	*Investment*	*Incomes from RoW*	

Figure S5. This figure shows what submatrices of the Social Accounting Matrix provided by JRC were adopted for the application of the SUT model described in this paper.

In this way outputs and outlays of the new SUT represent the balance between supply and demand and between the costs of production activities and activity incomes.

After having considered all the economic accounts, it is time to also include *environmental extensions*. To do so, EORA's national environmental extension for the same period took into account for the SAM (i.e. 2014) have been disaggregated on the same level of sectoral detailed provided by the SAM (Lenzen et al., 2013). It has been chosen to allocate environmental extensions to industrial activities. When no clear sector-to-sector correspondence between the two databases was detected, proxies have been adopted to allocate use of natural resources and release of harming pollutants and greenhouse gases. As an example, environmental extensions which were allocated to households in EORA database, were redistributed between household's final consumption and households' activities based on the weight of economic input consumption on the total. The result is a set of matrices of national accounts as represented in Figure S6. This framework is presented in monetary units, other than the environmental extensions which are accounted in physical units which varies between the different types of account (e.g. carbon emissions are evaluated in Gg and land use in kha).

The present structure, in the form of the observed exchanges during year 2014, works as a baseline on which technological interventions have been modelled. Both impact of producing all the needed commodity to model the intervention and the relative annual changes experienced due to the technological change have been evaluated on the basis of this baseline.

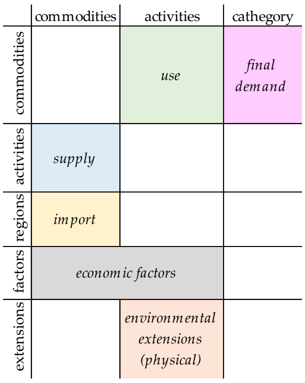


Figure S6. Structure of the SUT input-output model adopted in this research.

These interventions are characterized by a certain number of changes in the matrix coefficients, in the ways that were presented in the previous section. Thus, all the other aspects of the model of reality remained unchanged: the intervention is evaluated under the hypothesis of delivering the same amount of final demand, i.e. the same number of physical products and requested services. Ultimately, the model answers to the following question: "what would be the overall impact ceteris paribus of a certain technological intervention in delivering an amount of final demand equal to the baseline case?".

Supplementary Material S2. Proposed Interventions in Detail

B1 – Shading management via trees

The adoption of shading practices allows farmers to create suitable conditions for Arabica coffee, by reducing the temperature in the coffee canopy by around 2 to 3 °C (FAO, 2017). In addition, the complementarity between coffee and banana seems not to increase the competition in the use of resources, in particular of water, during average- rainfall seasons. (Sarmiento-Soler et al., 2019). This practice leads to a more improved food and nutrition security due to the fact that additional fruit production (banana in this case) can help coffee farmers to improve their income, by diversifying production and therefore reducing the limited negative effect on the economic returns of coffee plantations, due to the low reduction in the revenues generated by coffee (van Asten et al., 2015). Moreover, the quality of both coffee and bananas seems to be mutually enhanced due to the above and below ground complementarity in CBI systems. Hence the taste of finished products is better and can earn farmers a potential higher price (van Asten et al., 2015).

Shade grown coffee have also a high potential to mitigate the greenhouse gas emissions related to the coffee production. Evidences show that the average combined carbon stocks in shade-grown coffee increases from 10.5 t/ha (in unshaded monocultures) to 14.3 t/ha in shaded systems (van Rikxoort et al., 2014) (van Asten et al., 2015). This growth in the potential carbon stock is mostly due to the increase the above and below- ground carbon sequestration, in tree biomass and the soil (Albrecht and Kandji, 2003).

However, there are also some negative impacts such as the effect of intercropping on coffee yield which is highly dependent on several factors including the environmental conditions (climate, altitude, etc) and the shading tree species. Based on the available data and considering the altitude of Kenyan coffee plantation

(1500-2000 m above sea level), the reduction in coffee yield in CBI, compared to monocropping, could potentially range between 8 and 15% (during no favourable seasons), which could lead to a reduction in revenues of around 2% (Rahn et al., 2018). Moreover, the adoption of CBI requires high level of initial investment comprising several steps such as 1. Training the small farmers and cooperatives on the benefits and management of CBI; 2. Providing the planting material and ensuring water availability for irrigation; 3. Establishing the new plantation and/or rejuvenating the coffee plants.

B2 – Exploiting biomass from coffee organic waste

In order to implement the proposed intervention in the Kenyan Energy Model, the methodology presented in Figure S7 is adopted. For each of the 17 mills, to which the biomass is supposed to be gathered, are modelled:

- a *Supply* technology, bringing the biomass into the system, at the rate of 1.2 ton/h during the coffee harvesting months;
- a *Conversion* technology, with the role of converting the biomass into bio-methane, it represents the system of the anaerobic digester and the upgrader, with a capacity of 250 Nm^3/h and a yield of 200 Nm^3 of bio-methane per ton of biomass introduced;
- a *Storage* technology, with the purpose of balancing the seasonality of biomass availability, with a capacity of 250k Nm^3 methane storage;
- a *Conversion* technology, representing the alternative engine that burns bio-methane and produces electricity to inject into the grid, assuming the LHV of bio-methane to be 10 kWh/Nm^3, an efficiency of the machine of 45% and a size of the machine of 1 MW.

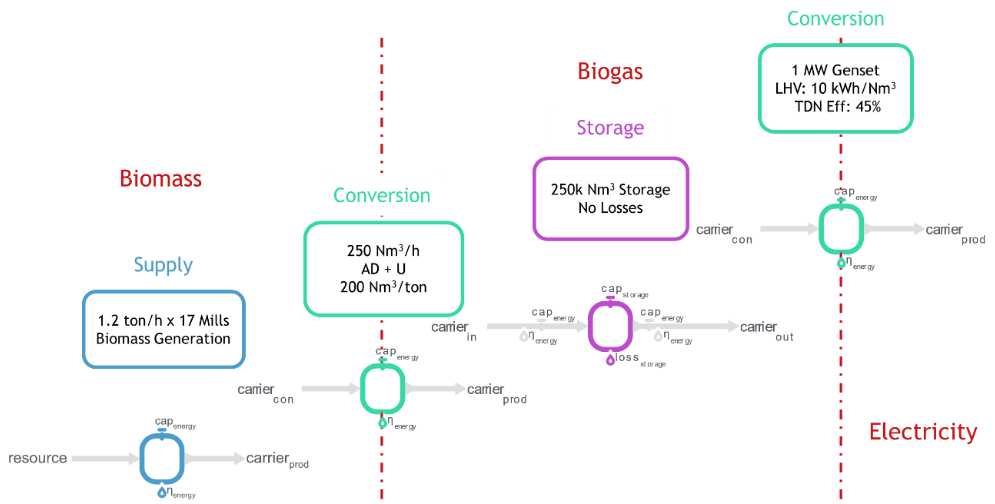


Figure S7. Modelling scheme of a single biomass power plant.

Supplementary Material S3. Detailed results by interventions

In this section the detailed results for each intervention are presented, starting from the result proposed by the optimization constrained to environmental objectives presented in the main paper.

In order to have a clear reading of charts, it must be recall that the interventions were modelled within the smallholder cooperatives, identified by the economic activity *COOPERATIVES*, and not in the coffee estates.

C1 – Shading management via trees

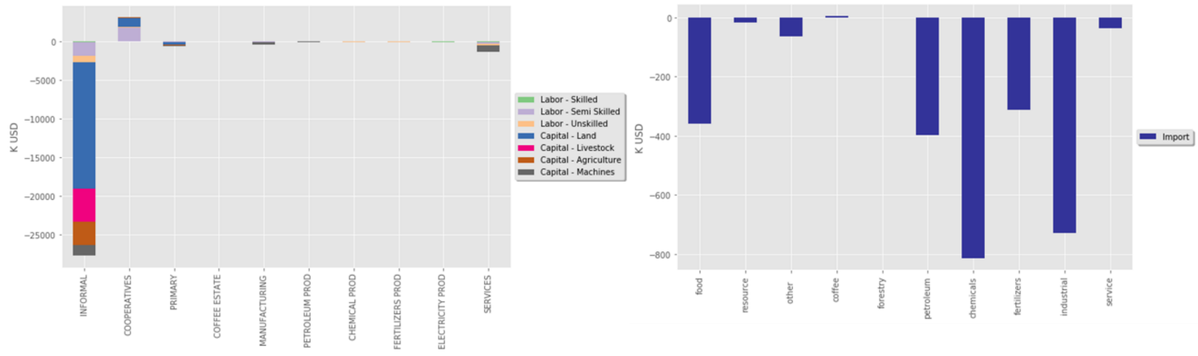


Figure S8. Changes in activities by factor of production and sector and import of commodities saving due to the intervention of covering 79% of coffee cooperatives' plants with banana trees

After having implemented the shock on the CIVICS model assuming a 79% coverage of the coffee plants own by cooperatives, some useful insights can be provided. The main economic benefit seems to be associated with the introduction of an additional revenue-generating activity which is the production of bananas coming out from the shading trees. This benefit more than compensate the decrease in coffee productivity in the cooperatives. In fact, even if, as it can be observed by the left-hand side of Figure S8, additional inputs are required within the coffee production informal activity (i.e. cooperatives), important savings are experienced in the other informal activities. This is due to the fact that fruits requirements from cooperatives are now partially covered by own production coming as by products from shading trees. On the right-hand side, the imported commodity savings associated with these two main activity changes shows important reduction in chemical products, thanks to cross-cropping benefits.

From an environmental perspective it must be pointed out that also considerable land and carbon emission savings is possible. In fact, up to 13 kha of cropland could be saved, a value equivalent to 15% of coffee permanent crops. Moreover, carbon emissions are saved not only in the most impacted sectors (i.e. the informal activities that are not producing coffee and the cooperatives that are directly storing carbon by means of planting trees) but also by means of less transport emissions and marginally and less electricity production as it can be seen in Figure S9.

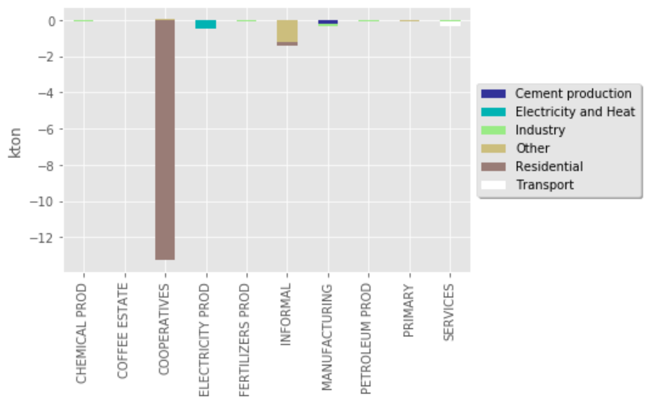


Figure S9. Carbon emission changes by sector and category due to the intervention of covering 79% of coffee cooperative plants with banana trees

C2 – Eco-pulper for the wet milling process

A huge improvement in terms of green-water usage, since that is the kind of water adopted for cultivating in Kenyan cooperatives is observed. Looking at the left-hand side of Figure S10, the decrease in water usage is very relevant, corresponding to a reduction of 1400 Mm^3 in the 10 years useful life of the machines. From the other hand, the increase in the use of fuels is responsible for a direct increase in carbon emission. Interestingly, the total amount of carbon emission could be offset by the gained benefits induced by increase in productivity. In fact, as can be noticed by the right-hand side of Figure S10, the increase in direct emission associated to the use of the machines (here accounted as "Residential") is overcome by the indirect effects associated with productivity increase. Relevant savings in cooperative activities, transportation services and in other interlinked sectors, may justify the intervention also from a pure carbon reduction perspective.

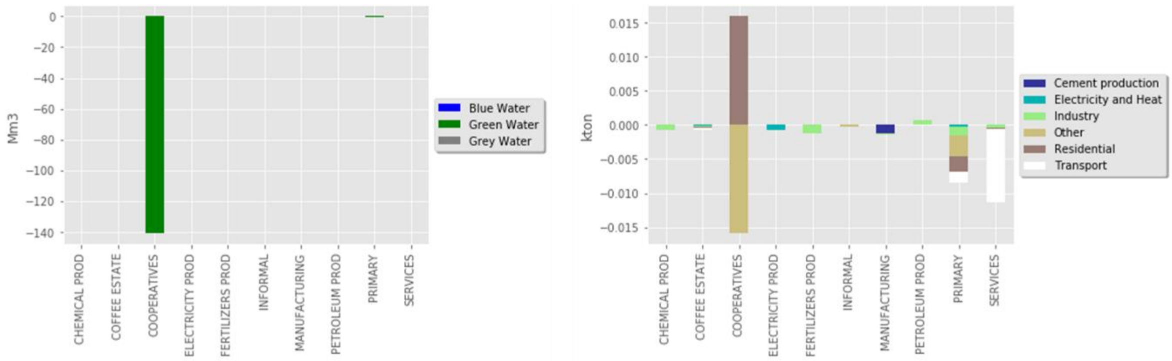
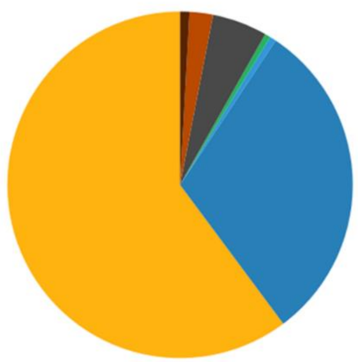


Figure S10. Environmental impact induced by the substitution of 34% of cooperatives' wet mills with near-zero-water and gasoline-powered eco-pulpers

C3 – Exploiting biomass from coffee organic waste

The results of the energy model are reported in Figure S11, reported in pie charts for simplicity. It emerges how the total energy produced is slightly less than 80 GWh over a year of operation. This amount of energy is replacing the same amount of energy, previously produced by HFO, reducing its use by 15%. A more detailed representation of the results is reported in Appendix B.

System Production Mix



	GWh
Geothermal	5464.8
Large Hydro	2765.0
Small Hydro	53.9
Onshore Wind	48.4
Heavy Fuel Oil	467.0
Gas Turbine	0.0
Biomass	199.2
Coffee Biomass	79.3

Figure S11. Electricity production mix after implementation of the Coffee Power Plants.

From Figure S12 emerges how the seasonal availability of the resource does not affect the dispatch of electricity, thanks to the presence of the storage.

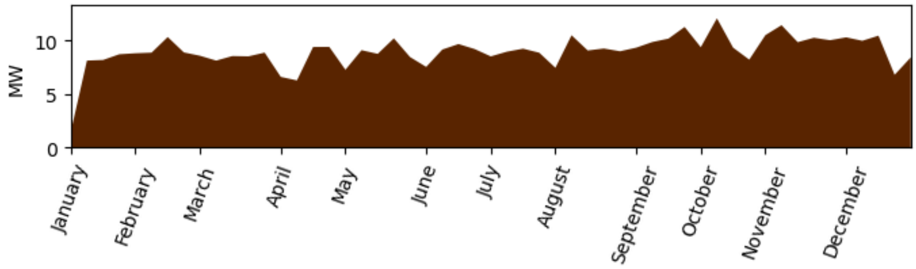


Figure S12. Aggregated yearly dispatch of the Coffee Power Plants.

The adoption of the biomass resource as a substation to part of the heavy fuel oil production comes with environmental benefits. In fact, it is possible to save 3% of the emissions coming from Kenyan electricity sector, corresponding to 54 kton of CO_2. Modelling the intervention in the IOA some other considerations around environmental and economic impacts can be made. As it can be observed by Figure S13 carbon emissions are not only saved every, but also emitted for producing the technology required by the intervention. Nevertheless, its carbon footprint is considerable smaller than the net annual carbon saving. It must be noted that this footprint is computed assuming that the plants are produced within Kenya, which probably overestimate the footprint.

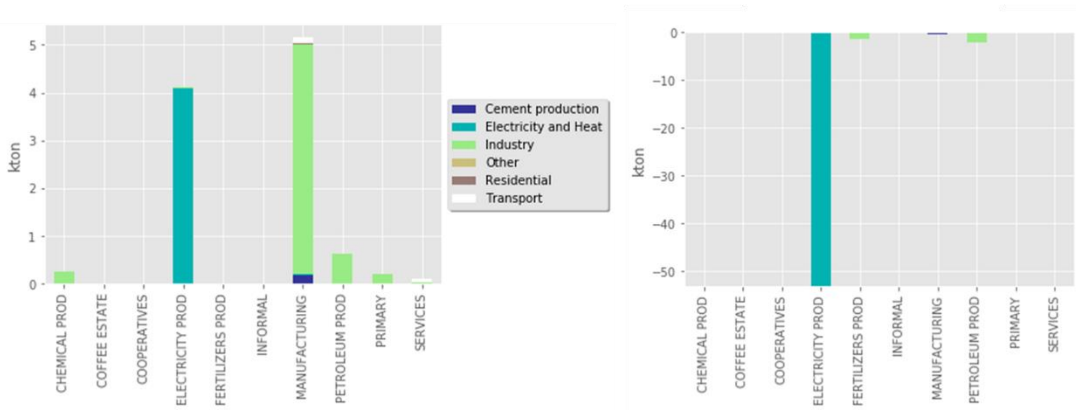


Figure S13. Carbon emission associated with production (left-hand side) and operation (right-hand side) of the coffee biomass power plants and fertilizer production plants.

The benefits are also present within the economic dimension. In fact, as it can be seen by Figure S14, the import of petroleum and fertilizers, two inputs on which Kenya has a very relevant exogenous dependence, could be avoided saving circa 20M USD every year. It should be noted that, even if this intervention does not increase the physical productivity of coffee, there is a relevant increase in resource efficiency: the coffee wastes, not exploited in the baseline case, is transformed in value by substituting two commodities otherwise imported. This intervention represents a possible practical example of circular economy.

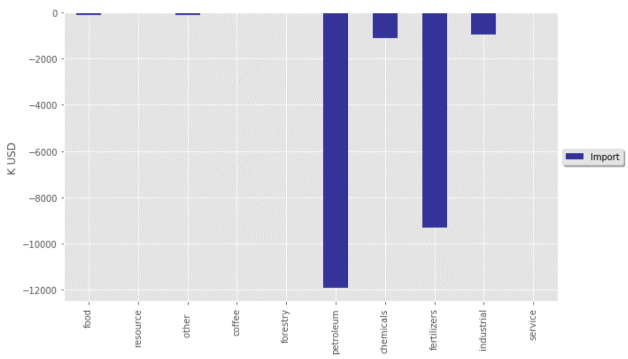


Figure S14. Avoided import due to the introduction of the coffee biomass power plants and fertilizer production plants.

Supplementary Material S4. Additional Data

Additional Data A

The list of modelled power plants representing the 2015 energy system is reported in Table S1.

Table S1. List of modelled power plants

Category	Power Plant	Capacity [MW]	Location
Wind	Ngong 1, Phase I	5	Nairobi Region
Wind	Ngong 1, Phase II	20	Nairobi Region
Geothermal	Olkaria 1 – Unit 1	15	Western Region
Geothermal	Olkaria 1 – Unit 2	15	Western Region
Geothermal	Olkaria 1 – Unit 3	15	Western Region
Geothermal	Olkaria 1 – Unit 4-5	140	Western Region
Geothermal	Olkaria 2	105	Western Region
Geothermal	Olkaria 3 – Unit 1-6	48	Western Region
Geothermal	Olkaria 3 – Unit 7-9	62	Western Region
Geothermal	Olkaria 3 – Unit 10-16	29	Western Region
Geothermal	Olkaria 4	140	Western Region
Geothermal	Olkaria Wellheads I & Eburru	29	Western Region
Hydro	Tana	20	Mt Kenya Region
Hydro	Masinga	40	Nairobi Region
Hydro	Kamburu	92	Nairobi Region
Hydro	Gitaru	225	Nairobi Region
Hydro	Kindaruma	72.5	Mt Kenya Region
Hydro	Kiambere	168	Mt Kenya Region
Hydro	Turkwel	106	Western Region
Hydro	Sondu Miriu	60	Western Region
Hydro	Song’oro	21	Western Region
HFO	Iberafrica 1	56	Nairobi Region
HFO	Iberafrica 2	53	Nairobi Region
HFO	Kipevu 1	60	Coast Region
HFO	Kipevu 3	120	Coast Region
HFO	Tsavo	74	Coast Region
HFO	Rabai-Diesel	90	Coast Region
HFO	Thika	87	Nairobi Region
HFO	Athi River Gulf	80	Nairobi Region
HFO	Triumph	83	Nairobi Region
Biomass	Biojoule	35	Western Region

The list of coffee mills as data collected during the field campaign is reported in Table S2.

Table S2. List of Coffee Mills. Source: Authors.

Mill	Latitude	Longitude	Region
NKG	-1.164030	36.952353	NBOR
CKCM	-0.490858	37.104492	MTKR
Kofinaf	-1.112537	36.911591	NBOR
Sasini	-1.140161	36.789959	NBOR
Highlands	-1.052856	37.093282	MTKR
CMS Eldoret	0.515948	35.288292	WSTR
Thka Coffee Mill	-1.052159	37.093444	NBOR
Kipkelion	-0.200894	35.349228	WSTR

Gusii Union Cofee Mill	-0.681485	34.776489	WSTR
Meru County Coffee Millers Co-Op Union Ltd	0.041435	37.658207	MTKR
Lower Eastern Mill	-1.519986	37.269550	NBOR
Tharaka Nithi County Coffee Mill Co-Op Union Ltd	-0.219065	37.731824	MTKR
Othaya Coffee Mill	-0.548359	36.944524	MTKR
Rumukia FCS Mill	-0.566323	37.016581	MTKR
Gikanda FCS Mill	-0.483448	37.126835	MTKR
Hema	0.339009	37.937246	MTKR
KPCU	-1.251293	36.909207	NBOR

Additional Data B

In this section a more detailed representation of the energy model results is reported. Figure shows the energy production mix of the four regions and is possible to observe the effects of presence of the coffee powered plants in the first three regions.

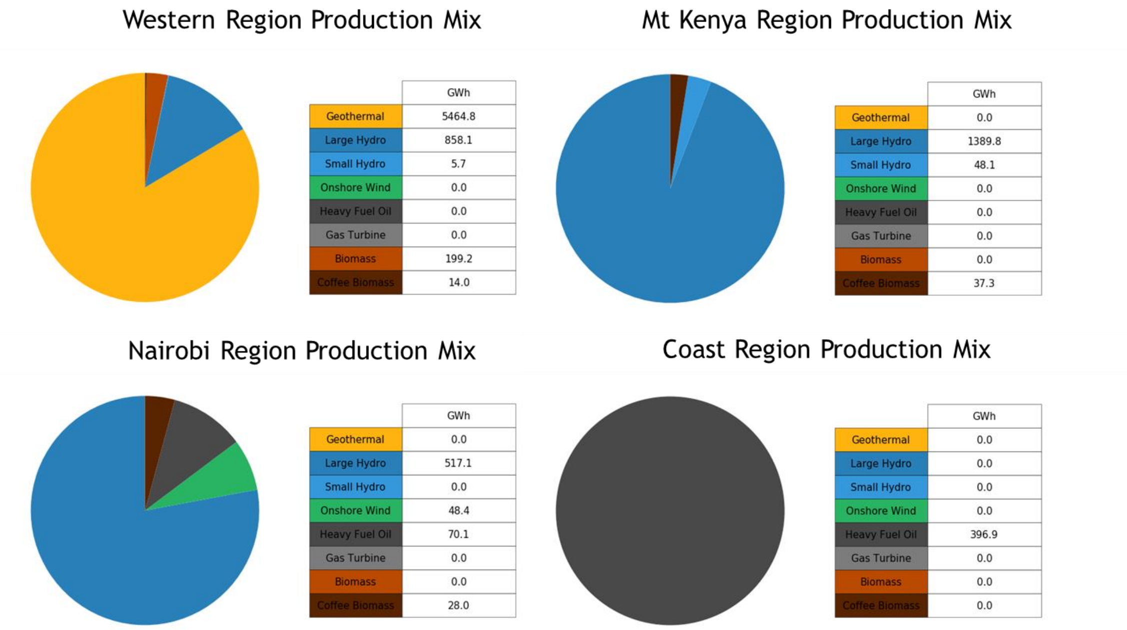


Figure S15. Energy production mix, per region, after implementation of the coffee power plants.

In Figure is reported the same result, but with a different rationale, the energy consumption mix is shown. And it is clearly visible the difference between the exporting regions (Mount Kenya and Western) and the importing regions (Nairobi and Coast).

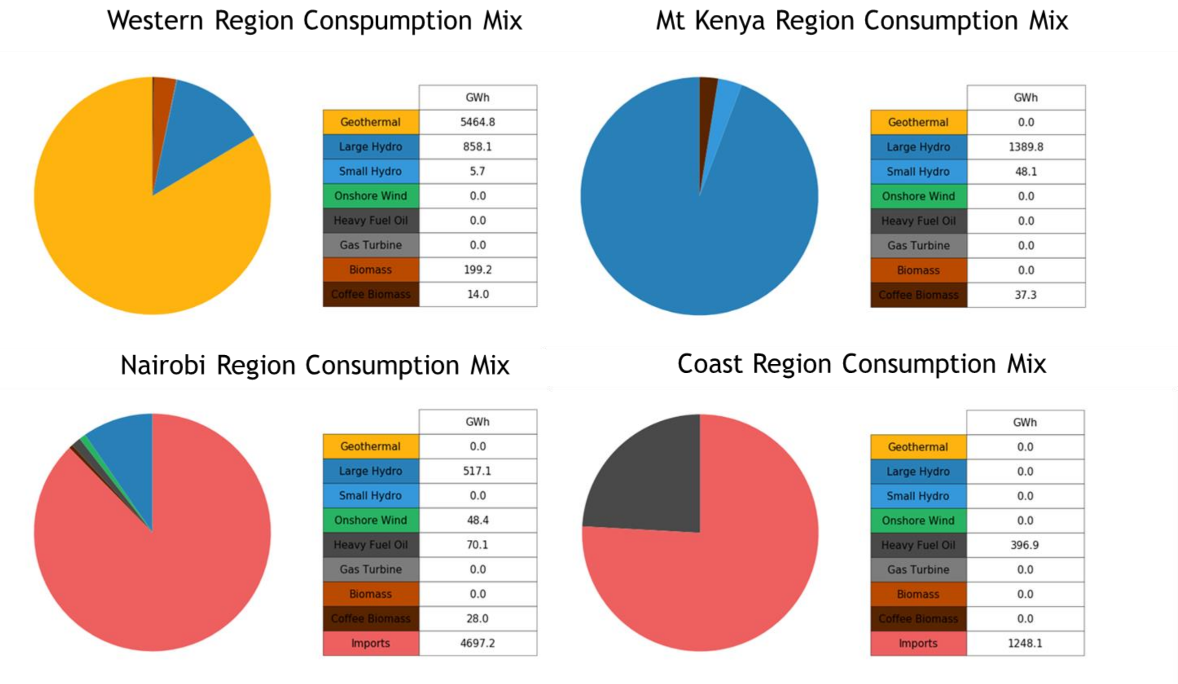


Figure S16. Energy consumption mix, per region, after implementation of the coffee power plants.

Additional Data C

In this appendix the techno-economic parameters adopted to model the defined interventions are presented in form of tables.

Shading management via trees

Table S3. Input parameters for shading tree management intervention

Description	Value	Unit of measure	Reference
Number of coffee plants per hectare	1800-2200[1]	-	Country Coffee Profile: Kenya, International Coffee Organization (International Coffee Council, 2019)
Fraction of shading trees to coffee plants	0.25	-	Exploring adaptation strategies of coffee production to climate change using a process_based model (Rahn et al., 2018)
Cost of purchasing a shading banana plant	1.3	$/plant	(“shading plant cost,” n.d.)
Cost of planting a shading banana plant	0.13	$/plant	Estimation
Banana yield	15	kg/plant	Banana-coffee system cropping guide(Wairegi et al., 2014)
Banana price	0.065	$/kg	Banana-coffee system cropping guide(Wairegi et al., 2014)
Reduction in physical yield (optimum level of shading)	8%-15%	-	Exploring adaptation strategies of coffee production to climate change using a process_based model(Rahn et al., 2018)

[1] In intercrop system the plant population is going to be less than the actual number in Kenyan coffee monocrops which is reported around 2500 plants per hectare

Reduction in monetary yield (potential price growth)	2%	-	(van Asten et al., 2015)
Increase in the total soil carbon stocks	3.8	t/ha	(van Asten et al., 2015)
Reduction in required capital-machines	27%	-	Effects of shade and input management on economic performance of small-scale Peruvian coffee systems (Jezeer et al., 2018)
Growth in demand for labour	38%	-	Effects of shade and input management on economic performance of small-scale Peruvian coffee systems (Jezeer et al., 2018)
Useful life of the shading plants	20	years	Estimation

Eco-pulper for the wet milling process

Table S4. Input parameters eco-pulpers intervention

Description	Value	Unit of measure	Reference
Cost of eco pulping machine	1430	$	(Alibaba.com, 2020; "CAL - Coffee Machinery - Mini Eco Pulper," n.d.)
Cost of delivery	46	$	Estimation
Required power	1.1	kW	Estimation[2]
Capacity of the machine	0.5	Tons of coffee/h	Estimation[2]
Efficiency of the machine	30%		Estimation[2]
Decrease in water footprint	85%	-	Estimation[2]
Number of smallholders to be covered by each machine	300-600	-	Assumption
Productivity increase	0%-2.5%	-	Assumption
Carbon intensity of the eco pulpers electricity consumption	0.27	kgC02/kWh	*(Combustion of Fuels - Carbon Dioxide Emissio>*, n.d.)
Useful life of the eco pulpers	10	years	Estimation

[2] Based on the type of the mini eco pulper

Exploiting biomass from coffee organic waste

Table S5. Input parameters for biomass powerplant intervention

Description	Value	Unit of measure	Reference
Specific cost of biodigester	10000	$\$/Nm^3/h$	Estimation
Specific cost of storage	0	$\$/Nm^3$	Assumption
Specific cost of generator	500	$/kW	Estimation
Electricity production in one year by new plants	80	GWh	Energy modelling output (Calliope)[3]
Carbon intensity of electricity production from heavy fuel oil	0.27	$KgCO_2/kWh$	("Combustion of Fuels - Carbon Dioxide Emission," n.d.)
Efficiency of the old diesel generators to be replaced	0.4	-	Estimation
Biomass to fertilizer rate	0.3	-	Assumption
Labour cost[4]	37.5		("Salaries by positions - Kenya.paylab.com," n.d.)
Size of biodigester	250	Nm^3/h	Estimation
Size of Generator	25000	Nm^3	Estimation
Size of Storage	1	MW	Estimation
Increase in use of transport commodity by cooperatives	30%	-	Assumption
Useful life of the machines	25	years	Estimation

Supplementary References

CAL - Coffee Machinery - Mini Eco Pulper [WWW Document], n.d.

Eco Mini Pulper Cost [WWW Document], n.d.

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Jezeer, R.E., Santos, M.J., Boot, R.G.A., Junginger, M., Verweij, P.A., 2018. Effects of shade and input management on economic performance of small-scale Peruvian coffee systems. Agric. Syst. 162, 179–190. https://doi.org/10.1016/j.agsy.2018.01.014

Rahn, E., Vaast, P., Läderach, P., van Asten, P., Jassogne, L., Ghazoul, J., 2018. Exploring adaptation strategies of coffee production to climate change using a process-based model. Ecol. Modell. 371, 76–89. https://doi.org/10.1016/j.ecolmodel.2018.01.009

Salaries by positions - Kenya.paylab.com [WWW Document], n.d.

[3] To be changed for every different number of Gensets

[4] Considering 2 technicians, one process engineer and one electrical and power engineer per each plant

shading plant cost [WWW Document], n.d.

van Asten, P., Ochola, D., Wairegi, L., Nibasumba, A., Jassogne, L., Mukasa, D., 2015. Coffee-Banana Intercropping Implementation guidance for policymakers and investors. Fao 10.

Wairegi, L., Asten, P. Van, Giller, K., Fairhurst, T., 2014. Banana-coffee system cropping guide, Africa Soil Health Consortium, Nairobi.