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Report

Comprehensive and Integrated Impact Assessment Framework for Development Policies Evaluation: Definition and Application To Kenya

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FONDAZIONE ENI ENRICO MATTEI

Table of contents

Table of Figures

Table of Tables

Abbreviations

SCA – Supply Chain Analysis
IOA – Input Output Analysis
EAC – Eastern African Countries
IEA – International Energy Agency
TPES – Total Primary Energy Supply
KNES – Kenya National Electrification Strategy
VRES – Variable Renewable Energy Sources
LP – Linear Programming
SUT – Supply and Use Tables
PRoI – Policy Return on Investment
PPBT – Policy Pay Back Time
SAM – Social Accounting Matrix
JRC – Joint Research Centre
HFO – Heavy Fuel Oil
OCGT – Open Cycle Gas Turbine
CCGT – Combined Cycle Gas Turbine
HFO-PP – Heavy Fuel Oil - Power Plant
CBI – Coffee Banana Intercropping
SDGs – Sustainable Development Goals
CIVICS – Comprehensive and Integrated Country Study
ASTGS – Agricultural Sector Transformation and Growth Strategy
NCG – Nairobi Coffee Exchange
USDA – United States Department of Agriculture
FAO – Food and Agricultural Organization of the United States
KARLO–CRI – Kenya Agricultural and Livestock Research Organization – Coffee Research Institute
SRIO – Single Region Input-Output Analysis
MRIO – Multi Regional Input-Output Analysis
WSTR – Western Region
MTKR – Mount Kenya Region
CSTR – Coast Region
NBOR – Nairobi
WEF – Water Energy Food

01 Introduction

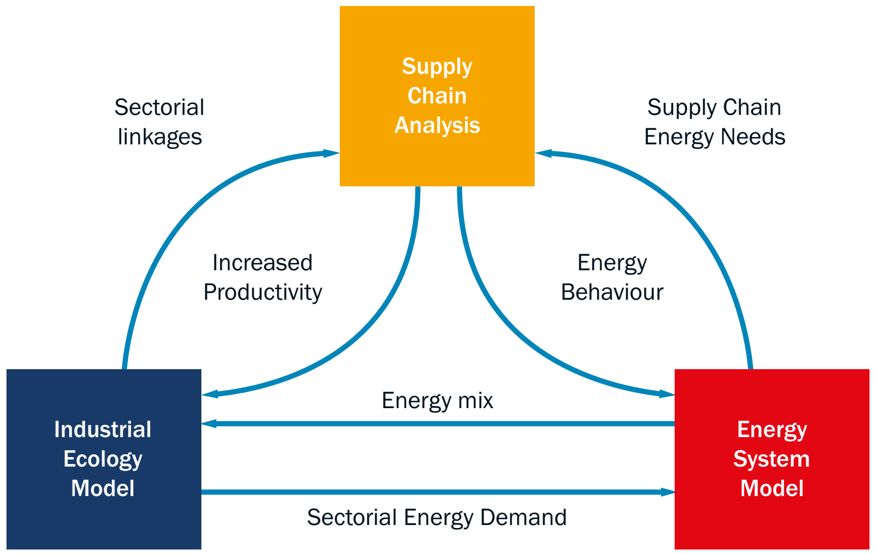
Over the last decades, the interest and evidence for the numerous interconnections among energy, environment and society have acquired increased importance for the international community. Indeed, processes and relationships among countries are becoming global and evolving in a complex framework. It is no more possible to consider development strategies without taking into account the whole system in its social and technological complexities. In the last decade, the recognized relevance of cross-sectoral interlinkages among economic sectors has driven research efforts towards deepening joint energy and economic modelling. Furthermore, the 2030 Development Agenda identifies energy access as a necessary precondition for human and social promotion, as well as an instrumental right to fight poverty (UN, 2015).

Sustainable development requires innovative solutions and strategies to match the economic growth with its multidimensional targets. The coexistence of the need to improve economic conditions, particularly in developing countries, and consciously use environmental resources, plays a central role in the global sustainable development challenge.

To address this issue, an informed decision-making process is essential and may be pivotal to support national development policies. To pursue sustainable development, policymakers need support from the scientific community. The adoption of a multidisciplinary framework of integrated tools would allow to face the problem with a comprehensive approach, enabling the evaluation of impacts of possible improvement policies. Indeed, these development strategies can affect the energy, social and economic sector of the country.

In light of this, and thanks to the scientific expertise acquired in years of research activity devoted to developing countries, climate change, energy and economy nexus and their linkage with policies, Fondazione Eni Enrico Mattei (FEEM) developed a multidisciplinary, comprehensive and integrated research approach called ComprehensIVe and Integrated Country Study (CIVICS). The aim of this project is to sustain national policies of developing countries, by drawing guidelines (see Figure 1), and combining the information deriving from them in a unique frame. The tools are i) Supply Chain Analysis (SCA), ii) Industrial Ecology Modelling and iii) Energy System Modelling. SCA allows the acquisition of insights regarding the supply chain of a specific local product considered strategic for the national economy. It permits to focus on bottlenecks and hotspots undermining the supply chain overall performance. This analysis allows to identify strategies and improvement solutions that can be implemented in order to overcome main issues. Being the economic and energy sectors interconnected, it is reasonable to expect that these improvement strategies have an impact at local and global level, which can be evaluated thanks to Input-Output Analysis (IOA), which is a modelling approach of Industrial Ecology. For this reason, it can be stated that IOA acts as a bridge between a robust characterization of the supply chain under investigation and a detailed modelling of the energy system. Indeed, thanks to the exchange of information between SCA and IOA, (as the output of the SCA are input for the IOA), it is possible to evaluate impacts at social, economic and environmental level of the formulated improvement strategies. Furthermore, the integration of results between IOA and energy modelling enables the formulation an energy strategy ad-hoc for these interventions, addressing at the same time the sustainable development objectives (e.g. CO2 reduction).

Figure 1. CIVICS Integrated Modelling Framework.



The peculiarity of this research approach relies particularly on the integration process mentioned. All these tools are combined in a framework developed ad-hoc for decision-makers, willing to assess impact of their national strategies and to frame them in the sustainable development framework. Particularly, the added value given by the strong focus on the energy sector relies on the possibility of forecasting future energy scenarios based on the combination of local needs and conscious exploitation of renewable resources.

1.1 Developing economies: the case of Kenya

Kenya consists of a total area of 587,306 km^2, of which 576,076 km^2 is land and the remaining 11,230 km^2 is covered by water, being the world's 48th largest country. Its climate varies from tropical on the coast to arid in the interior, influenced primarily by the inter-tropical convergence zone, by relief (Great Rift Valley and high mountains, up to 5,199 m above sea level) and by large water bodies (FAO, 2015). Long-term average annual precipitation is 630 mm, ranging from less than 200 mm in Northern Kenya to over 1,800 mm on the slopes of Mount Kenya. The rainfall distribution pattern is bimodal, with long rains falling from March to May and short rains from October to December for most parts of the country (WRMA, 2013). The Country is made up of 47 semi-autonomous counties and has a population of more than 47.6 million people.

Kenya's great diversity in terms of physical, geographical, and social economic attributes, provides it with comparative advantages, enabling growth and economic powerhouse in the region. For these reasons, it can be rightly considered as the economic and financial hub of East Africa. In 2019, Kenya was ranked as the 65th largest economy in the world, with a Gross Domestic Product (GDP) of $95,503 million. Over the last decade, the Country has grown with an average of over 5%, mostly relying on agriculture, forestry, tourism, fishing, energy and manufacturing (The World Bank, 2020). This growth has been supported by improved agricultural output, ongoing public infrastructure spending and positive business sentiment, which have been sustained by better returns from the agricultural harvest, strong remittance inflows and lower food prices. In particular, while the services sector has continued to account for most of total GDP growth, also the industrial activity has been gradually growing over the last years. The improvement in business sentiment, increase in private consumption, a favourable external demand from the Eastern African Countries (EAC) and the regional markets have been crucial factors to facilitate the process. The contribution of the industrial sector rose from 0.5% to 1.0% points of GDP between 2017 and 2018, and also the manufacturing sector contribution to GDP growth has improved over the last years. Concerning other economic activities, trends in wholesale, retail trade, accommodation and transportation sub-sectors, as well as Information & Communication Technology (ICT) and real estate sub-sectors has been encouraging, despite continuing suffering from the weak business environment for the financial services sector (The World Bank Group, 2019).

Key public investments promoted by the Kenyan Government have been mostly directed to support the implementation of the national agenda (so called "Big Four" Agenda) according to four priority development pillars: i) enhancing food and nutrition security, ii) providing affordable housing, iii) increasing manufacturing and agro-processing and iv) achieving universal health coverage, as an attempt to strengthen the commitment toward sustainable development. In 2008, Kenya launched "Vision 2030", a blueprint covering the period up to 2030, aiming at supporting the industrialization process while improving the quality of life for all the citizens. Significant progresses were made in such direction. The ongoing last phase of the Vision 2030, the so-called Third Medium Term Plan (MTPIII), focuses on nine key foundations for national transformation, namely: infrastructure, information and communication technology, science technology and innovation, land reforms, public sector reforms, labour and employment, national values and ethics, ending drought emergencies, security, peace building and conflict resolution. Moreover, MTPIII prioritizes eight sectors to drive economic growth such as: agriculture and livestock, manufacturing, tourism, trade, business process outsourcing, financial services, oil, gas and mineral resources and the blue economy (Government of Kenya, 2018b).

In this context, the agriculture sector has a pivotal role in ushering sustainable economic development. Agriculture in Kenya is not only central to the achievement of "a globally competitive and prosperous country with a high quality of life by 2030" (as stated by the Vision 2030), but it is also expected to deliver on Kenya's global commitments, including the Sustainable Development Goals (SDGs) (Boulanger et al., 2018; Government of the Republic of Kenya, 2007). The sector is a key driver of growth, jobs and poverty reduction and it accounts for the majority of income for rural households, contributing to reduced poverty among poor rural households (minus 30% estimated in 2018). Thus, resource mobilization to enhance large scale production and to boost smallholder productivity is critical to contribute to the national prosperity (Kenya Institute for Public Policy Research and Analysis, 2019). Nowadays, agricultural incomes (from crops, livestock and fishing) account for 64% of the income sources of the poor and 53% of incomes for the non-poor (The World Bank, 2019a). Moreover, the sector establishes the industrialization framework by supplying raw materials to other industries (over 75% of industrial raw materials) and it lays the foundation of numerous off-farm activities such as logistics and research (Kenya Institute for Public Policy Research and Analysis, 2019). In fact, agriculture contributed indirectly to 27% of GDP in 2019, through linkages with manufacturing, distribution and other service-related sectors and approximately 45% of the Kenyan government revenue is derived from agriculture (The World Bank, 2019a).

However, despite having one of the highest productivities among the EAC, a large share of agriculture in Kenya is still vulnerable to harvest failure due to drought (as in 2019), being for the most part rainfed. For this reason, over the medium term, ongoing policy and institutional reforms are focusing on stabilizing agricultural output and reduce the risk, by supporting irrigation schemes, post-harvest losses management and input markets. The government has recently launched the Agricultural Sector Transformation and Growth Strategy (ASTGS) to guide sector programs over the next ten years toward the increasing of incomes, value addition and food security and ultimately contributing to drive the Kenyan economy to a projected annual growth of around 10% (The World Bank, 2019b).

1.2 Energy context of Kenya

According to the International Energy Agency (IEA), the Total Primary Energy Supply (TPES) per capita of Kenya in 2017 was 0.54 toe/capita, compared with the African average of 0.65 toe/capita and the world average of 1.9 toe/capita. Electricity consumption per capita was of 166 kWh/capita, compared with an African average of 574 kWh/capita. Regarding electricity, Kenya had in 2017 an installed capacity of 2.2 GW, and the electricity sector is particularly rich of carbon-free power production technologies: in 2017 46% of electricity generation was generated through geothermal power plants and 31% form hydropower, leaving only 21.8% of the electricity nationally consumed to be produced by fossil fuels, in particular heavy fuel oil (HFO). Finally, 1.2% of electricity was produced by solid biofuel power plants.

It is to notice that natural gas was not present in the mix of 2017 for power production, as well as wind and solar power, despite of the great potential of the country, they were still in developing stage. As of today, many projects are reported to be under construction or commissioned, especially in the north of the country. In the least cost development plan the outlined growth for the electricity generation capacity expansion is "The total installed capacity [...] grows from 2.2 GW in 2017 to 7.2 GW in 2030 and to 9.9 GW in 2037. The contribution from the respective technologies for the period 2017-2037 is as outlined: Geothermal decreases from 29.1% to 26.7%, Hydropower decreases from 36% to 17.9%, Coal increases from 0% to 19.5% while Natural gas increases from 0% to 7.6%. It is noteworthy that Wind and solar will increasingly play a major role in the generation mix during the planning period, rising from 1.1% to 8.5% and 0% to 8.6% respectively" (Republic of Kenya, 2018).

Regarding the issue of access to electricity, electrification rate in 2017 was assessed to be around 70%, ranking quite high compared with the rest of the continent (in 2017 according to the Energy Access Outlook Sub-Saharan Africa had an electrification ratio of 43% (International Energy Agency, 2017), while reliability of the supply remains a relevant issue for the majority of the population. The Kenya National Electrification Strategy (KNES) pledged in 2018 to reach 100% access to electricity at national level by 2022 (Government of Kenya, 2018).

1.3 The coffee sector in Kenya

Agriculture is a major driver of growth for the Kenyan economy and it is the dominant source of employment. Between 2013 and 2017, the agriculture sector contributed on average to 21.9% of the Kenyan GDP (34.2% in 2018), with at least 54% of the total labour force employed in agriculture (approximately nine million Kenyans). In addition, agricultural products account for up to 65% of merchandise exports and includes tea (22.3%), cut flowers (9.3%) and coffee (3.7%) (International Coffee Organization, 2019; World Bank Group, 2019). The coffee industry contributes in terms of foreign exchange earnings, tax revenue, income generation and employment creation and it returns annually on average around $230 million in foreign exchange earnings. In terms of contribution to the labour market, some estimations dedicate up to 30% of the total agriculture labour to the coffee sub-sector, of which 60% is provided by women (International Coffee Organization, 2019; Nairobi Coffee Exchange, 2014). Based on a study conducted by the Joint Research Centre in 2018, that uses backward linkages (to compare a product capacity and potential to create employment and wealth), coffee values indicated that it has a strong impact on the economy in terms of production, employment and value added. In addition, the study showed that for every unit injected in coffee it will generate 1.08 units of output, 1.53 units of employment and 1.15 units in value added (Boulanger et al., 2018; Kenya Institute for Public Policy Research and Analysis, 2019).

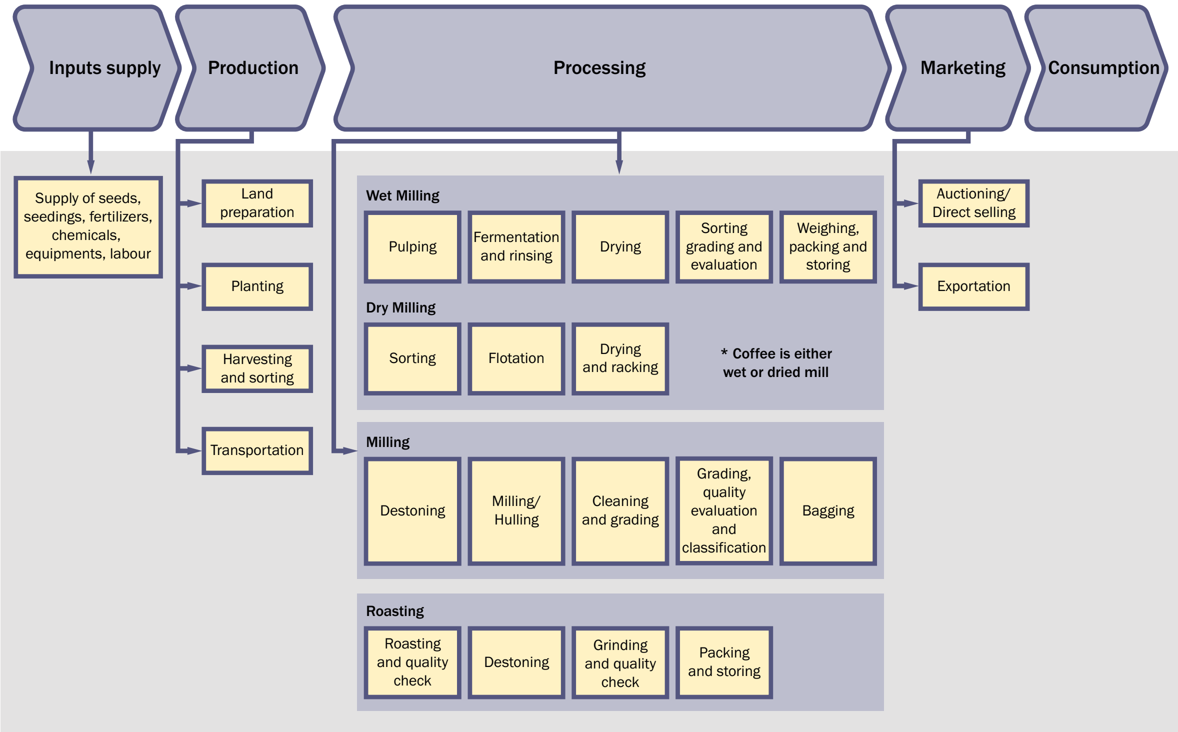
The country relies on a developed coffee logistics hub (which is the main for Eastern Africa) where all the main international coffee traders are represented and has a large pool of coffee expertise, from farming to marketing, logistics, and trading. However, Kenya contributes with a small share to the global coffee market (in 2018 Kenya was ranked as the 25th largest coffee exporter) and it accounts for 11.7% of the African production. In 2018, Kenya exported around 43,000 tons (worth $243 million) of green coffee to 47 destinations, mostly serving the markets of United States, Germany, South Korea, Sweden, and Belgium-Luxembourg (OEC, 2018). Table 1 shows the auction sales prices for the main coffee grades for the coffee year 2017/2018.

Table 1. Auction sales price per coffee grade for coffee year 2017/2018. Source: (Agriculture and Food Authority, 2018)

Coffee Grade	Price ($/50 kg)
AA	345.52
AB	247.17
C	171.48
E	252.52
PB	219.26
T	84.04
TT	155.61

Over 99% of Kenya's coffee is Arabica, which is regarded as a specialty, and it is among the highest rated quality coffee in the world (Bagal, Belletti, Marescotti, & Onori, 2013). Figure 2 shows the main steps of the coffee value chain. The main actors are represented by coffee growers, private sector, international stakeholders and public institution, whereas the Agriculture and Food Authority- Coffee Board of Kenya is the regulatory body and in charge of the sector's development.

Figure 2. Coffee main processes and actors' main activities



Coffee growers are made up of approximately 3,000 estates and around 800,000 smallholders clustered under 500 cooperative societies. On average, smallholder growers account for 75% of the coffee planted land, but only slightly over half of the production while the remaining is under the estates sub-sector (respectively 56% and 44% of the production) (Agriculture and Food Authority, 2018; International Coffee Organization, 2019).

Average national productivity for Arabica coffee in Kenya is estimated around 300 kg/ha of clean coffee for smallholder farms, which is very low compared to average yields for Arabica worldwide (698 kg/ha) and in neighboring countries, such as Rwanda (1160 kg/ha) and Ethiopia (995 kg/ha) (Damianopoulos, 2005; Thuku, G. K., Gachanja, P., & Almadi, 2013). Brazil and Vietnam show average productivity of 1,650 kg/ha and 2,100 kg/ha respectively. This gap may be the result of different factors such as: sub-optimal or obsolete agricultural practices, scarce availability of technical skills and knowledge, limited access to inputs and technologies (such as modern coffee varieties, chemicals, fertilizers, irrigation) and the land size. At the same time, high incidence of pest and diseases, such as coffee berry disease and leaf rust, remains a major issue, affecting cost and yields for most growers in Kenya (and in the region) (International Coffee Organization, 2019; Kenya Coffee Platform, 2018; UNCTAD, 2018)

Access to inputs for coffee growers, such as seeds, seedlings and fertilizers, is facilitated by public institutions (e.g. the Kenya Agricultural and Livestock Research Organization - Coffee Research Institute KALRO – CRI) and licensed suppliers. During the harvesting seasons (April-June and October- December), smallholders usually deliver ripe cherries to the cooperative society for primary processing. Over 90% of Kenya's coffee is processed by the wet method, while the remaining 10% of coffee is dry processed (so-called *mbuni* coffee). The wet processing consists in the removal of the outer layer of coffee cherries, also known as pulping, fermentation, washing, under-water soaking, final washing and grading, skin drying, final drying and conditioning. Estates are generally able to wet-process their coffee at their own facilities. Wet processing has been identified as the most critical stage along the value chain, able to affect the final quality of the product and, in the long run, the sustainability of the whole process. Although, coffee produced by this method is usually regarded as better quality and commands higher prices, therefore contributing to the profitability of the business, on the other hand, as a water-based process, it can result in large water depletion and environmental pollution. Wet-processing waste management usually represents a challenge for the cooperatives, as some of the adopted practices generally include the re-using of the waste water, its drainage into lagoons or the use of the solid waste as manure. Breakdown of recycling machineries, outdated technologies, lack of adequate spaces/land, weather hazards (such as prolonged heavy rains and flooding) and poor waste management knowledge represent an additional risk along the primary coffee processing (Mwangi, R. W., Mwenda, L.K.M., Wachira, A. W., Mburu, 2017).

After the primary processing, parchment coffee is delivered to a commercial dry coffee mill for hulling and grading to finally obtain clean/green bean. Coffee is then marketed either through the Auction System at the Nairobi Coffee

Exchange (NCE) or through the direct sales channel, which account respectively for over 80% and less than 20% of the total marketed coffee. Through the NCE, coffee exporters/ dealers buy coffee for both local and export sales. Coffee marketing agents are contracted by farmers to sell their coffee to the highest bidder in the auction. Licensed producers are also entitled to perform direct sales, but more often commercial marketing agents play as intermediates by drawing up sales agreements and handling other marketing logistics. Growers should be then paid after 14 days from the date of the auction (Adil Suliman Hussain et al., 2020a).

Concerning the roasting and the local market, in 2019, the domestic market counted 25 roasters (whom processed 138,500 bags of coffee), licensed to roast, pack and market the coffee (International Coffee Organization, 2019). Furthermore, the number of coffee shops in Kenya increased from 14 in 2001 to 278 in 2017. The local retail prices of roasted economy coffee in 2017/ 2018 was $2.25 per 500 g, while premium local coffee retailed at $9.18 per 375 g for Java brand, $11.95 to $12.51 per 500 g of AA Blue Mountain and 500 g of Decaf Safari, suprema & Gourmet retailed between $11.25 and $14.01 (Agriculture and Food Authority, 2018).

Coffee roasting is a complex process in which the beans are rapidly brought to high temperatures, causing chemical changes in the beans and bringing out their peculiar delightful aromas, in particular:

- Drying - in which the water content of the beans begins to vaporize, and pressure starts to build up inside the beans;
- The Maillard reaction – this is when the beans start to turn brown and it occurs at around 150°C. At this stage gases including carbon dioxide, water vapor, and some volatile compounds are created. Also, the internal pressure increases enough to break the cell walls of the beans and this event is known as first crack;
- Development – the roast changes from an endothermic to an exothermic reaction and the beans increase in porosity, oils migrate to the cell walls, colour darkens, and a lot of chemical reactions take place (Belchior, 2019).

The flavour and aroma developed during the process represent an additional critical factor to determine the coffee quality (Ruosi et al, 2012). During the process, coffee beans will lose between 17-20% of their weight, thus 100 kg of green beans will provide around 80 kg of roasted coffee (Rosa, 2019). After roasting, coffee goes under a final cleaning, and it is grinded and packed.

However, it appears that the majority of the secondary value addition practices (such as roasting and packaging), occur within the importing countries, as Kenya mostly export semi-processed product (green beans). This results in lower returns, especially for the coffee growers, who receive a limited share of the final coffee cup retail price, estimated about 6-7%. The complex system of intermediaries along the value chain, such as local traders, exporters and retailers, contributes to capture the remaining share of the profit margins, despite the value of the retail sales has more than doubled over the last decades. For this reason, enhancing the value addition of the coffee sector, especially to the advantage of the producers, represents a key challenge for Kenya, as reflected by Vision 2030 and the Agricultural Sector Transformation and Growth Strategy (Government of the Republic of Kenya, 2007). Engaging the cooperatives in secondary processing practices, such as coffee milling, grading, roasting and packing, as well as in direct selling, could attract premium prices, contributing to the livelihoods of the producers and therefore to the sustainability of the entire sector (Wambuimwangi, 2014).

Despite the fact that coffee is still one of the strategic products for Kenyan domestic economy, its role has been downgraded over the last decades. A decrease in Kenyan (and, more in general, African) coffee production and export have been registered over the last 30 years, from 24.4 million bags in 1980 (27% of world share, 1.7 million from Kenya), to 17.4 million bags in 2015 (12% of world share, less than 1 million from Kenya). This decline is due to a downward trend in production, which is expected to drop to a new record low for 2019-2020 in Kenya (around 650,000 bags – 60 kg/bag) as affected by the prolonged drought and low returns. In addition, and similarly to other coffee producing countries, price volatility and significant fluctuations have deterred Kenyan producers and other value chain actors from making the necessary investments for increasing competitiveness, productivity and production (International Coffee Organization, 2019; USDA Foreign Agricultural Service, 2019). Additional aspects affecting competitiveness of coffee industry in Kenya are: the increasing cost of inputs (such as labour and imported fertilizers), the high incidence of pests and diseases, the poor governance of marketing cooperatives, the weak origin branding and labelling and the high risks associated with production and post-harvesting (such as quality deterioration, pilferage, and theft).

Kenyan Government has announced a number of initiatives to revitalize the coffee industry tackling some of the core issues such as: supporting farm expansion, adoption of improved coffee varieties, increasing value addition and the access to farm inputs (including fertilizers), seeking for affordable credit options for coffee growers. These efforts are projected to spur the domestic coffee production over the next five years (International Coffee Organization, 2019).

02 CIVICS Methodological Framework

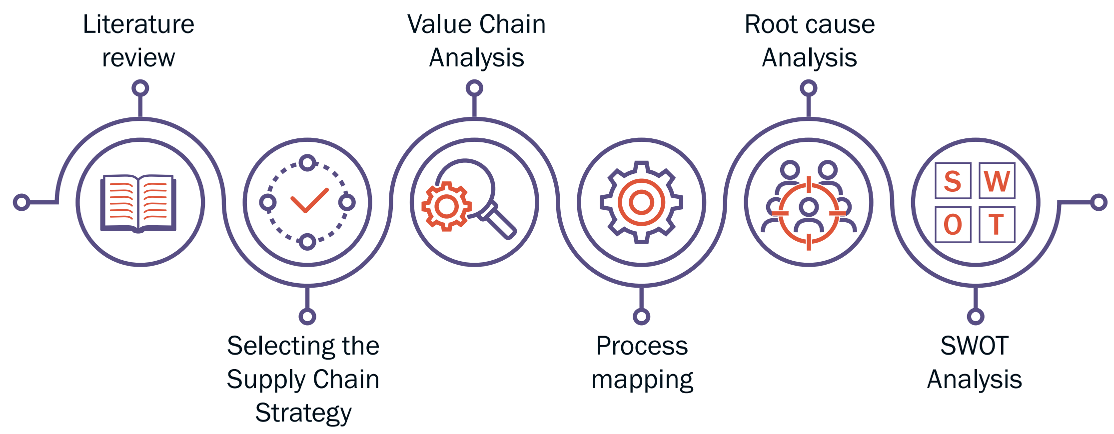
2.1. Supply Chain Analysis

Supply chain analysis is the process of investigating and studying the role and contribution of each economic agent (actors such as producers, traders and consumers, as well as legal entities such as businesses, authorities and development organizations) along a supply chain, that contributes directly to the generation of a final product or service. This activity involves the evaluation of every stage of the supply chain, starting from the raw material or intermediate product acquisition and finishing downstream, after several stages of transformation and increase in value, and the final delivery of the product to the costumer (Adil suliman Hussain et al., 2020b).

The need for such kind of analysis can be easily understood when considering the rise of globalization, which caused global trading to become more common, increasing the role and importance of supply chain management. Global supply chains usually extend between industrialized and developing countries, in which the variation of economy, regulations, legalization and standards pose difficulties in managing the supply chain. Usually, developing countries play the role of raw material suppliers or manufacturers to industrialized countries, due to the widespread lack of know-how and expertise regarding the processing steps of a product. However, they face problems affecting the performance of the supply chain, which include instability of governments and policies, corruption, labour intensive industries, deteriorated infrastructures, limited use of new technologies, underemployment, child labour, and low education level of the population (Galal & Moneim, 2016). Also, the fragmented market on which many supply chains of developing countries are based, alongside with the low access to quality services and information for all the stakeholders of the supply chain (particularly small producers) and the informal economy somehow regulating many steps of the chain, make it difficult to collect precise and accurate information in order to carry out a rigorous study of the supply chain of a specific product.

In order to address this issue, FEEM developed a customized methodological approach to supply chain analysis (Adil Suliman Hussain et al., 2020b), based on the steps shown in Figure 3.

Figure 3. SCA Methodological steps. Source: (Adil Suliman Hussain et al., 2020b).



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 compete 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.

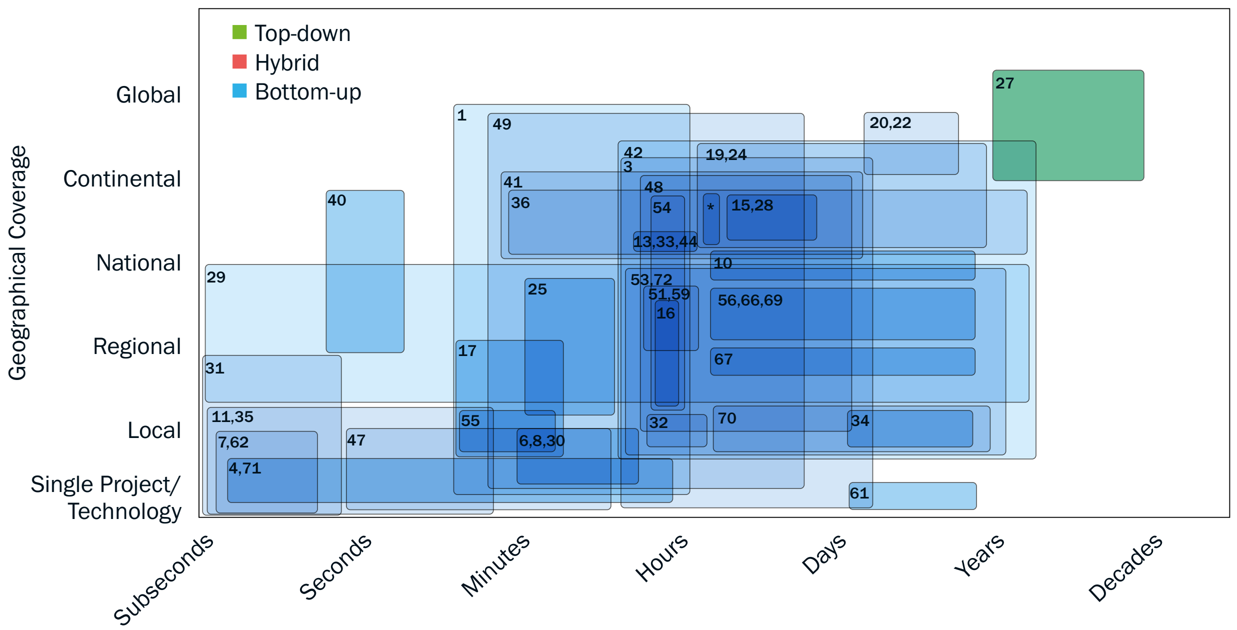
Process mapping is used in conjunction with value chain analysis to provide in depth understanding of specific processes along the supply chain and to support in the identification of bottlenecks. Also, to understand if there are unnecessary, inefficient or duplicated activities in a process. Root cause analysis is utilized to look deeper into problems identified to define and pin down their actual cause/s. Also, to develop countermeasures and implement solutions to fix the problems in processes and systems, so the problems will not appear again. 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 (Adil Suliman Hussain et al., 2020b).

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. Thanks to an accurate and robust literature analysis of the improvement strategies identified, the results of this tools are the first input of the Industrial Ecology model, which will be widely described in the following section.

2.2. Energy System Modelling

Energy system modelling is the practice of building a mathematical representation of a physical energy system, in order to understand its dynamics and reaction to interventions, or future scenarios. It can be summarized as a discipline to support energy policy and long-term strategic energy planning decisions with "insights" generated by "models". The energy system represented can vary in wide range time and space scales, assuming different scopes.

Figure 4. Illustration of geographical coverage vs temporal resolution of different models. Adapted from: (Ringkjøb, Haugan, & Solbrekke, 2018).



In particular, for this work it is possible to narrow the discussion to engineering models for energy systems sizing / investment planning and operation / dispatch optimization. The geographical scope of our modelling will be the national scale, a time horizon of one year and a time resolution of one hour. The interest of the energy modelling phase of this work is to represent the national electricity generation, transmission and distribution system of a country and evaluate its reaction to the studied policies and interventions.

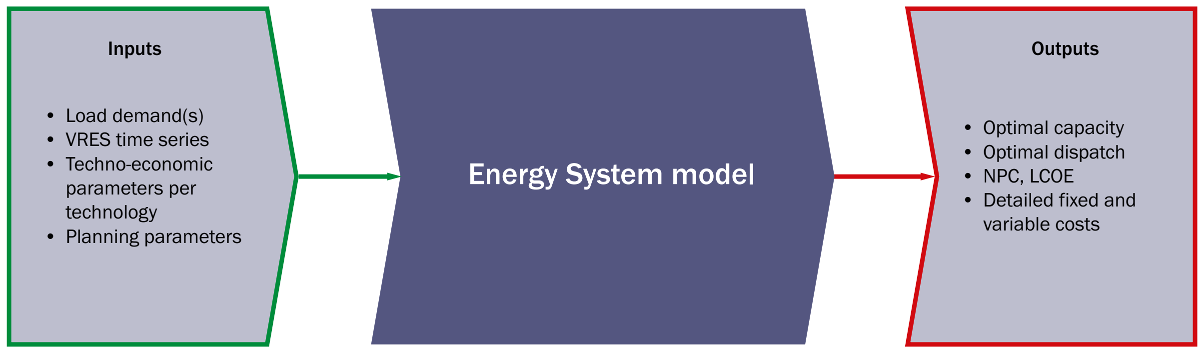
The key characteristics of modern energy models are high spatial and temporal resolution, adaptability to different geographical scales and energy vectors, and high technological detail. These factors determine the ability of the model to better integrate variable renewable energy sources (VRES) in the modelled system, since, unlike fossil fuel-based technologies, these resources are characterized by strong time and space dependency. Being able to characterize hourly availability of solar PV and wind energy availability, or detail the position of these technologies, increases the capability of the model to integrate them into the analysis. The technological detail and the multi-vectoral representation open up for the possibility to model sectors integration, e.g. modelling the penetration of heat pumps or induction cookers in the system to study the deployment of “power-to-heat” policies. Electric vehicles and hydrogen production plants are other examples of technologies that allow the study of sector coupling practices.

Last but not less important, among the issues of energy models is the theme of openness (Pfenninger et al., 2018). It is widely recognized that releasing the models with open licenses makes them verifiable, and hence, more trustable. “Black-box simulations cannot be verified, discussed or challenged” (Pfenninger, 2017) and hinder the reliability of the public policies built on them. Furthermore, in opposition to proprietary, and often expensive, software, difficult for developing economies to afford, open source is free to use, increasing the possibility for developing countries ownership and empowerment programs.

2.2.1. Behind the scenes of Energy Modelling

Most engineering bottom-up energy models are optimization models, typically minimizing the cost of investment and/or operation of the system, defined objective function, subject to a set of techno-economic constraints.

Figure 5. Typical logical framework of an energy system model.



The majority of models adopt a Linear Programming (LP) formulation; LP optimization is a deterministic optimization method that allows finding the exact absolute optimum solution within the given domain. Optimization models can be exploited to identify a preferred mix of technologies, given a set of constraints, in order to achieve a specific target and obtain the theoretically optimal solution, assuming that real-world decisions are made according to its objective function.

The standard set of constraints, which the optimization of an energy model is subject to, is:

Power and Energy Balance:

Energy Demand = Energy Produced – Energy to Storage + Energy from Storage – Energy Curtailed + Unmet Demand

At each timestep, in every region. Globally and yearly.

Technological Constraints:

Energy from Ren Sources = Energy Availability x Number of Generators x Inverter Efficiency

Energy from Fossil Fuels < Generator Nominal Capacity x TimeStep

At each timestep, in every region.

Economical Constraints:

Cost = Capital Cost + Operating Cost – Salvage Value

Policy Constraints: can assume different forms, from an emission cap, an assigned cost to an emission, maximum or minimum capacity of a particular technology in a particular year of region, maximum or minimum investment on a particular technology in a particular year of region, among others. It can basically consist in any kind of constraint, which in turn is the result of a policy or an intervention that is intended to be studied on the modelled system.

2.2.2. Calliope Modelling Framework

In particular, the selected modelling framework is the open-source software Calliope (Pfenninger & Pickering, 2018), a "linear programming framework for spatial–temporal energy system optimization" (Pfenninger & Keirstead, 2015). The framework allows for a 1-year time-horizon, works with 1-hour timestep and is based on the power nodes model, meaning that the geographical resolution of the model is left to the modeller depending on the specific needs, creating a power node, where energy can be produced, consumed and transferred from one another. The advantage of being able to customize the modelled power nodes is that the geographical scope and resolution representable with the framework is completely up the necessities of the modeller, and are able to adapt to the availability of data, often a critical aspect when modelling systems in developing economies.

In order to build a model in Calliope, four main objects need to be defined:

- **Technology:** a technology that produces, consumes, converts or transports energy;
- **Location:** a site which can contain multiple technologies and which may contain other locations for energy balancing purposes, the abovementioned nodes;
- **Resource:** a source or sink of energy that can (or must) be used by a technology to introduce into or remove energy from the system;
- **Carrier:** an energy carrier that groups technologies together into the same network, for example electricity or heat.

Once the physical system has been characterized through these elements, the machine will optimize the operation of the energy system in order to satisfy the energy demand(s) with the available technologies, at the minimum cost.

For more detailed information about Calliope, see (https://calliope.readthedocs.io/en/stable/).

2.3. Input Output Analysis

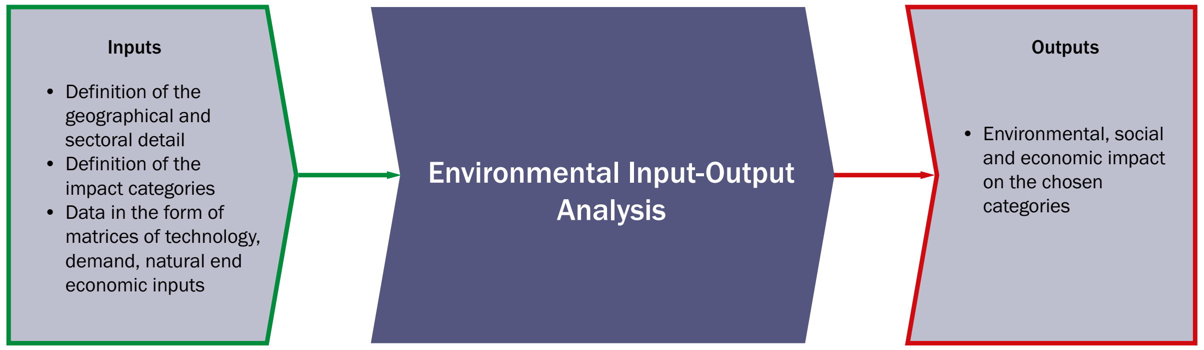
Industrial Ecology is the multidisciplinary field of knowledge that studies the behaviour of complex integrated human/natural systems (Shenoy, 2015). There are many possible methodologies among the analytical tools offered by Industrial Ecology. Nevertheless, IOA represents the most suitable and comprehensive methodology for evaluating a structural change in a determined supply chain while considering at the same time the implication on the complex network of interlinkages among different economic sectors.

IOA refers to macroeconomic analysis approach based on the study of the sectoral interrelations of an economy (Miller & Blair, 2009). This type of economic analysis was developed by the Nobel Prize for Economics in 1973 (Leontief, 1974) and today represents one of the most widely used methodologies for assessing policy evaluation, both in terms of economic and environmental impact (Palazzo, Geyer, & Suh, 2020).

IOA requires the use of input-output tables, economic-wide databases able to capture the flows of monetary value between different sectors, while accounting for economic factor (i.e. capital, labour and taxes) use and, when the table is "environmentally extended", natural resource interactions (e.g. carbon emissions, water withdrawal). It is possible to limit the analysis to only one country or to include explicitly the technology of commercial partners. The former case is labelled as single-region input-output analysis (SRIO), while the latter is called multi-regional input-output analysis (MRIO). The renewed interest in assessing the environmental impacts of human activities has led to the development of increasingly rich MRIO databases capable of describing the relationship between the economic and the environmental dimensions with a global perspective (Lenzen, Moran,Kanemoto, & Geschke, 2013; Stadler et al., 2018; Timmer et al., 2012), with the first attempts to depict sectoral interrelations in physical units (Merciai & Schmidt, 2018).

Nevertheless, the regional detail of these databases is still far from representing developing regions – such as sub-Saharan countries – in detail. For this reason, in these cases a SRIO approach should be used. This kind of models on average guarantee greater detail in terms of commodities (i.e. products) and economic activities (i.e. industries), taking advantage, if data are available, of the so-called Supply and Use framework, although they do not offer the possibility of detailing interactions taking place out of the analysed economy.

Figure 6. Typical logical framework of an environmental input-output model



2.3.1. The Supply and Use framework

As it has been shown by Lenzen, the framework offered by Supply and Use Tables (SUT) could be adopted to directly perform impact analysis (Lenzen & Rueda-Cantuche, 2012). Actually, the SUT formulation can improve the incorporation of environmental extensions data into input-output models, by offering both industry and product representation.

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 1, here shown:

1

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

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

Where:

- I_c and I_a are two row summation sub-vectors, one for commodity (c) and one for activities (a);
- Yc 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 represented economy by means of coefficients which are showing the following: from one hand how much inputs of commodity are required to produce one unit of industrial activity (u) and, 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 divided by 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 2, as already anticipated in equation 1.

2*

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

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

2.3.2. Modelling technological intervention

The model adopted in the present research is a demand driven SUT input-output model. Therefore, it is assumed that a certain amount of final demand must be delivered and the economic structure (represented by the above explained matrices) must provide the required quantities of commodities. In this framework it is possible to assume a change in a specific interrelation between two economic activities of a supply chain by intervening on a specific coefficient. Nevertheless, it must be considered that, even if for some extent the structure of the economy may slightly change without exogenous intervention (e.g. an abundant harvest because of favourable weather for a certain year) no major technological change comes spontaneously.

Since the objective of the present work is to evaluate the impact of a technological change related to both implementation and use, it is required to distinguish every intervention by two steps. In both cases, there will be an impact in both socio-economic factors (linked with production through the matrix of monetary exogenous coefficients f) and environmental extensions (linked with production through the matrix of physical exogenous coefficients e), respectively F and E.

- Investment assessment: in this step it is required to characterize all the commodities needed to have the technology produced and installed (e.g. the cost of machinery and the required training course). From a modelling point of view, this will be translated by simply adding the required commodities in the final demand vector (see equations 3). The investment will be handled, as shown in equation 3, with the current technology assessment (no subscripts identify baseline data, while subscript i identifies investment data);
- Operation assessment: in this step it is required to describe all the cross-sectoral changes which are occurring due to the installed technology (see equations 4). The structural change in operation will be influenced, as shown in equation 4, by how the baseline final demand is delivered (subscript o identifies data after implementation of the intervention). These changes may be translated in the model in the following ways:

  - Change in the use coefficients matrix (u): a specific coefficient of the u matrix may reflect a change in how much input of a certain commodity is required for one unit of output (e.g. a machinery, not used in the baseline, will directly increase the consumption of diesel in a certain sector);

- Change in the satellite account coefficients matrices (f and e): both in the economic factor and environmental extension matrix a change in a specific coefficient may occur (e.g. a machinery, not used in the baseline, will directly emit an additional amount of CO_2 emissions in a certain sector);
- Change in the market share matrix (v): the share of the market of a specific activity for a specific commodity is representing how much of each activity is required every time a certain commodity is demanded. Therefore, in a demand-driven model as the one here employed, a change in the v matrix could be used to model change in productivity of a specific activity (e.g. the productivity of coffee sector increases because of the introduced technology). In fact, productivity is how much output is produced for each unit of input, or, in the case of a demand-driven model, how much input you need to deliver the same output.

In the case of a change in a unit of industrial output 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. It is therefore 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.

3

$$\Delta \underline{\underline{F_i}} = \underline{\underline{f}}\,[\overbrace{(\underline{\underline{I}} - \underline{\underline{z}})^{-1}\,\underline{Y_i}}^{X_i}] - \underline{\underline{f}}\,[\overbrace{(\underline{\underline{I}} - \underline{\underline{z}})^{-1}\,\underline{Y}}^{X}]$$

$$\Delta \underline{\underline{E_i}} = \underline{\underline{e}}\,[(\underline{\underline{I}} - \underline{\underline{z}})^{-1}\underline{Y_i}] - \underline{\underline{e}}\,[(\underline{\underline{I}} - \underline{\underline{z}})^{-1}\,\underline{Y}]$$

4

$$\Delta \underline{\underline{F_o}} = \underline{\underline{f_o}}\,[\overbrace{(\underline{\underline{I}} - \underline{\underline{z_o}})^{-1}\,\underline{Y}}^{X_o}] - \underline{\underline{f}}\,[\overbrace{(\underline{\underline{I}} - \underline{\underline{z}})^{-1}\,\underline{Y}}^{X}]$$

$$\Delta \underline{\underline{E_o}} = \underline{\underline{e_o}}\,[(\underline{\underline{I}} - \underline{\underline{z_o}})^{-1}\underline{Y}] - \underline{\underline{e}}\,[(\underline{\underline{I}} - \underline{\underline{z}})^{-1}\,\underline{Y}]$$

2.3.3. Evaluating and comparing interventions within the CIVICS framework

The scope of the CIVICS framework is to assess economic development opportunities in a specific socio-economic context from a country perspective. At the same time, it is possible to assess how these opportunities are configured with respect to national environmental objectives. To do so, it is required to evaluate the opportunities pointed out by the SCA, adopting the same analytical criteria. In this sense, the approach should be seen as a way to coherently compare investment opportunities within the same limiting modelling assumptions. In particular, it is of crucial importance to clearly define what is the main indicator that drives the choices between the set of investment opportunities.

Each opportunity is identified by a possible technological intervention. This intervention has an impact which is not limited to the sector in which the direct changes take place, but also on the interlinked activities. In real life, these changes occur while many other interrelated activities change in magnitude or in needed inputs mix. Nevertheless, since it is not possible to take these changes into account neither is it coherent to assess the impact of a change while considering also non-related effects, it is the case to take advantage of a modelling framework. The model is a representation of an approximated reality where it is possible to isolate the effect of each specific intervention.

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?".

If an intervention is beneficial in reducing the amount of input required for delivering the same products and services that were produced and delivered in the baseline case, this means that the intervention can unleash the potential for e.g. expanding the production, increasing the wages or improving the margins. Since it is not possible to evaluate the potential effects of these possible political choices, it is preferred to build up a general economic indicator which considers the total savings triggered by each intervention with respect to level of investment that is required to experience the benefits.

The name of indicator is *policy return on investment* (PRoI) and represents the expected yearly economic return on the investment from a national perspective, considering all the direct and indirect implication of changing the sectoral interdependencies as requested by the intervention. The yearly economic return embodies not only the savings in the form of economic factors from the sector where the intervention occurs (e.g. being more productive leads to using less capital land per unit of output) but also in the form of avoided import (e.g. the new configuration implies a self-production of an organic fuel that replaces a fraction of the imported oil) and avoided internal input request (e.g. trees are introduced for their shading potential but they also produce locally-consumed fruit as a by-product which substitute a fraction of bought food).

5

$$PRoI = \frac{Savings_o\ [M\$/y]}{Investment_i\ [M\$]} = PPBT^{-1}$$

The inverse of PRoI is the *policy pay-back time* (PPBT) and represents the number of years needed to pay-back the investment faced. It should be underlined that this pay-back time must not be compared with entrepreneur level payback time, which is based on an individual perspective.

PRoI or PPBT are therefore used as a general economic indicator that reports the level of increase in economic efficiency of the country involved in each intervention. Of course, there are many other possible indicators that can influence the choice between taking the investment opportunity or not. For example, one can be interested by the amount of carbon emission that will be saved every year, the amount of blue-water that could be adopted for other purposes, the amount of labour by skill that would be induced by the investment. All these indicators are case-specific, since for each policy different indicators become relevant.

Clearly, for sake of consistent comparison, each of these indicators should be referred on the basis of the same functional unit, which could be, as a general rule, the same level of investment (e.g. $1 million) (Arzoumanidis, D'Eusanio, Raggi, & Petti, 2020). In this way it becomes possible to coherently compare interventions within a coherent approach on the basis of the same functional unit, providing useful insights for policymakers for each relevant dimension. Indeed, it is possible to build one indicator for every appropriate SDG. This application of CIVICS is called *Multi-Criteria Analysis*.

Furthermore, this approach could be further extended adopting linear programming, which can serve as a *Policy Goal* application of CIVICS. In fact, assuming linearity between investment level and savings (see equation 5), therefore neglecting possible non-linear dependencies between the magnitude of the intervention and the relative costs and benefits, it is possible to build an optimization problem shaped on policy-maker objectives. For example, as it can be seen by the set of inequalities in 5, it is possible to have a mix (mix) of intervention expressed in millions of investment that meets budget constraint and social and environmental objective while minimizing the amount of input required to deliver the same final demand (i.e. maximizing savings).

5

$$Max\left(\underline{mix}^T\ \underline{PRoI}\right)$$
$$\text{s.t.}\ \ \underline{mix}^T\ \underline{1} \leq Budget$$
$$\underline{mix}^T\ \underline{i_j} \geq Minimum\_social\_or\_environmental\_objective_j \quad \forall j$$

Where i represents the net intensity change expected with respect to social or environmental objective j. Note that, all the underlined variables are vectors with dimension as big as the number of possible interventions.

The results of these optimization can work as a compass for policymakers as it will be shown in Chapter 4 for the case study of coffee in Kenya.

3. Application of the CIVICS framework: the coffee sector in Kenya

3.1. Supply Chain Analysis in Coffee Kenya

Despite the decrease in coffee production and exports, local policies are concerned about supporting the coffee industry. As previously mentioned, the reasons behind this decrease in productivity and competitiveness are various and they can be summarized in two categories:

- Exogenous reasons, linked to a global decline in coffee prices over the last 40 years;
- Endogenous reasons, that can be associated to the poor management and governance of the cooperative system, the very low internal consumption, poor productivity and innovation.

In order to identify the root causes of the endogenous reasons, a supply chain analysis was carried out (Adil Suliman Hussain et al., 2020a) to identify possible interventions along the supply chain in order to improve productivity, innovation and competitiveness, by identifying gaps and opportunities, addressing production phase bottlenecks and the needs of different stakeholders.

Interventions to improve agronomic practices and the sustainable intensification of coffee plantations, to improve the sustainability and the value addition of the supply chain have been proposed, in particular:

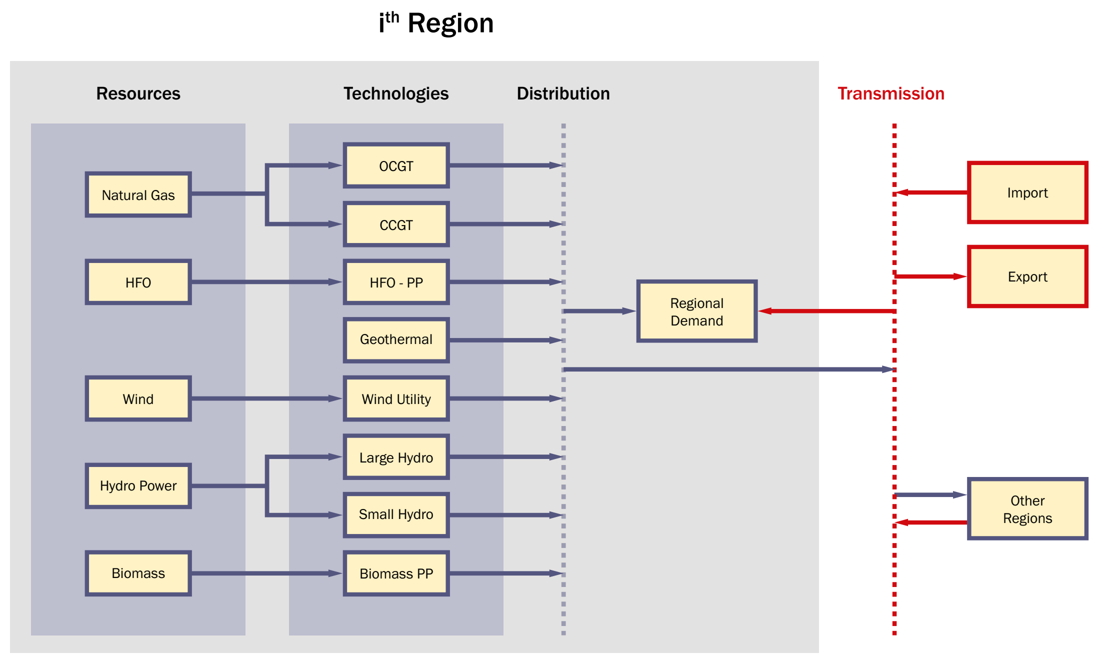
- Shading management via trees in coffee plantations;
- Shading management via shading nets in coffee nurseries;
- Innovative water-saving pulping machineries for the wet milling process (so-called eco-pulper);
- Implementation of the roasting process as a secondary processing value addition practice;
- Exploiting coffee wet-processing waste as a source of biomass for energy and fertilizer production.

All these interventions have been contextualized considering Kenya specific background situation, whether they have been already implemented or not in similar cases and already existing technologies easily available, in order to provide a set of realistic interventions. Furthermore, since the lowest level of coffee productivity is observed within smallholder production, all the interventions have been modelled as if they took place at rural cooperative level.

3.2. Energy System Modelling in Kenya

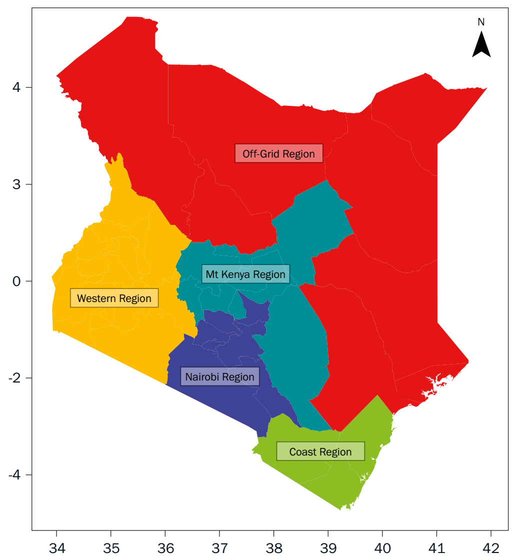
In order to build a model of the Kenyan National Electricity System the first step is to understand the reference energy system that has to be modelled. That is done according to the accuracy of available data. Figure 7 reports the structure of the reference energy system.

Figure 7. Reference Energy System.



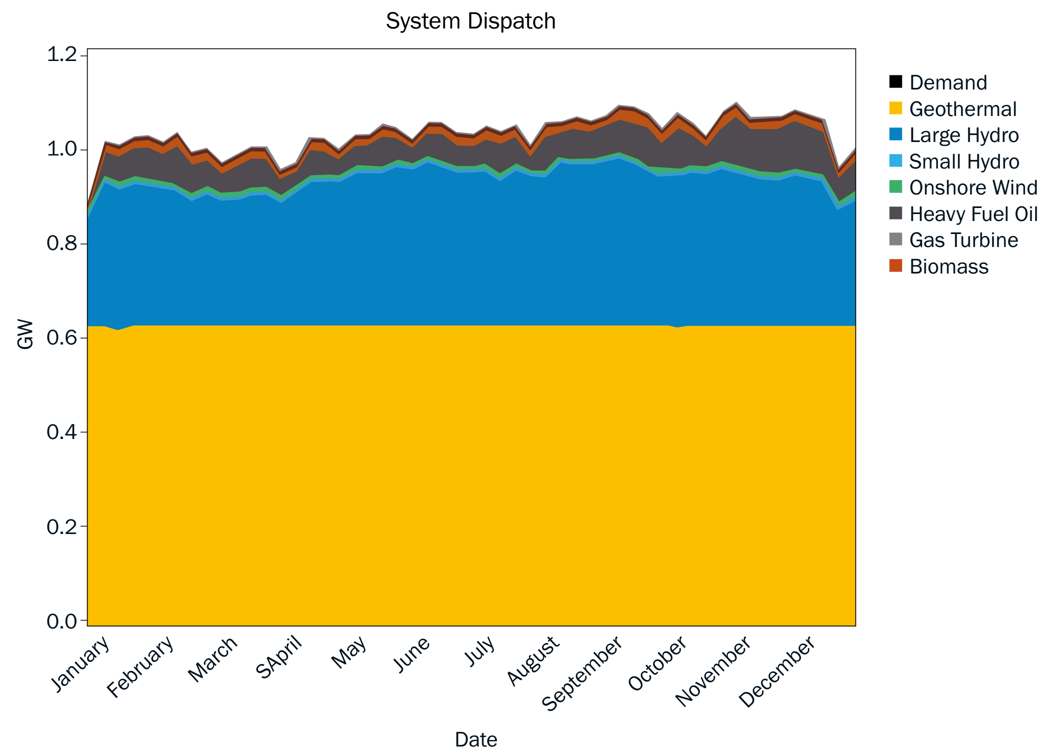
Thanks to a field campaign conducted in 2019, during which several Kenyan stakeholders from the energy sector where interviewed, it was possible to obtain several information keys for the model characterization. A detailed list of the power plants operating in the country and connected to the national 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 8. For the list of modelled power plants, see Appendix A - Table A 1.

Figure 8. Regions of the electricity market of Kenya. Western Region (WSTR), Mount Kenya Region (MTKR), Nairobi Region (NBOR), Coast Region (CSTR).



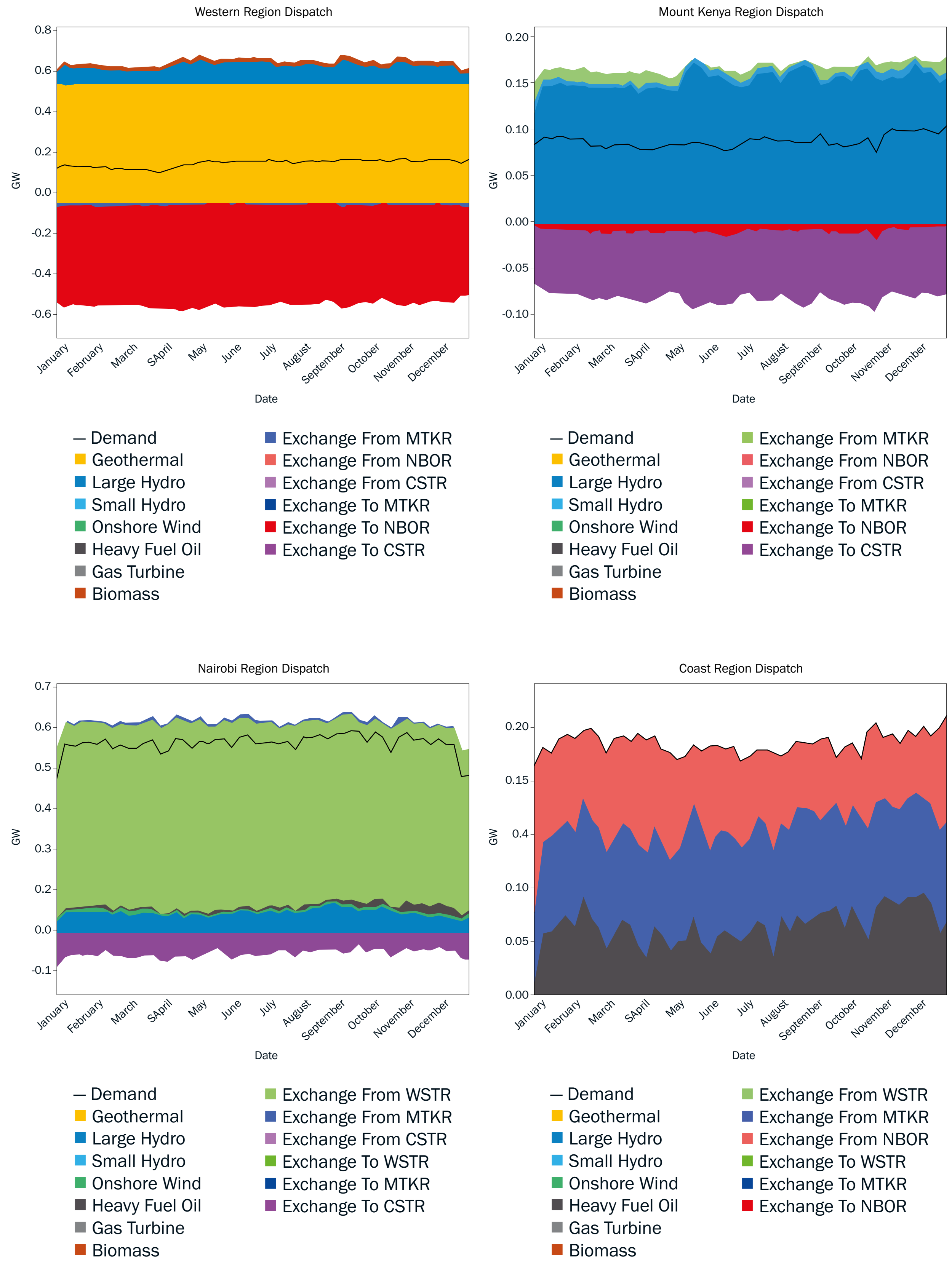
Once the model is built, having characterized the power production technologies, the transmission technologies and the load demand curve of the country, the dispatch strategy is optimized per every hour. Figure 9 shows the overall output of the model in form of generated electricity by source over the entire year.

Figure 9. Electricity dispatch by source. Model Output.



The multi-node nature of the model allows for a deeper analysis of the results. In Figure 10 the optimized dispatch strategies are reported for each of the four regions. In addition to the previous representation of the results, it 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. Moreover, it is possible to observe how the Western Region (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 10. Electricity dispatch by source, per region. Model Output. Western Region (WSTR), Mount Kenya Region (MTKR), Nairobi Region (NBOR), Coast Region (CSTR).



3.3. Input-Output in Kenya

In order to model Kenya's 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, Boulanger, Dudu, Ferrari, & Mcdonald, 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 the 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 11, which is a modified version of Figure 7 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, Ferrari, & McDonald, 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.

Figure 11. 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.

	Commodities	Margins	Activities	Factors	Households	Enterprises/ Corporations	Government	Savings-Investment	Rest of the Word	*Total*
Commodities (C)		$T_{C,M}$ Transaction costs (trade / transport)	$T_{C,A}$ Intermediate (inputs) consumption		$T_{C,H}$ Household consumption		$T_{C,GA}$ Government expenditure	$T_{C,S\text{-}I}$ 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 corporation income to households	$T_{H,G}$ Government transfer to households		$T_{H,RoW}$ Transfers to Households from RoW	*Household income*
Enterprises/ Corporations (E)				$T_{E,F}$ Factor income distribution to enterprises			$T_{E,F}$ Government transfer 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 / Transfer to Government	$T_{G,E}$ Direct Enterprise taxes / Transfer to Government			$T_{G,RoW}$ Transfers to Government from RoW	*Government income*
Savings-Investment (S-I)				($T_{S\text{-}I,F}$) *(Depreciation)*	$T_{S\text{-}I,H}$ Household savings	$T_{S\text{-}I,E}$ Enterprise savings	$T_{S\text{-}I,G}$ Government savings	($T_{S\text{-}I,S\text{-}I}$) *(Capital account transfers)*	$T_{S\text{-}I,RoW}$ Capital transfers from RoW (Balance of Payment)	*Savings*
Rest of the Word (RoW)	$T_{RoW,C}$ Imports			$T_{RoW,F}$ Factor income distribution to RoW	$T_{RoW,H}$ Household transfers to RoW	$T_{RoW,E}$ Corporation income to RoW	$T_{RoW,G}$ Government transfers to RoW			*Payment to RoW*
Total	*Supply*	*Margins*	*Costs of production activities*	*Expenditure on factors*	*Household expenditure*	*Enterprise expenditure*	*Government expenditure*	*Investment*	*Income from RoW*	

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

	Commodities	Activities	Cathegory
Commodities		*Use*	*Final demand*
Activities	*Supply*		
Regions	*Import*		
Factors	*Economic factors*		
Extensions		*Environmental extensions (physical)*	

04 Results

As mentioned in section 3.1, the first result of the application of the CIVICS framework has been the identification of some possible interventions, for the coffee supply chain, with the goal of improving the overall value chain efficiency and sustainability. These interventions have been hypothesized on the basis of either supply chain stakeholders' inputs or supply chain analysis. They represent the input data for the other models of the framework, and are summarized in the following terms: shading management via shading nets in coffee nurseries (shading nets); shading management via trees in coffee plantations (shading nets); innovative water-saving pulping machineries for the wet milling process (eco-pulpers); exploiting coffee wet-processing waste as a source of biomass for energy and fertilizer production (coffee biomass); implementation of the roasting process as a secondary processing value addition practice (coffee roasting).

The methodological framework offered by CIVICS allows policymakers to orient themselves on the basis of the same modelling approach which, although being only a partial representation of reality, offers the same interpretative rules for all the interventions compared.

The set of interventions which came out of the Supply Chain Analysis, except for the intervention concerning coffee roasting, have been analyzed and compared in the section 4.1. on the basis of the same methodological approach, which is the one presented in chapter 2. In fact, the introduction of a new sector and commodity requires to overcome the underlying assumptions, requiring the hypothesis of a new output of the economy, in the form of a different final demand. The authors invite the reader to section 4.2. for further considerations on this intervention and the others.

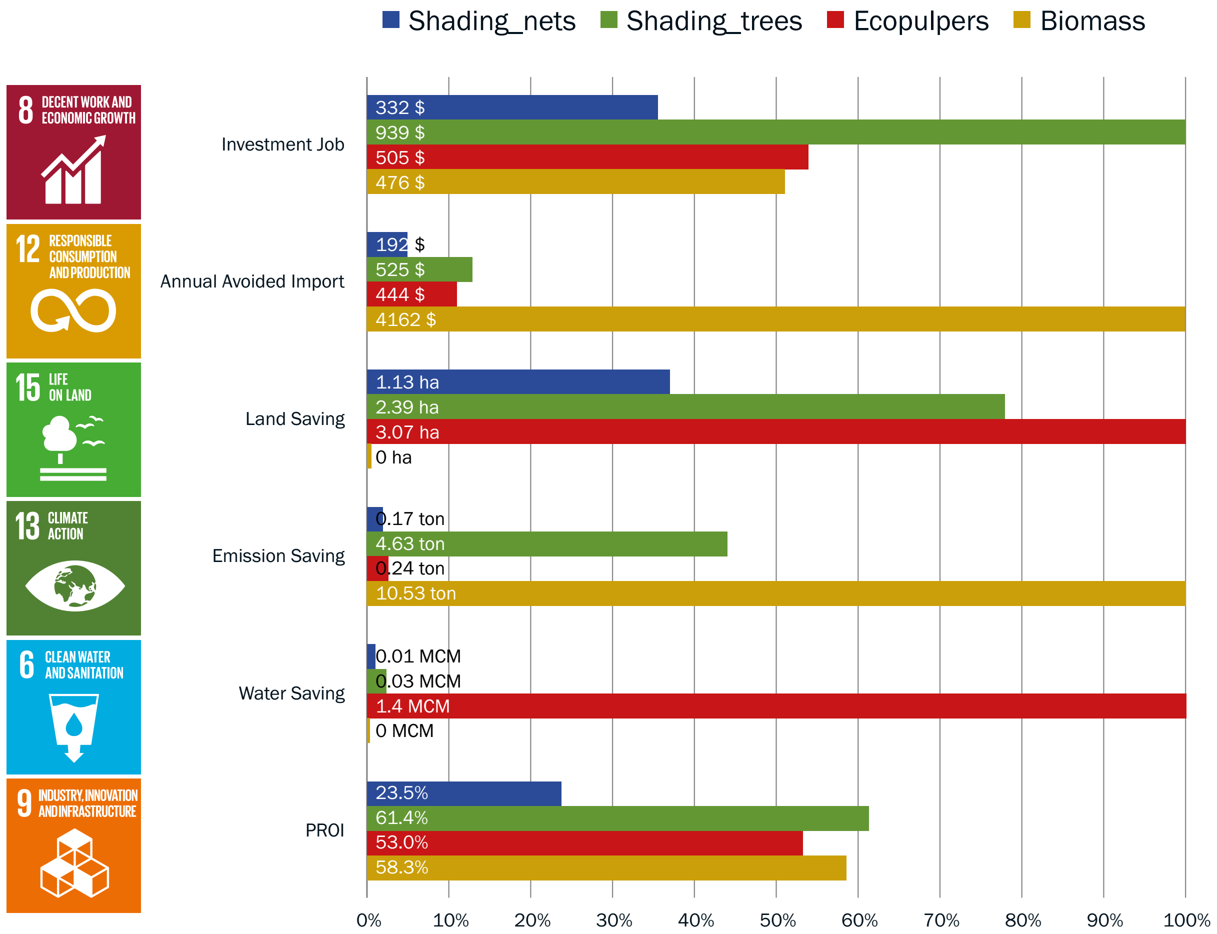
4.1. Comparative analysis

In order to guarantee a coherent comparative analysis, the proposed changes in the productive process of coffee in Kenya required the same functional unit. A functional unit is a quantified description of the function of a product or service that serves as the reference basis for all calculations regarding impact assessment (Arzoumanidis, D'Eusanio, Raggi, & Petti, 2020). In this case, adopting the perspective of a policy-maker which has interest in innovating the coffee sector while increasing the overall efficiency of the national economy, the effects of investments should be weighted and compared on the same level of spending in the interventions. In particular, the same investment level adopted for the analysis is 1 million Ksh, the local currency, corresponding to approximately $9,000.

Within this modelling structure, assuming a policy goal and a set of implementation strategies, it is possible to adopt the two applications of the CIVICS framework, depicted in chapter 2.3.3.

- *Multi-Criteria Analysis*: evaluate the impact of different interventions and create a set of comparable and case-specific indices. In the present case the focus is on 6 indicators which are connected to as many SDGs.
- *Policy Goal*: find an optimised mix of strategies which is complaint to the policy-maker main concern while respecting other policy objective. For this specific case study, a budget constraint of $100 million is set. In this case the maximization of the savings of economic production factors is first compared in the absence of further constraints and then subjected to a constraint on green-water savings and reduction of CO_2 emissions.

Figure 13. Comparison between SDG-oriented indices represented the net gain from every intervention assuming the same level of investment (i.e. 1 million Ksh corresponding to nearly $9,000) in average scenarios. For the first 5 indicators 100% correspond the highest value among the considered options, while for PRoI is expressed as a percentage of savings with respect to the investment.



For what concerns the *Multi-Criteria Analysis*, Figure 13 represents an exhaustive summary of the comparative analysis. Investment jobs represent the amount of additional labour, by means of required wages expenditure for $9,000 of investment. Introducing shading trees would represent a positive increase in local labour impact. This could have desirable effects in getting closer to the objective depicted by SDG 8, introducing positive conditions to enable economic growth and decent jobs. Being more resilient to external shocks can play a role in increasing economic conditions but is not easy to put in practise when the considered economy is largely dependent on import of crucial commodities (e.g. petroleum). The biomass intervention permits to decrease the dependence on imported products, own-producing a non-negligible share of them. Furthermore, extracting value from an otherwise unexploited resource, such as coffee wastes, positively influence responsible production and consumption as suggested by SDG 12. SDGs 15, 13 and 6 are here associated respectively to land, carbon dioxide and water reduction. For what concerns land there are not direct changes, but effects connected to a different use of resources for delivering the same amount of goods. Instead, carbon emissions are importantly reduced due to the shift in electricity mixed (from heavy oil to biomass combustion). Water savings are extremely relevant when wet mills are substituted by eco-pulpers. Finally, the PRoI is reported as a valuable indicator of SDG 9 since technological progress, a key to finding lasting solutions to both economic and environmental challenges, can facilitate sustainable development by means of infrastructural change in the overall economic efficiency.

In such a context the ranking of priority could be shaped on the indicators, in order to build an analytic hierarchy process. In particular, a system of weights, with a pre-defined mathematical set of rules and meanings, could nudge policymakers toward less subjective choices.

For what concerns the *Policy Goal* application of the CIVICS framework, a budget has been set allowing investments among the selected interventions, but the result may change if environmental objectives are introduced.

Figure 14. Graphical representation of Policy Goal investment choices when only budget and physical limits constraint the problem.

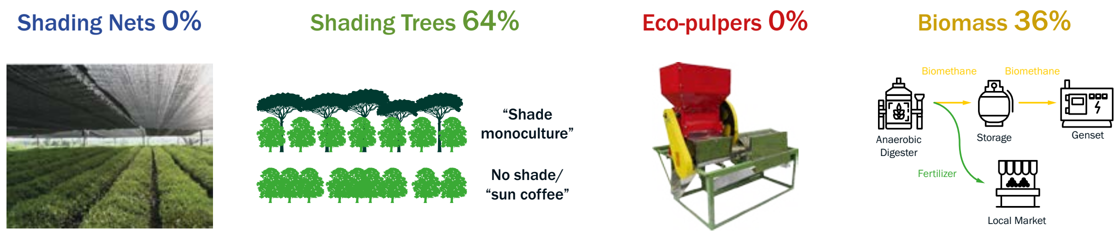
Policy Goal

Maximising Policy Return

$Max\ (PROI_1X_1 + PROI_2X_2 + PROI_3X_3 + PROI_4X_4)$

Constraints

- **Budget** constraints (i.e. we cannot invest more than X M$ - 100 M$ in our case)
- **Physical** constraints (i.e. land devoted to coffee is constant)



You cannot cover more than the available coffee plant

You cannot substitute more than the available coffee wet mills

You cannot use more than the available coffee biomass

Together with budget and other objective-oriented constrained, physical implementation limits should be considered when designing the optimization model. In particular, it is not possible to cover more than the coffee plantation in place in the considered baseline economy, substituting more than the wet mills in place or exploiting more than the biomass produced from coffee processing.

Figure 14 shows the choices of the model without considering environmental objective. Here the logic is straightforward: the only limits of the model are represented by physical boundaries, otherwise it would select only the intervention with the highest PRoI. But since it is not possible to cover with trees more than the coffee plants, the budget is invested also in the second most profitable intervention (i.e. biomass plant).

Figure 15. Graphical representation of Policy Goal investment choices when also environmental constraints are introduced.

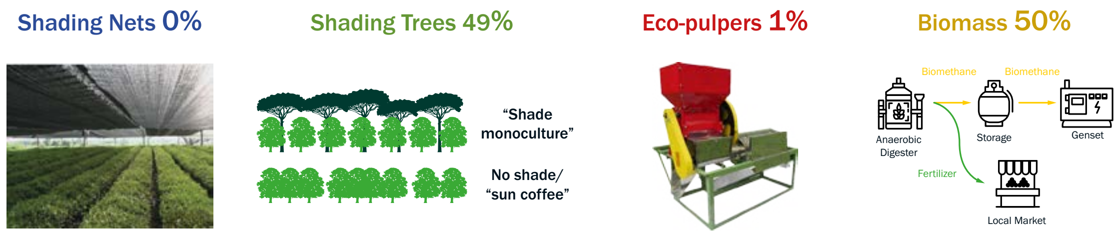
Policy Goal

Maximising Policy Return

$Max\ (PROI_1X_1 + PROI_2X_2 + PROI_3X_3 + PROI_4X_4)$

Constraints

- **Budget** constraints
- **Physical** constraints
- **Environmental** constraints



Covering all the coffee plant with banana trees

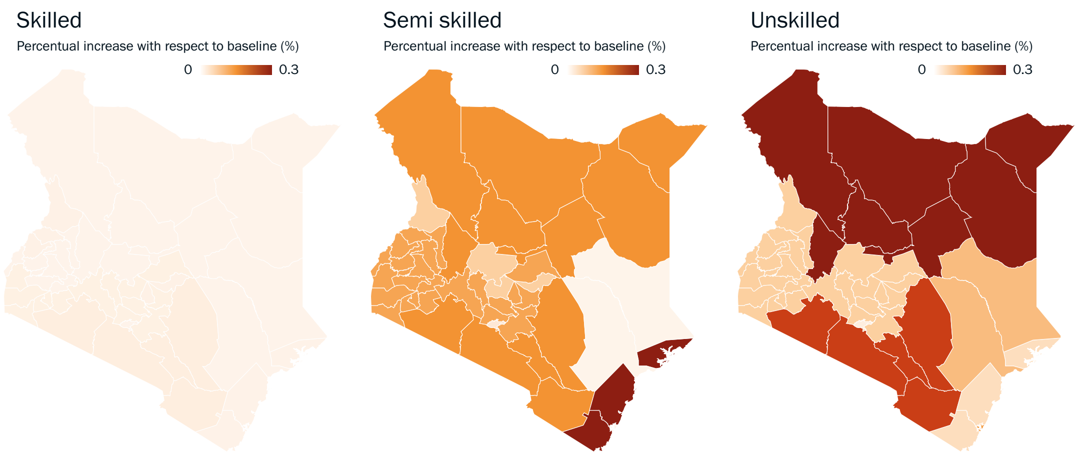
Renewing 40% of the wet mills

Using all the available coffee biomass with 17 biomass power plants of 1 MW

The introduction of environmental constraints, specifically in the form of a minimum annual saving with respect to the baseline of 80 kton of CO_2 and 340 Mm^3 per year, slightly modify the intervention choices. Now all the biomass potential is exploited in order to reach the carbon reduction objective; similarly, the desired reduction of water can be reached only by adding eco-pulpers into the interventions mix. The selected mix of intervention can be performed simultaneously and the combined results of the changes introduced by the new technologies and practices can diverge from the linear behaviour assumed for finding the optimal mix.

An example of the combined effect of the intervention is represented by the employment consequences by skill level driven by the investment of the $100 million budget if allocated as proposed by the optimization with *Policy Goal* that includes environmental aspects.

Figure 16. Labor induced by all the $100 million mix of interventions by skill level and region.



Investments in the coffee sectors trigger labour increase in other sectors all over Kenya but the main change is associated with increase in demand for low-skill workers in the North area of the country.

The employment effects generated by the investment are only one of the possible variables of interest to the policymaker. Each intervention has its peculiarities and must be contextualized with respect to the state of the art of each technology and the contingent needs detected in Kenya.

4.2. Results by intervention

In this section the detailed results for each intervention are presented, starting from the result proposed by the optimization constrained to environmental objectives presented above. For the intervention of shading nets, not selected by the optimization, the results reported refer to the same coverage proposed using shading trees. The case of roasting, is not included in the comparative analysis for different model design premises, is presented assuming to export 1/5 of the green coffee exported in the baseline as roasted.

Every section is introduced by a general overview of the state of the art of the technology or practise considered, with a focus on the Kenyan context.

In order to have a clear reading of charts, it must be recalled that, as discussed in section 3, the interventions took place within the smallholder cooperatives, identified by the economic activity *COOPERATIVES*, and not in the coffee estates.

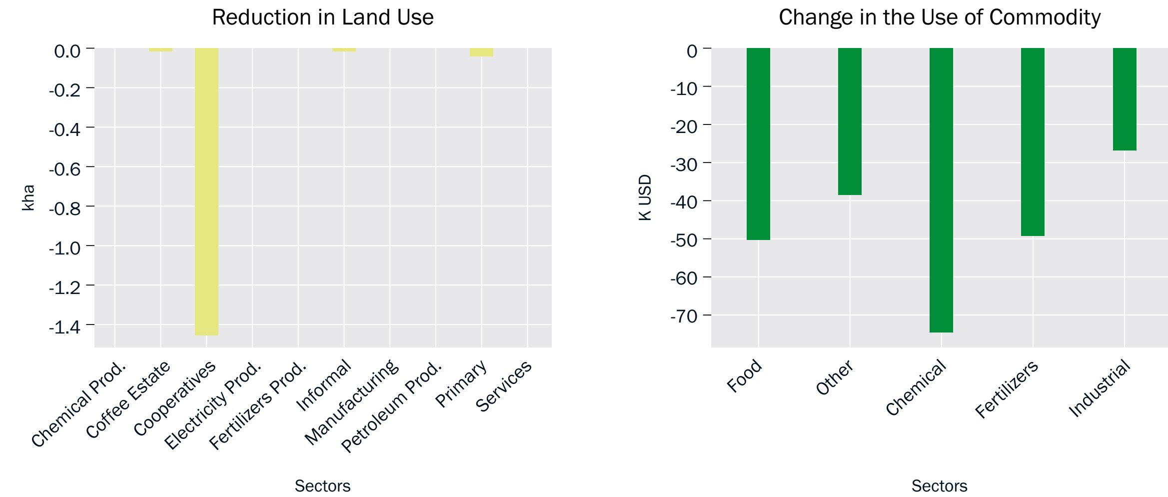
4.2.1. Shading management via nets

Shading nets represent a technology adopted in coffee nurseries and greenhouses, in Kenya and worldwide, as a protection of coffee seedlings (from birds, excessive solar radiation, extreme weather events), to provide uniform shadow and to control air movement, and eventually resulting in the improvement of the quality of coffee seedlings before the transplanting. The nets, which are usually made of UV treated monofilament raw materials, can help the farmers to improve their production, by improving the early stages of coffee seedling development and regulating the microclimate conditions. These kinds of materials can be sourced in Kenya and they are supplied by local companies to coffee nurseries.

In the framework of this study, the aim was to understand whether these kinds of nets can be considered feasible and economically beneficial to be adopted by the Kenyan coffee smallholders. For this reason, a quantitative investigation was carried out with the assumption of an increase in coffee productivity in the range of 0.5% to 2.5% due to the adoption of shading nets with various shading levels. It was considered that each cooperative would be able to own a nursery with area between 0.5-1 ha. The following results are expressed on the basis of an investment equal to circa $50 million, required to cover all the coffee plantations of the 500 cooperatives. The input parameters adopted for implementing this intervention in input-output analysis of Kenya are reported in Appendix C - Table C 2.

The increase in productivity has the consequence of saving both economic activities and commodities that are not required anymore: the main savings are experienced in the "cooperatives" activity by mean of saved land, which also impacts on the capital land which is required to produce coffee. Furthermore, a considerable amount of import would be avoided due to the intervention, saving mainly chemical products, fertilizers and food (see Figure 17).

Figure 17. Land savings and import savings due to the intervention of covering 80% of cooperatives' coffee plants with shading nets.



Nevertheless, these considerable gains are not compensated and thus are not enough to justify the intervention. In particular, it has a PRoI which goes from 0.05 to 0.47, corresponding to a range of PPBT that cannot justify the expense for a technology that needs to be substituted almost every year (from 2.1 years in the best-case scenario to 21 years).

Thus, even considering an extraordinary increase in physical productivity, shading nets are not considered an economically viable opportunity.

4.2.2. Shading management via trees

Optimal coffee-growing conditions include cool to warm tropical climates, good rainfall and rich soils. Rising temperatures and recurrent droughts experienced by many regions in the world, including the traditional coffee growing areas, as a result of climate change, represent a challenge for the coffee cultivation. Therefore, adaption practices are required in order to minimise the risks and the decline in coffee productivity. Among those, coffee shading (so called shade-grown coffee) represents a climate-smart practice, able to improve the microclimate conditions within the plantation. Intercropping coffee plants with shading trees can mitigate the effects of rising temperatures and weather extremes (e.g. frost) and therefore the practice is gaining popularity especially within small-holder contexts. Moreover, coffee intercropping can contribute to sustainable land intensification and to maximise the complementarity in the use of resources. The impact of the practice has been studied in some coffee growing countries in East Africa, but the number of studies remains limited (Wairegi, L. W. I., Bennett, M., Nziguheba, G., Mawandac, A., De los Rios, C., Ampairec, E., Jassogne, L., Palic, P., Mukasac, D., Van Asten, 201AD) (van Asten et al., 2015). According to International Coffee Organization, most Kenyan coffee is grown without shade and further research are ongoing to provide informative context-specific results to determine the most suitable shade tree combination to the local conditions (International Coffee Council, 2019).

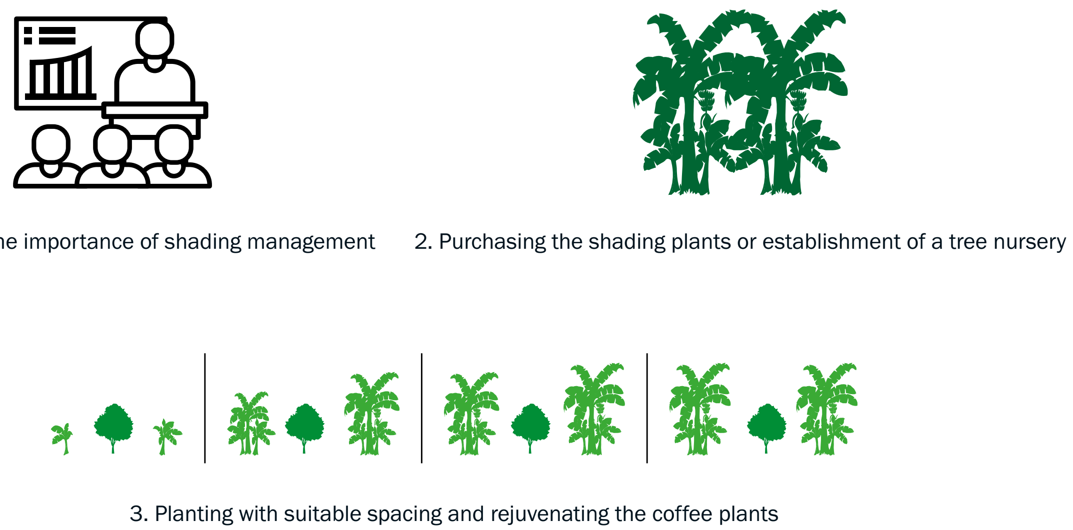
In the framework of this study, Coffee-Banana trees Intercropping (CBI) has been taken into consideration. Based on the available literature, it seems clear that the advantages and disadvantages of this practice are highly context specific. However, for the aim of this study, some of them were assumed to be as potentially valid also for the Kenyan context. In particular, researches conducted by Food and Agriculture Organization of the United Nations (FAO, 2017) and International Institute of Tropical Agricultures and partners (In East and Central Africa) (van Asten et al., 2015) has proven that Agroforestry systems offered for coffee plants can bring multiple benefits for smallholders as follows:

- **Increased resilience to climate change and extreme weather events:** Prolonged drought can negatively affect coffee productivity and cause massive yield losses. The adoption of shading practices allows farmers to create suitable conditions for Arabica coffee, by reducing excessive temperature variation and in general the exposure to adverse climate conditions. In fact, shade trees can reduce temperatures 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. In fact, it was observed that the soil water content was reduced by only 6% in CBI system compared to coffee monocultures (Sarmiento-Soler et al., 2019);
- **Increased incomes and improved food and nutrition security:** Additional fruit production (banana in this case) can help coffee farmers to improve their income, by diversifying production and therefore reducing the impact of yield losses. Moreover, compared to monoculture, CBI increases total revenue per unit area, contributes to food and nutrition security by providing an additional harvest, maximises land productivity and offsets cash flow constrains in newly established coffee plantations. Intercropping seems to have a 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);
- **Improved plant growth and enhanced coffee quality:** The quality of both coffee and bananas seems to be mutually enhanced due to the above and below ground complementarity and especially because of the extension of the cherry ripening period. Therefore, as the result of this practice, most of the coffee growing features such as photosynthesis process, leaf area index, the weight and size of the cherries and even their biochemical composition can be improved. Hence the taste of finished products is better and can earn farmers a potential higher price (van Asten et al., 2015);
- **Reduction of greenhouse gas emission:** Coffee production contributes significantly to greenhouse gas emissions. Climate-smart practices, like CBI, have a high potential to mitigate emissions by increasing the above and below- ground carbon sequestration, in tree biomass and the soil (Albrecht and Kandji, 2003). 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). Besides, due to the increased overall productivity of CBI, the total carbon footprint is reduced, by maximising the use of agricultural inputs over a larger agriculture produce.

Potential disadvantages and barriers for the adoption of CBI have been also pointed out. According to the current literature, the following drawbacks can be identified:

- **Negative impact on physical yield:** The impact of intercropping on coffee yield is highly dependent on several factors which are interdependent and eventually determining the competition in the use of resources between the plants, in particular the environmental conditions (climate, altitude, etc) and the shading tree species. It was observed that the coffee yield in CBI seemed to decrease over 1700 m above sea level, during average precipitation season, and over 1300 m above sea level during below-average precipitation season. 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);
- **High level of initial investment:** The adoption of CBI requires several steps, in particular (Figure 18): 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.

Figure 18. Required investment steps for implementing shading tree management

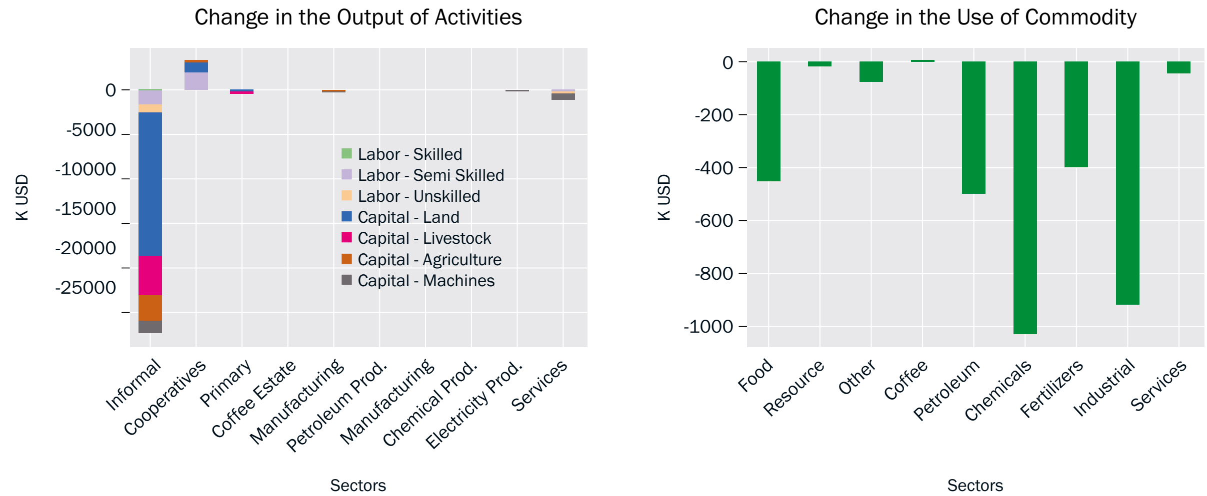


In the framework of our study, some approximations were necessary to estimate the costs associated to each step of CBI implementation. In particular, the costs of the shading trees and those associated to the establishment of the plantation are the only ones considered as "initial required investment", calculated according to the considered area of the intervention, the optimum tree density and the cost per banana tree ($1.3). The assumptions made about the costs referred to a case study in Guatemala might not fully reflect the reality on the ground in Kenya. However, considering the limited available references, it has been the most related data that can be found for the purpose of this study;

- **Potential impact on the required economic factors in coffee production:** To assess the impact on the factors of production, we based the estimations on Rosalien E. Jezeer, Maria J. Santos, René G.A. Boot, Martin Junginger, Pita A (Jezeer, Santos, Boot, Junginger, & Verweij, 2018). According to it, the CBI approach in Kenya seems to be suitable for communities that are constrained by capital (land and equipment) but where labour force is available. We assumed that the Kenyan coffee farming systems could be classified as "medium-input" systems. Concerning the shading class, by adopting an optimum shading level of around 65%, the system can be categorized as "high-shaded". Therefore, we could estimate that, due to the implementation of the CBI, coffee growers would experience a reduction of around 27% in required machinery capitals and equipment and a growth of around 38% in labour.

Based on all the above-mentioned advantages and disadvantages as the result of adopting CBI strategy, the input parameters adopted for implementing this intervention in input-output analysis of Kenya are reported in detail in Appendix C - Table C 1.

Figure 19 Changes in activities by factor of production and sector and import of commodities saving due to the intervention of covering 80% of coffee cooperative plants with banana trees

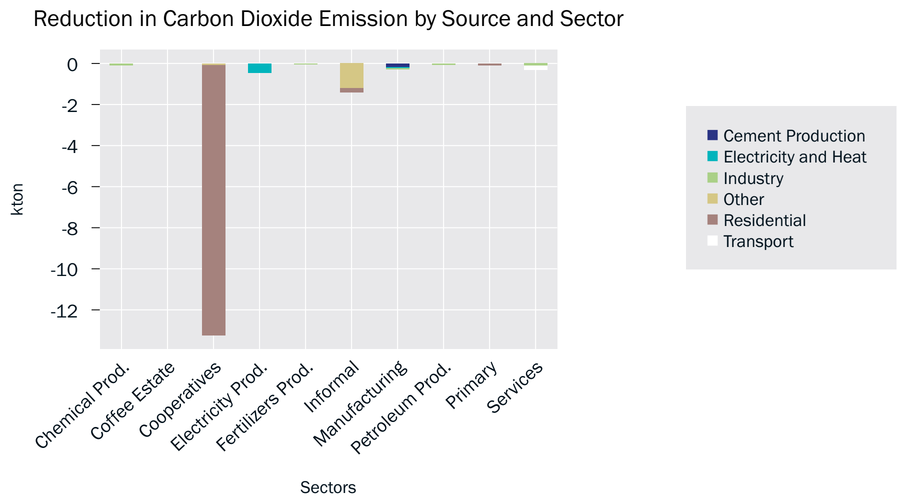


After having implemented the shock on the CIVICS model assuming a 100% coverage of all the coffee plants owned by cooperatives, some useful insights can be provided. The main economic benefit seems to be associated with the introduction of an additional revenue-generating activity which is the production 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 19, additional inputs are required within the coffee production informal activity (i.e. cooperatives), important savings are saved in the other informal activities. This is due to the fact that fruits requirements from cooperatives are now partially covered by own production coming from 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.

These changes in use of factor of productions and import of commodities adds up to a value that guarantees the highest PRoI to this intervention among the ones considered: from 0.60 to 0.83 corresponding to a PPBT always within 1.7 years.

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 marginally and less electricity production as it can be seen in Figure 20.

Figure 20. Carbon emission changes by sector and category due to the intervention of covering 80% of coffee cooperative plants with banana trees



This intervention has also a considerable effect in creating jobs for its implementation. In fact, as it was expected by the preliminary literature analysis, the initial investment is considerable and it triggers a request of labour that may open local occupancy opportunities for low-skill workers.

4.2.3. Eco-pulper for the wet milling process

The pulping process is the last step of green-coffee production which takes place within the smallholders' farms, before drying. This step usually takes place in water and it is also called wet processing. In the first step of the wet process, the skin and the pulp of the cherry are removed by a pulping machine, which consists of a rotating drum or disk that presses the berries against a sharp-edged or slotted plate, separating the pulp from the seed. Pulp still clings to the coffee seed, however, as a thin mucilaginous layer. That layer is eliminated by fermentation, actually a form of digestion in which naturally occurring pectic enzymes decompose the pulp while the wetted seeds are held in tanks for one to three days. Washing clears all remaining traces of pulp from the coffee seeds, which are then dried either by exposure to sunlight on concrete terraces or by passing through hot-air driers. The dry skin around the seed, called the parchment, is then mechanically removed, sometimes with polishing.

This process take place in the so-called wet mills, where the quality of coffee can be compromised as a result of poor pulping. Losses incurred at the farm level could be significant, but there are available data to indicate their extent (International Coffee Council, 2019). From field visits during the preliminary phase of this study and from national and international reports, it is noted that farmers have taken great care to minimize losses by traveling short distances to the wet mills at which they are registered, usually the closest to their farm land.

Pulping is normally based on a large water withdrawal and discharge, representing a risk for the sustainability of the process as well as for the surrounding communities. Furthermore, the wet-milling stage can spoil the cherry, impacting on the quality of the product. Nowadays available technology, the so called "eco-pulper" machineries, is able to drastically reduce the impacts on water sources, by minimizing the water consumption and wastewater production. These machines can process up to 1 ton/hour, reducing the processing time, serving several farms which can actually share the financial risk associated with the investment.

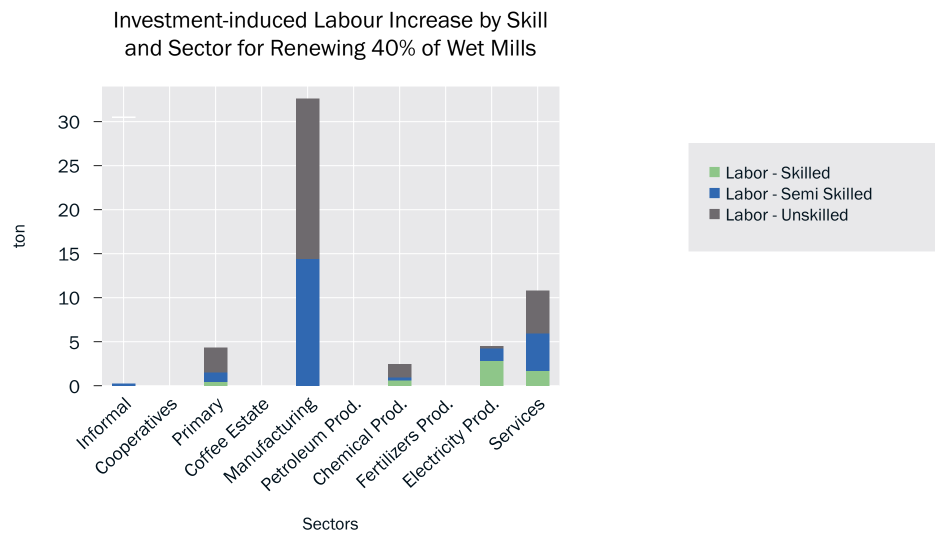
Since there is no information in the literature related to the extent of spoiled coffee generated by traditional wet milling, a sensitivity analysis will be performed for exploring possible net productivity changes due to the new pulping technology. The range will be from +0.5% to +2.5%.

The proposed intervention is to invest on one eco-pulper for every 450 farms. In such a way it could be possible to share the investment and its use, spreading the working hours along the days after harvesting. The technology modelled for this intervention has a capacity of 1 ton/h with water and 0.8 ton/h without water, uses practically zero water and is powered by gasoline at the cost of 1500 $/machine. The machine uses a coffee disc and rigid type chops, which cuts down maintenance costs and makes it extremely durable. The input parameters adopted for implementing this intervention in input-output analysis of Kenya are reported in detail in Appendix C - Table C 3.

The results are consistent with what was expected before modelling the intervention. The volumes of the resulting impacts are based on the optimization choice of substituting almost 40% of the wet mills.

The investment has a positive local impact in increasing the demand of labour in the Kenyan market. The machine that has been considered as the proper technology for the intervention is produced by a local firm. Of course, as it can been observed in Figure 21, even if some indirect effects in the third sector can be noticed, the main increase, by mean of semi-skilled and unskilled labour, is demanded in the manufacturing sector.

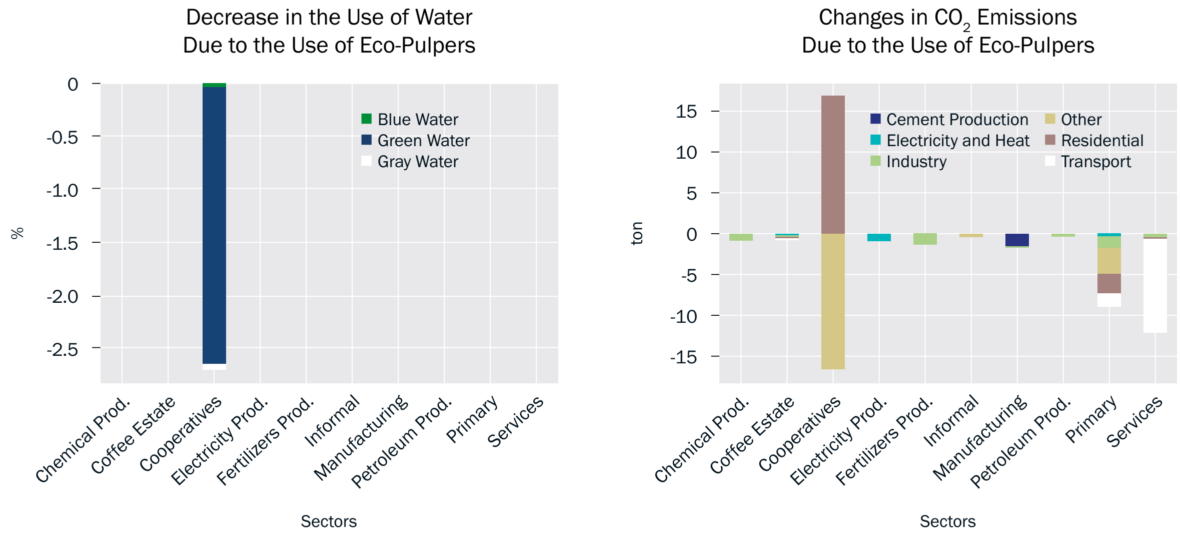
Figure 21. Sectoral increase in demand of labor induced by the eco-pulper intervention by skill level



The investment is quickly payed-back (PPBT of 1.8 years) by the induced slight increase in coffee productivity, with a PRoI ranging between 0.53 and 0.97. Of course, this performance is highly sensitive to assumed increase in productivity (i.e. decrease in cherry spoiling), becoming economically unsustainable when the increase in productivity is in the order of +0.5%.

Nevertheless, the intervention does not only impact on economic factors but also on environmental ones. In fact, the main environmental aspects that are perturbed by the large adoption of eco-pulpers are related to water and carbon emissions. In fact, there is a huge improvement in terms of green-water usage, since that is the kind of water adopted for cultivating in Kenyan cooperatives. Looking at the left-hand side of Figure 22, the decrease in water usage is very relevant, accounting for the 2.5% of the overall cooperative's productive activities, corresponding to a reduction of 1400 Mm3 in 10 years. 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 22, the increase in direct emission associated to the use of the machines (here accounted as "Residential") is overcome by the indirect effects associated with a baseline increase in productivity. Relevant savings in coffee associated cooperative activities, transportation services and, less importantly, in other interlinked sectors, may justify the intervention also from a pure carbon reduction perspective.

Figure 22. Environmental impact induced by the substitution of 40% of cooperatives' wet mills with near-zero-water and gasoline-powered eco-pulpers



4.2.4. Exploiting biomass from coffee organic waste

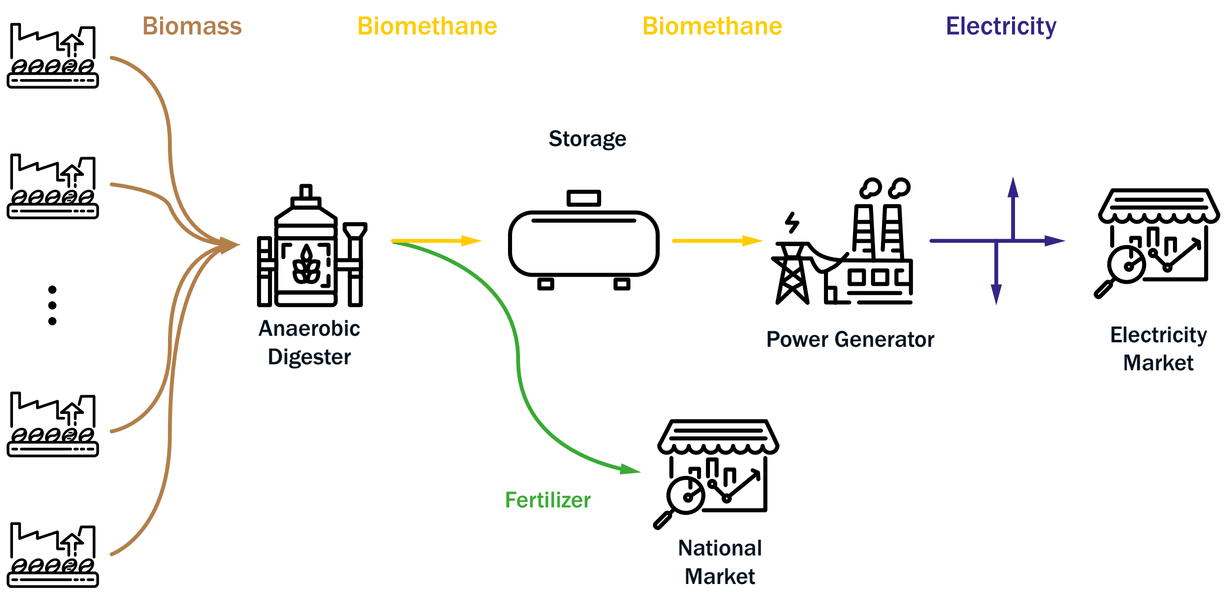
As previously mentioned, from the supply chain analysis, it has emerged that the wet processing generates waste, such as water and exhausted biomass. As also supported by Murthy (Murthy & Madhava Naidu, 2012) and Ulsido in Ethiopian context (Ulsido & Li, 2016) and Mwangi (Mwangi, R. W., Mwenda, L.K.M., Wachira, A. W., Mburu, 2017) in Kenya, this waste, if not properly managed, discharged into the environment without any treatment, can affect the environment and pose a risk to the communities.

Following the principles of the circular economy, the proposed intervention aims to take advantage of the waste biomass to feed an anaerobic digester coupled with a biogas upgrader to produce bio-methane (Surendra, Takara, Hashimoto, & Khanal, 2014). It is noteworthy that, in addition to the production of biogas, the anaerobic digestion of agricultural waste also produces an organic residue, namely digestate, which is rich in nutrients. If this digestate is utilized in plant production, nutrients will be reintegrated into the soil nutrient cycle, contributing to maintain soil quality and fertility. Utilization of digestates may replace or at least reduce the use of mineral fertilizer, since usually are rich in plant-available nutrients such as ammonium (NH4+), phosphate (P) and potassium (K) (Battista, Frison, & Bolzonella, 2019) (Sogn et al., 2018) . Moreover, the re-use of digestate for plant production, including coffee, is of particular interest for the Kenyan economy, being fertilizers massively imported in the country and on which the domestic agricultural sector relies heavily (Balié, J., Battaglia, L., Boulanger, P., Dudu, H., Ferrari, E. & Mainar Causapé, 2019).

The wet-mill process produces two different kinds of biomass waste, namely pulp (assumed to be 200% of the weight of the final green coffee production) and parchment (assumed to be 20% of the weight of the final green coffee production), the amount of waste produced refers to (Gathuo, Rantala, & Maatta, 1991) who performed a specific analysis on the coffee industry of Kenya.

Two slightly different kinds of intervention are proposed, based on the same idea of exploiting biomass waste for biogas production. The first, that will be referred to as the "on-grid solution", proposes to collect the biomass from different cooperatives at mill level, installing a power producing machine in each of the 17 mills, reported in Appendix A, Table A 2. The power produced by such machines is assumed to be injected in the national grid, and the fertilizer produced enters the national market. Given the extreme seasonality of the availability of the coffee waste biomass it is necessary to account for a storage system, in which the bio-methane is stored to allow the electricity generation to be carried out all year long. The impact of such intervention is explored with a twofold approach taking advantage of the two modelling strategies presented in this work. Through the energy system model of the country it is possible to assess how the national electricity system reacts to the new generating technologies, integrating them into the energy mix, and to observe how and when this energy is used, while the Input Output analysis permits to estimate the impacts on the economy of changing the energy matrix and changing the production methodology of a share of the fertilizers used, from imported to locally produced.

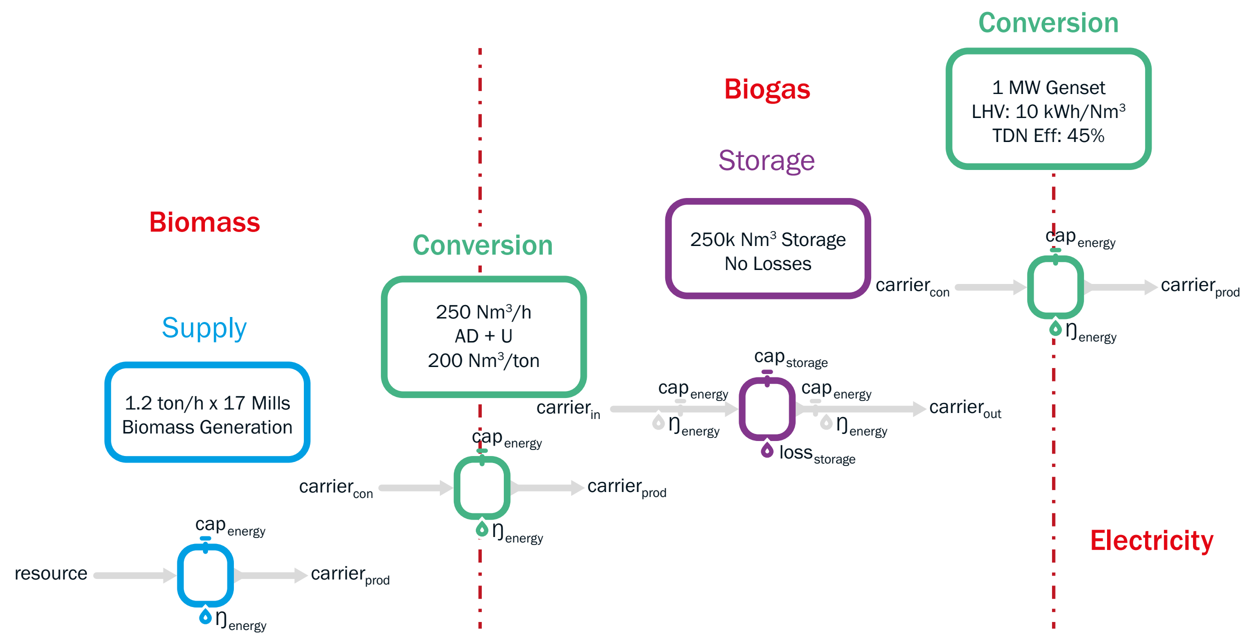
Figure 23. Structure of the "on-grid solution" proposed implementation.



In order to implement the proposed intervention in the Kenyan Energy Model, already presented in Section 3.2. Energy System Modelling in Kenya, the methodology presented in Figure 24 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.

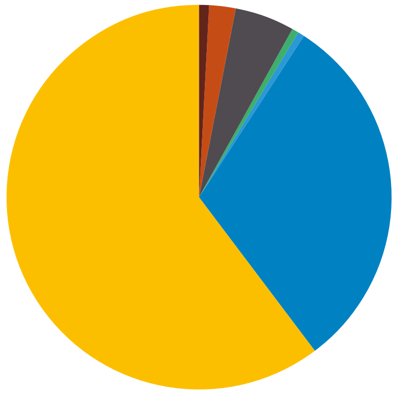
Figure 24. Modelling scheme of a single biomass power plant.



The results of the energy model are reported in Figure 25, 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.

Figure 25. Electricity production mix after implementation of the Coffee Power Plants.

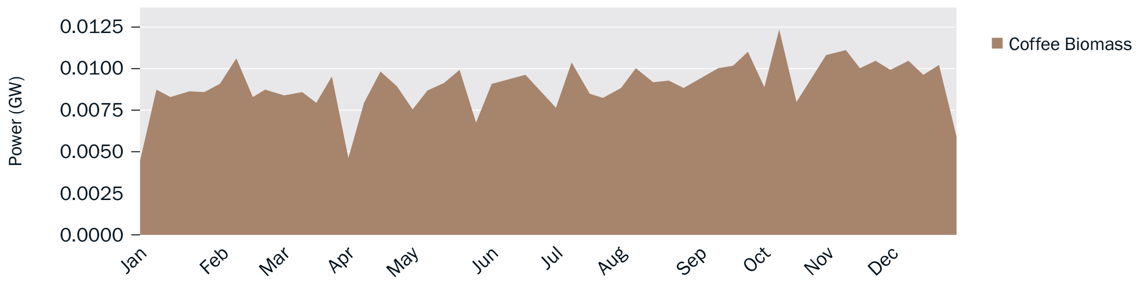
System Production Mix



	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

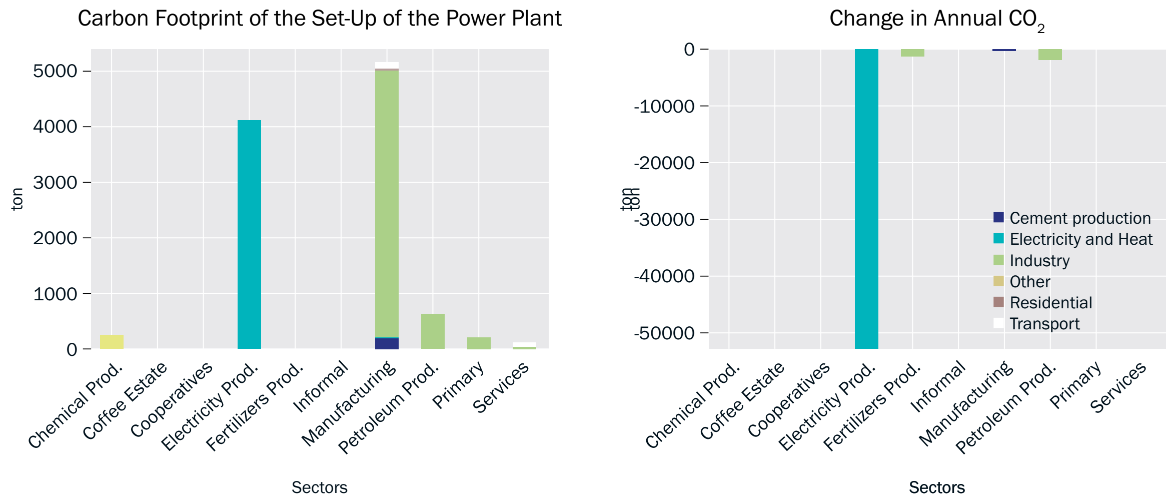
From Figure 26 emerges how the seasonal availability of the resource does not affect the dispatch of electricity, thanks to the presence of the storage.

Figure 26. Aggregated yearly dispatch of the Coffee Power Plants.



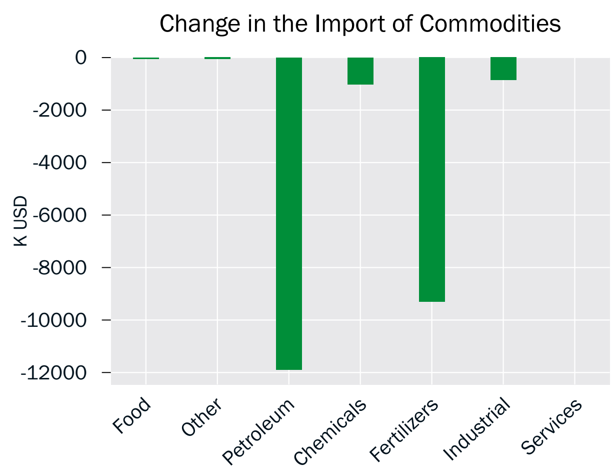
The adoption of the biomass resource as a substation to part of the heavy fuel oil production comes with environmental benefits. In fact, it is possible to save 3% of the emissions coming from Kenyan electricity sector, corresponding to 54 kton of CO2. Modelling the intervention in the Input Output some other considerations around environmental and economic impacts can be made. As it can be observed by Figure 27 carbon emissions are not only saved every year (for almost the whole part by direct avoided emission in the electricity sector), but also emitted for producing the technology required by the power plant and the fertilizer producer. Nevertheless, the carbon footprint of the intervention is considerably 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 27. Carbon emission associated with production (left-hand side) and operation (right-hand side) of the coffee biomass power plant and fertilizer production plant



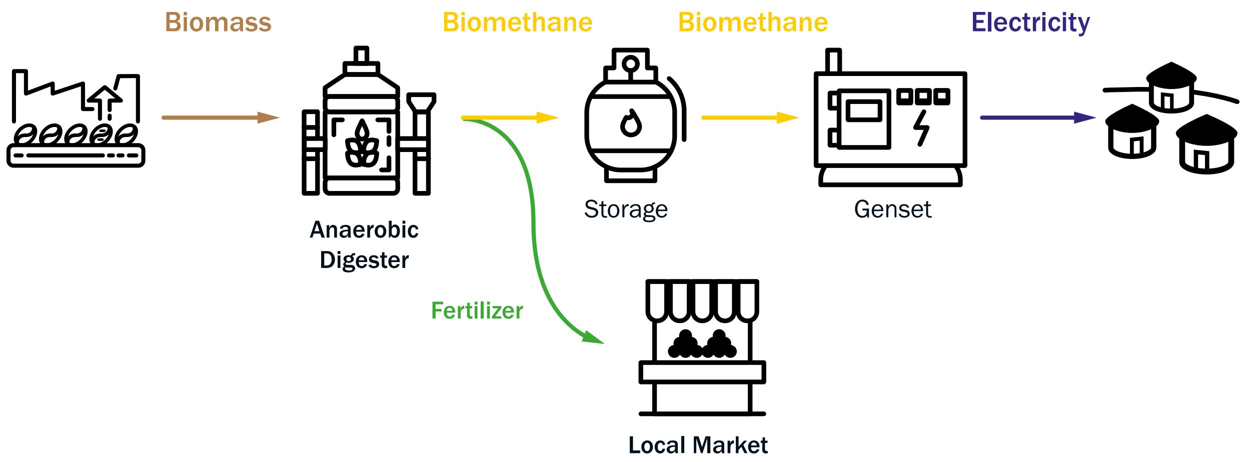
The benefits are also present within the economic dimension. In fact, this intervention is the one between the ones analysed that maximize the amount of saved import per unit of investment. These commodities, as it can be seen by Figure 28 are mainly petroleum and fertilizers, two inputs on which Kenya has a very relevant import dependence, saving circa $20 million 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. Therefore, this intervention represents a possible practical example of circular economy.

Figure 28. Avoided import due to the introduction of the biomass power plant and the fertilizer producer



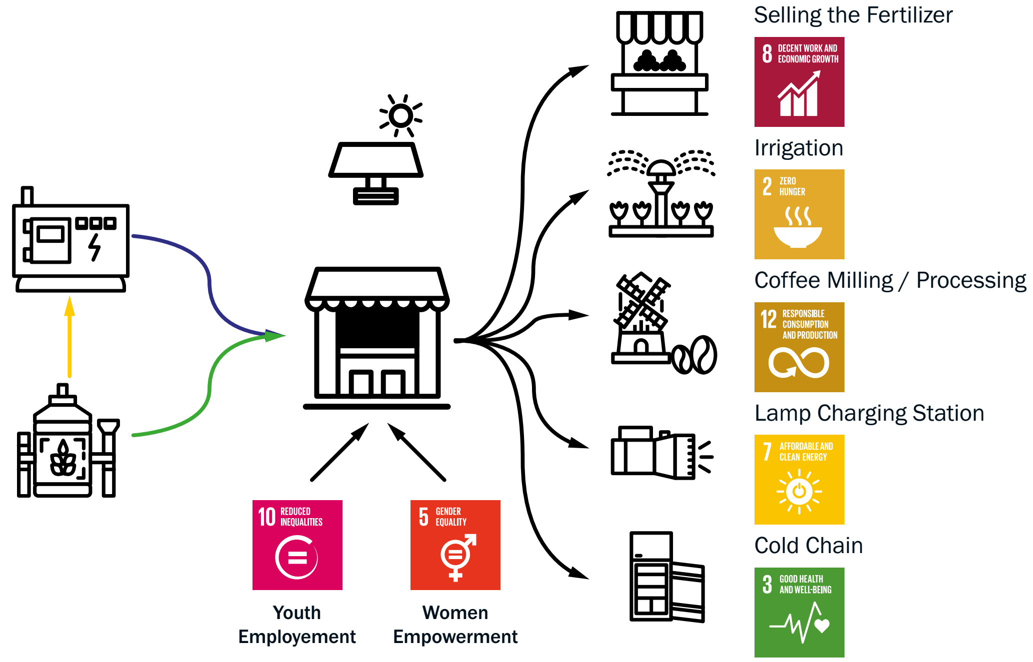
The second proposed intervention will be referred to as the “off-grid solution” and is depicted in Figure 29. The idea behind this intervention is the well-established concept that providing access to electricity alone to a community is not enough, in order to initiate a development process (Riva, Ahlborg, Hartvigsson, Pachauri, & Colombo, 2018). Supporting the start-up of the income generating activities, together with ad-hoc business models for electricity tariffs and energy assets ownership and management, is strongly related to the actual unleash of sustainable development (Best & Garside, 2016). From this concept stems the idea of the smart electricity station (or energy kiosk https://www.solarkiosk.eu/); in this particular case, with small size electricity generation and production of a valuable good for the community the idea of energy kiosk is particularly fitting.

Figure 29. Structure of the “off-grid solution” proposed implementation.



The proposed scenario foresees the establishment of smart electricity stations (“energy kiosks”) that may serve as hub for those communities involved, directly or indirectly, in the early stage of the coffee supply chain. The energy is meant to be produced from the biogas and could be integrated with a set of photo-voltaic panels and battery pack for electricity storage. Figure 30 displays the proposed scheme and its contribution to the SDGs. It can be realistically assumed that a small-scale facility, such as the smart electricity stations, might foster the interest of young people (both women and men), both as an income generating activity and an opportunity to develop related business initiatives, therefore ultimately contributing to the income diversification in the rural areas in Kenya.

Figure 30. Possible benefits and implications of Energy Kiosk implementation. On the right side the possible uses of energy that might be of benefit for the community and on the bottom the possible social benefits from a correct business model for the management of the kiosk, with the relative triggered SDGs.



The possible activities that might sprout around the digester/ electricity facility are:

- **Selling the fertilizer:** is the easier activity to implement given the nature of the process. The fertilizer, obtained as by-product of the biomass gasification, could be used by the coffee grower cooperatives or sold, generating additional incomes;
- **Powering irrigation:** the electricity produced by the kiosk could serve, in addition to covering the latent demand of electricity of unelectrified rural communities, to power irrigation systems for plant production (including coffee), increasing productivity, stabilizing yields and contributing to improve the incomes for the growers;
- **Powering coffee processing:** another potential use for the electricity produced is to power coffee milling, supposed to take place in the surroundings of the kiosk. Biogas, resulting from the anaerobic digestion, could also be used as fuel for secondary coffee processing (such as roasting), generating value-addition;
- **Smart electricity station:** is one of the most common business models for energy kiosk, the facility becomes a one-stop hub to charge lamps and mobile phones at a flat fee, provide phone bundles, facilitate mobile money transfers and power wi-fi for the members of the community;
- **Cold chain related needs:** where the kiosk is situated in the vicinity of school facilities, dispensaries or local markets, the electricity produced could be used to power refrigerators to store drugs or as a food preservation method for children’s snack during school time or for sale, building upon lesson learnt from previous projects, such as the Africa Milk Project (https://www.africamilkproject.it/le-fasi-del-progetto/).

4.3.5. Introduction of coffee roasting industry

Currently roasters in Kenya use roasting machines, grinders and packing machines to produce whole beans, ground coffee, instant coffee, and capsules. In addition, according to the USAID, Kenyan roasters are considered to be highly skilled and capable on all levels – from roasting technique to quality control, including packaging (USAID, 2017). However, only 5% of Kenya's coffee is exported in roast and ground form thus Kenya is missing out on the benefits from value addition, this is due to barriers imposed by consuming countries and mainly because consumers in these countries prefer freshy ground coffee. This is because once roasted, coffee starts to lose its freshness, thus the type of packaging used plays a vital role in preserving the freshness of roasted coffee. Placing roasted coffee immediately in air-tight packaging with a one-way gas outlet valve to allows roasters to preserve the freshness of the coffee for a longer period.

Furthermore, it is important to understand that coffee itself represents a very small percentage of the final product vale. According to the International Trade Center, although it is estimated that 10% of the $200 billion retail market is retained in the country of origin, the value of coffee in one cup, retained in the producing country is probably 1%. A study commissioned by the British Coffee Association indicated that the United Kingdom retains 76% of the value of every cup of coffee consumed in the country (International Trade Center, 2020). Thus, Kenya can substantially gain from roasting coffee within the county and then exporting it. Introducing roasteries within co-operatives societies will result in the generation of a greater share of profits from each bag of coffee to the co-operatives, which will in turn increase incomes for farmers and their communities. For example, in Rawanda a group of five washing stations started CaféRwa, to roast and export coffee, in 2019 the online retail price of their roasted coffee was 36 $/kg, while farmers received 7 $/kg free on truck green equivalent selling their coffee in roasted form. This is a healthy premium compared to the 4 $/kg they received before for most of their green coffee sales (International Trade Center, 2020).

Kenya's current account has been suffering from a deficit since 2015 and it is forecasted that this will continue until 2022 due to the higher imports value of goods and services compared to lower exports value. Considering that coffee is one of the main agricultural exports for Kenya, exporting it in its green bean form fetched little foreign exchange, however enhancing the exports of coffee through value addition will allow the Kenyan government to fetch more income and support it to come out of this persistent deficit (Kenya Institute for Public Policy Research and Analysis, 2019). Moreover, green coffee beans are not subject to export duty or tax in Kenya as they are considered to be a raw material, while roasted coffee exports are subject to a 16% Value Added Tax (VAT) on the value added to the coffee exported (International Coffee Organization, 2019). Thus, exportation of roasted coffee will also increase the government revenue through VAT and will contribute to fiscal resource mobilization required for sustainable development in Kenya. In addition, roasting coffee can contribute to growth in the manufacturing sector, which in turn contributes towards the achievement of 10% economic growth envisioned in the Kenya Vision 2030.

By roasting coffee, co-operatives gain insights into what customers want/need and can provide feedback to farmers so they can understand what the beans best qualities are and what are they lacking. Based on these farmers can improve the quality of their coffee beans and this will in turn allow them to obtain higher prices when selling the remainder of their green beans for export. Moreover, setting up roasteries will also contribute towards the creation of new jobs in those communities and allows co-operatives to sell single origin coffee that is easily traceable and that can be sold at a higher price. Moreover, traceability systems are an integral part of food safety management in many countries, including the European Union and a legal requirement for food busines operations.

From a modelling perspective, this intervention differs from the others. Since it is not possible to represent this change without impacting on a new final demand, thus it is not possible to include this in a comparative analysis. Furthermore, the intervention has been modelled introducing two new accounts to the original SAM. In fact, in order to model the production and export of a new commodity, from the one hand a new row product must be introduced (i.e. "Roasted Coffee"), from the other hand a new productive activity must be characterized (i.e. "Coffee Roasting").

The introduction of the new sector within the SAM representation of the economy requires to start from a possible level of price for the commodity which could be balanced by the value added to the green-bean coffee, assumed to be the only form of traded coffee before the introduction of the new sector. In that perspective, the modelling of the intervention results in clearly defining the level of input from other sectors and from factor of production which could economically sustain the level of pricing observed in the market.

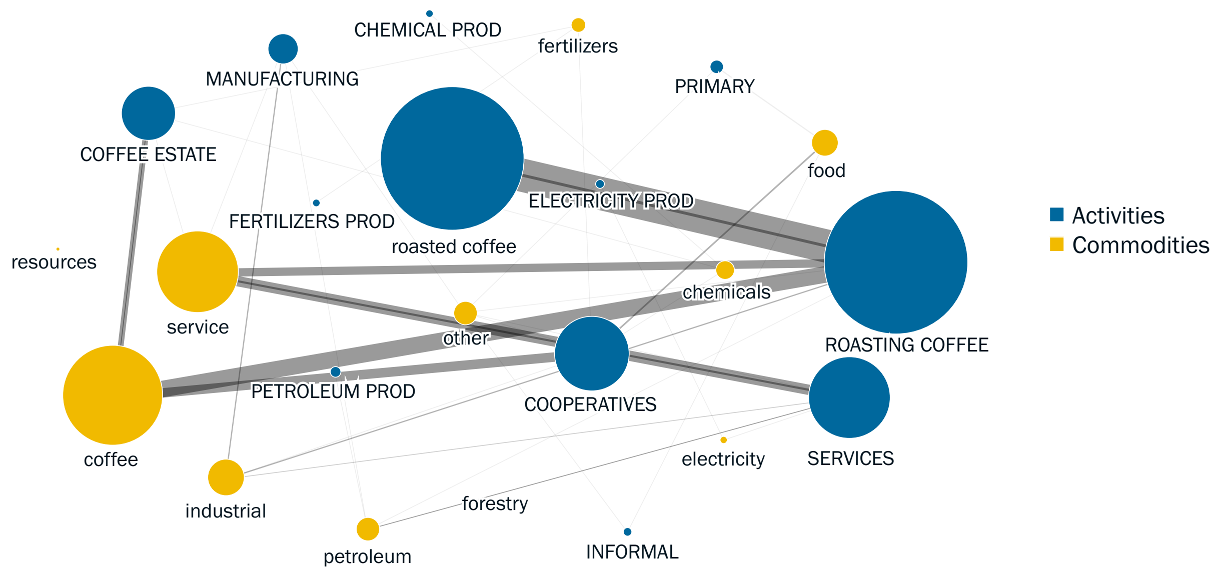
In this case a low-price level, corresponding to around 18 $/kg, of roasted coffee has been assumed. Furthermore, the intervention has been scaled to a volume of trade of 20% of baseline green-coffee export. This was done to evaluate the introduction of the new technological process at a volume level that can realistically reflect a future in which this technology has established itself in a relevant way. In fact, at the actual state, it is difficult to imagine that Kenyan roasted coffee can find a spot in highest quality coffee markets.

One of the main obstacles to make Kenyan roasted coffee competitive in the market is represented by its low freshness. That is why the process has been modelled with a high value packaging input, representing the second most relevant physical input (4%) after green coffee beans, which represents the 46% of the value of roasted coffee. These inputs where derived by adding all the needed capital, which have been amortized assuming 10 years operating life for high values machineries and 5 years for testing equipment. Furthermore, labour input has been assumed considering actual required personnel and corresponding wages. As stated above, taxes amount for 16% of the total value of export while transportation and self-consumption have been determined by observing similar sector activities, adding up correspondently 4% and a 9%. The approach aims to determine the difference between the determined exogenous value of the export and all the possible inputs necessary for the realization of a product able to meet the standards of the international market.

Thus, the main first result of the analysis is the 18% margin that can be offered by the investment in all the facilities required for roasting coffee in Kenya. This value guarantees a reasonable economic sustainability of the activity, setting the necessary conditions to think to publicly support the intervention.

The second result of the analysis is related to the induced effects of introducing the roasting activity. In order to represent this, a network chart has been produced.

Figure 31. Network chart of required inputs and outputs if an additional unit of final demand of "Roasted Coffee" commodity is added in the final demand.



In Figure 31 commodities and activities level of production are represented by yellow and blue circles respectively. The bigger the circle the higher is the volume of production that is in place. These circles are connected one by the other by the flows of its output. As in the previous case, the thicker is the line which connects two circles the higher is the economic flow between the two. As it has already reported, the chart confirms that the main input to the activity of roasting coffee is green coffee beans but also the industrial products, in the form of packaging materials, are not negligible. These commodities are of course produced by one or more economic activity. This is the case of green coffee production which can be produced by both coffee estates and cooperatives which uses services, fertilizers and food as input, reflecting the close interrelation between activities. In this perspective, expanding the roasted coffee sector will impact marginally on coffee-interlinked economic sectors and more relevantly on coffee cooperatives. The introduction of a new stable request of green beans can represent a chance for higher and more resilient return for cooperatives which could work as a more stable economic incentive for focusing on increase productivity, possibly investing in further technological advancement.

05 Conclusion

In the rapidly changing context of the sub-Saharan African continent, the concept of Sustainable Development outlined in the United Nation's Agenda 2030 acquires a particularly significative role. One of the most relevant aspects that emerge from the Agenda is the systemic nature of the relation between humans and the environment, and the related challenges that have to be faced. It is not possible to reduce these challenges to mono-sectorial issues, but involve different spheres ranging from industrial to environmental ones. This calls for holistic approaches when facing such challenges able to propose integrated solutions and scientifically sound policy support.

In the context of the Agenda, energy is recognized as a pivotal element in the framework of sustainable development; in its most basic form, energy is seen as driving force of human development, having access to reliable, clean and affordable energy is key to have access to improved education, health conditions and possibility for business development. The relation of energy with the environment is clear in the form of GHG emissions that derive from the standard energy conversion technologies and switching to cleaner energy technologies is important for ensuring a carbon neutral future. Power production and business development are two main drivers of a nation's economy, and for this reason, in the process of providing a decision support tool for policy makers, energy and its relation with the economic fabric of the country cannot be overlooked.

The relevance of the interconnection between energy and other sectors in sustainable development is well framed by the WEF (Water-Energy-Food) Nexus (FAO, 2014), and with the aim of providing a policy support system that is scientifically solid and evidence driven, able to grasp the complexity related with the WEF Nexus, the CIVICS framework has been presented in this work.

CIVICS, the ComprehensIVe and Integrated Country Study, aims to be a framework of tools able to support decision makers of developing countries, by evaluating the impact of the proposed policies, and framing them in the bigger picture of SDGs, while ensuring that the desired local outcome is achieved. In the report a series of examples of the application of CIVICS to different policies in the coffee sector of Kenya has been outlined in order to provide examples of the potentialities of the approach.

In particular attention can be drawn to the modularity and customizability of the framework, making it flexible to the context in which it is applied, and suitable to evaluate policies that range from national or regional level (e.g. substituting the machineries for coffee pulping on the entire coffee supply chain) down to very context specific local interventions (the evaluation of the impact of the implementation of an energy kiosk in a rural community). The model is offering different tools that can be used in synergy or as stand-alone impact evaluations methods accordingly to the needs of the specific context. In addition to that is worth highlighting how an interesting feature is to use CIVICS as bench marker between policies interventions, offering the possibility to assign a series of indicators to the proposed policies, in order to evaluate the proposals within a single framework and provide insights based on their relevance with the SDGs, for example, or other technical or socio-economic measures that might be of interest for the policy maker. This may turn out to be a powerful instrument in the hands of an external evaluator to understand the most suitable intervention to be applied among policies that are potentially going to be implemented. Furthermore, it is possible to exploit an operational research method to identify the optimal mix of interventions under a constraint budget to meet the desired policy outcomes.

In the end we can draw some key take-on from the presented approach, in particular it emerged how the use of an integrated framework is pivotal to achieve full potential of the adopted models, that gain strength and provide deeper insights when coupled with the others. More importantly, the double nature of the approach, that aims at guaranteeing the achievement of the specific local goals that each country sets for its own development path, but without overlooking the everyday more relevant, framework of the sustainable development outlined by the Agenda 2030 as global blueprint for inclusive global development.

06 Appendix A

The list of modelled power plants representing the 2015 energy system is reported in Table A 1.

Table A 1. 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 A 2.

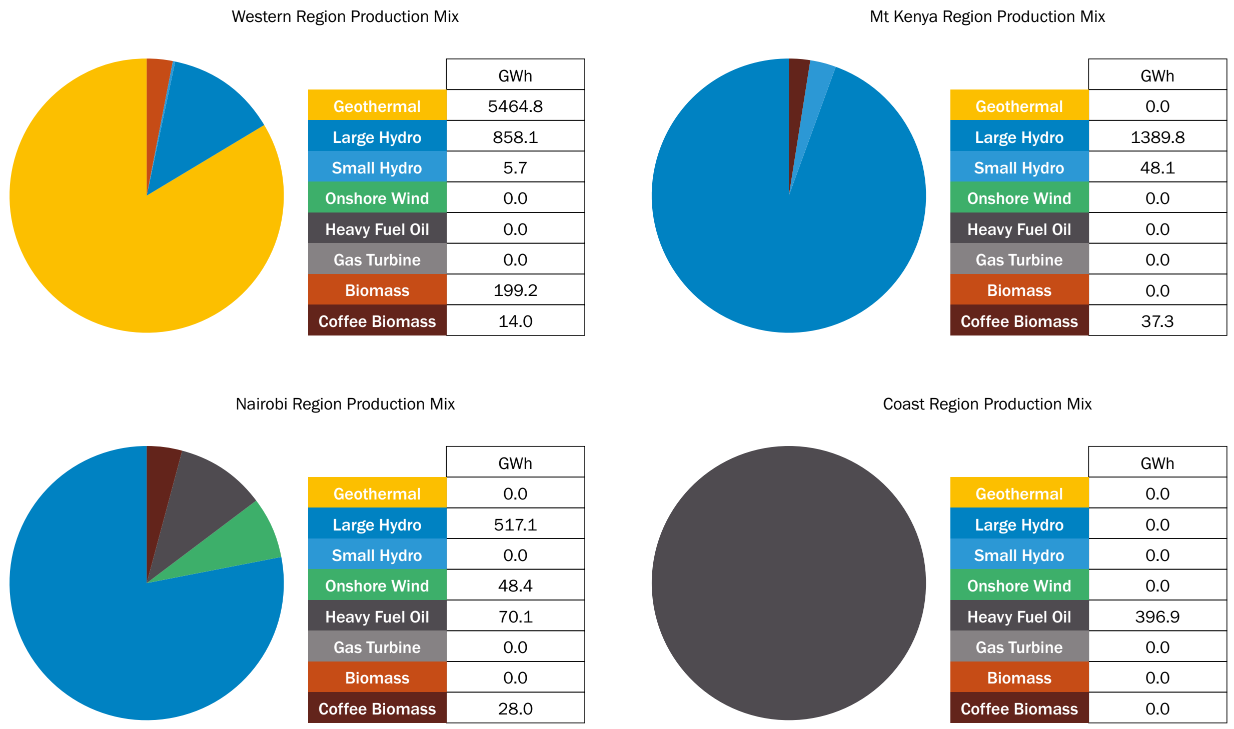
Table A 2. List of Coffee Mills. Source: Authors.

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

Appendix B

In this section a more detailed representation of the energy model results is reported. Figure B 1 shows the energy production mix of the four regions and it is possible to observe the effects of presence of the coffee powered plants in the first three regions.

Figure B 1. Energy production mix, per region, after implementation of the coffee power plants.

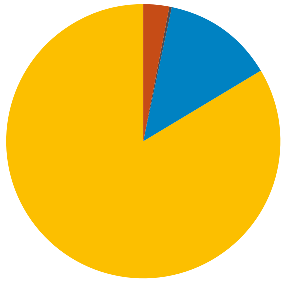


	Western Region GWh	Mt Kenya Region GWh	Nairobi Region GWh	Coast Region GWh
Geothermal	5464.8	0.0	0.0	0.0
Large Hydro	858.1	1389.8	517.1	0.0
Small Hydro	5.7	48.1	0.0	0.0
Onshore Wind	0.0	0.0	48.4	0.0
Heavy Fuel Oil	0.0	0.0	70.1	396.9
Gas Turbine	0.0	0.0	0.0	0.0
Biomass	199.2	0.0	0.0	0.0
Coffee Biomass	14.0	37.3	28.0	0.0

Figure B 2 reports the same result, but with a different rationale, the energy consumption mix is shown. Moreover, the difference between the exporting regions (Mount Kenya and Western) and the importing regions (Nairobi and Coast) is more visible.

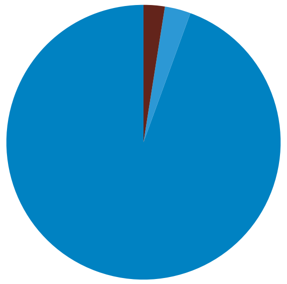
Figure B 2. Energy consumption mix, per region, after implementation of the coffee power plants.

Western Region Consumpion Mix



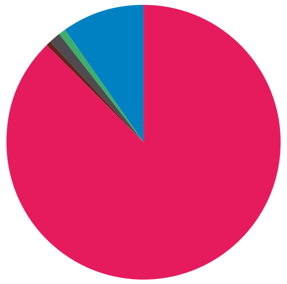
	GWh
Geothermal	5464.8
Large Hydro	858.1
Small Hydro	5.7
Onshore Wind	0.0
Heavy Fuel Oil	0.0
Gas Turbine	0.0
Biomass	199.2
Coffee Biomass	14.0

Mt Kenya Region Consumpion Mix



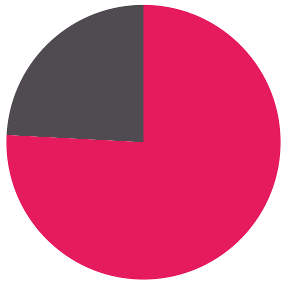
	GWh
Geothermal	0.0
Large Hydro	1389.8
Small Hydro	48.1
Onshore Wind	0.0
Heavy Fuel Oil	0.0
Gas Turbine	0.0
Biomass	0.0
Coffee Biomass	37.3

Nairobi Region Consumpion Mix



	GWh
Geothermal	0.0
Large Hydro	517.1
Small Hydro	0.0
Onshore Wind	48.4
Heavy Fuel Oil	70.1
Gas Turbine	0.0
Biomass	0.0
Coffee Biomass	28.0
Imports	4697.2

Coast Region Consumpion Mix



	GWh
Geothermal	0.0
Large Hydro	0.0
Small Hydro	0.0
Onshore Wind	0.0
Heavy Fuel Oil	396.9
Gas Turbine	0.0
Biomass	0.0
Coffee Biomass	0.0
Imports	1248.1

08 Appendix 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 C 1. 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, Asten, Giller, & Fairhurst, 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)
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

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 hectare11 Philippe Hugon, *L'economie de l'Afrique*, Paris 2013

Shading management via nets

Table C 2. Input parameters for shading nets management intervention

Description	Value	Unit of measure	Reference
Shading nets specific cost per unit of area	0.992 [2]	$\$/m^2$	("Farm Shade Netting | Graduate Farmer Marketplace," n.d.)
Number of cooperatives	500	-	Country Coffee Profile: Kenya, International Coffee Organization(International Coffee Council, 2019)
Area covered by each cooperative	0.5-1	ha	Assumption
Increase in productivity	0%-2.5%	-	Assumption
Useful life of the shading nets	1	year	Estimation

Eco-pulper for the wet milling process

Table C 3. Input parameters eco-pulpers intervention

Description	Value	Unit of measure	Reference
Cost of eco pulping machine	1430	$	("CAL - Coffee Machinery - Mini Eco Pulper," n.d.; "Eco Mini Pulper Cost," n.d.)
Cost of delivery	46	$	Estimation
Required power	1.1	kW	Estimation
Capacity of the machine	0.5	Tons of coffee/h	Estimation[3]
Efficiency of the machine	30%		Estimation[3]
Decrease in water footprint	85%	-	Estimation[3]
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	$kgCO_2/kWh$	*(Combustion of Fuels - Carbon Dioxide Emissio>*, n.d.)
Useful life of the eco pulpers	10	years	Estimation

2 The average value of the suggested range based on the shading level is considered

3 Based on the type of the mini eco pulper

Exploiting biomass from coffee organic waste

Table C 4. 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) [4]
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 [5]	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

4 To be changed for every different number of Gensets

5 Considering 2 technicians, one process engineer and one electrical and power engineer per each plant

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