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LIFE CYCLE THINKING FOR SUSTAINABILITY ASSESSMENT AND DECISION-MAKING IN SELECTED FOOD SUPPLY CHAINS IN COSTA RICA

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Abstract

The Agenda 2030 contains 17 integrated Sustainable Development Goals (SDGs). SDG 12 for Sustainable Consumption and Production (SCP) promotes the efficient use of resources through a systemic change that decouples economic growth from environmental degradation. The Food Systems (FS) pillar in SDG 12 entails paramount relevance due to its interconnection to many other SDGs, and even when being a crucial world food supplier, the Latin American and Caribbean (LAC) Region struggles with environmental and social externalities, low investment in agriculture, inequity, food insecurity, poverty, and migration. Life Cycle Thinking (LCT) was regarded as a pertinent approach to identify hotspots and trade-offs, and support decision-making process to aid LAC Region countries as Costa Rica to diagnose sustainability and overcome certain challenges. This thesis aimed to 'evaluate the sustainability of selected products from food supply chains in Costa Rica, to provide inputs for further sustainable decision-making, through the application of Life Cycle Thinking'. To do this, Life Cycle Assessment (LCA), Life Cycle Costing (LCC), and Social Life Cycle Assessment (S-LCA) evaluated the sustainability of food-waste-to-energy alternatives, and the production of green coffee, raw milk and leafy vegetables, and identified environmental, social and cost hotspots. This approach also proved to be a useful component of decision-making and policy-making processes together with other methods. LCT scientific literature led by LAC or Costa Rican researchers is still scarce; therefore, this research contributed to improve capacities in the use of LCT in this context, while offering potential replicability of the developed frameworks in similar cases. Main limitations related to the representativeness and availability of primary data; however, future research and extension activities are foreseen to increase local data availability, capacity building, and the discussion of potential integration through Life Cycle Sustainability Assessment (LCSA).

Key words: sustainable production, food systems, Life Cycle, coffee, food waste, milk, vegetable.

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Abbreviations and Acronyms

AD	Anaerobic Digestion
AHP	Analytic Hierarchy Process
APROZONOC	Asociación de Productores Orgánicos de la Zona Norte de Cartago / Organic Farmers Association from the Northern Cartago Zone
BR	Basic Requirements
CA	Central America
CNPL	Cámara Nacional de Productores de Leche / National Dairy Producers Chamber
CO2 eq	Carbon dioxide equivalent
CP	Composting
CR	Consistency ratio
CRC	Costa Rican Colones (currency)
CSO	Consejo de Salud Ocupacional / Occupational Health Council
Cu	Copper
DCC	Dirección de Cambio Climático / Climate Change Directorate
DIGECA	Direccion de Gestión de la Calidad Ambiental / Environmental Quality Management Directorate
EC	European Commission
E-LCC	Environmental Life Cycle Costing
EPD	Environmental Product Declaration
FAO	Food and Agricultural Organization of United Nations
FE	Freshwater eutrophication
ff	fanega (volumetric unit of coffee measurement equivalent to two double hectolitres)
FIDA	Fondo Internacional de Desarrollo Agrícola / or IFAD International Fund for Agricultural Development
FITTACORI	Fundación para el Fomento y Promoción de la Investigación y Transferencia de Tecnología Agropecuaria de Costa Rica /Agricultural Innovation and Technology Transference Foundation of Costa Rica
F-RS	Fossil Resource scarcity
FS	Food Systems
FUSIONS	Food Use for Social Innovation by Optimising Waste Prevention Strategies (FP 7 EU Project)
FW	Food Waste
GBS	Global Bioeconomy Summit
GDP	Gross Domestic Product
GHG	Green House Gas
GWP	Global Warming Potential
ha	hectare
ICAFE	Instituto Costarricense del Café / Costa Rican Institute of Coffee
ICO	International Coffee Organisation
INDER	Instituto de Desarrollo Rural / Rural Development Institute
INEC	Instituto Nacional de Estadística y Censo / National Institute of Statistics and Census
INTECO	Instituto de Normas Técnicas de Costa Rica /Costa Rican Technical Norms Institute
IPPC	Intergovernmental Panel on Climate Change
ISM	Interpretive Structural Modelling
ISO	International Organization for Standardization
IVI	Importance Value Index
LAC Region	Latin America and Caribbean Region

LCA	Life Cycle Assessment
LCC	Life Cycle Costing
LCSA	Life Cycle Sustainability Assessment
LCT	Life Cycle Thinking
LF	Land Fill
LPG	Liquified Petroleum Gas
LU	Land use
MAG	Ministerio de Agricultura y Ganadería /Agriculture and Livestock Ministry
MDGs	Millennium Development Goals
MEIC	Ministerio de Economía Industria y Comercio / Ministry of Economy, Industry and Commerce
MICITT	Ministerio de Ciencia y Tecnología / Science and Technology Institute
MICMAC	Matrice d'impacts croisés multiplication appliquée á un classment
MINAE	Ministerio de Ambiente y Energía / Ministry of Environment and Energy
Mo	Molybdenum
M-RS	Mineral Resource scarcity
MTSS	Ministerio de Trabajo y Seguridad Social / Ministry of Work and Social Security
N	Nitrogen
NAMA	Nationally appropriate mitigation actions
NDC	Nationally Determined Contribution
OECD	Organisation for Economic Co-operation and Development
OPS	Organización Panamericana de la Salud /Panamerican Health Organisation
P	Phosphorous
PCR	Product Category Rule
PNUD	Programa de Naciones Unidas para el Desarrollo / or UNDP United Nations Development Programme
REFRESH	Resource Efficient Food and dRink for the Entire Supply cHain (H2020 EU Project)
SAM	Subcategory assessment method
SCP	Sustainable Production and Consumption
SDG	Sustainable Development Goals
SEPSA	Secretaría Ejecutiva de Planificación Sectorial Agropecuaria / Executive Secretary of Agriculture Sector Planning
SETAC	Society of Environmental Toxicology and Chemistry
S-LCA	Social Life Cycle Assessment
SSIM	Structural self-interaction matrix
TA	Terrestrial acidification
TEC or ITCR	Instituto Tecnológico de Costa Rica /Costa Rican Technological Institute
UCR	Universidad de Cost Rica / University of Costa Rica
UN	United Nations
UNEP	United Nations Environmental Programme
UNICEF	United Nations Children's Fund
USD	United States Dollars
WC	Water consumption
WFP	World Food Programme

CHAPTER 1: Introduction

1.1. Sustainable production and consumption, a focus on food systems

Sustainability has been a part of global, regional, and national agendas for decades. The currently accepted definition for sustainable development was presented in the Brundtland Commission's report of 1987 (UNEP/SETAC, 2009) as a challenging and intricate vision to fulfil current needs as well as the ones from future generations, while necessarily interconnecting three pillars: environment, economy, and society (Mensah & Ricart Casadevall, 2019). The international community poured this concept into strategic efforts to accomplish such development; one of these efforts was the declaration of the Millennium Development Goals (MDGs) in 2000. At the present, the Sustainable Development Goals (SDGs) of the Agenda 2030 subscribed by Members of the United Nations (UN), constitutes the main set of guiding elements to achieve sustainable development, considering five main themes: people, planet, prosperity, peace and partnerships, combined in 17 integrated and indivisible SDGs (UN, 2015).

Sustainable consumption and production (SCP) is explicitly expressed as one of the SDGs, no.12. This goal aims at ensuring sustainable patterns through a systemic change that promotes resource efficiency and decouples economic growth from environmental degradation. The definition of SCP, assumed by the United Nations Environmental Programme (UNEP), was based in the 1994 statement of the Norwegian Ministry of Environment, who stated that SCP is "*The use of services and related products, which respond to basic needs and bring a better quality of life while minimizing the use of natural resources and toxic materials as well as the emissions of waste and pollutants over the life cycle of the service or product so as not to jeopardize the needs of future generations*" (UNEP, 2010). Two main elements derive from this definition. On one hand, it poses an approach related to the life cycle of services or products, and not only the attention at a single stage of a product or service, *i.e* use, production, transport. On the other, it sets the bases for improved and extended utility of extracted resources as well as the decreased degradation of the environment. Both elements lead current research, policies and business trends, resulting in several approaches such as bioeconomy and circular economy (Corona, Shen, Reike, Rosales Carreón, & Worrell, 2019), which are at the heart of an increasing number of frameworks in national and regional agendas to promote sustainable economic growth. The bioeconomy entails the use, production and conservation of biological resources as well as its related knowledge, science and technology in all sectors of economy (GBS, 2018 a), through intrinsic circularity traits. In this regard, the circular economy proposes the reduction of raw material extraction and the recirculation of resources for more time in the system, creating benefits to society, industries, and the environment (Corona, Shen, Reike, Rosales Carreón, & Worrell, 2019).

The SDG 12 applies to different economic sectors, from tourism to transport, to procurement, and food systems (FS) (UNEP, 2010). The latter is considered a leading sector of the global economy (Accorsi & Manzini, 2019), and involves different actors and stages of the food supply chain, acting to provide healthy, affordable and safe food for a growing population (Vittuari, et al., 2019). The principles from biocircular economy are natural for FS; therefore, they are also considered more often as a critical determinant for the extension of achievement of many SDGs and as an entry point for many sustainability strategies. Transformation into more sustainable and inclusive FS can support other goals related to ending hunger (SDG 2), reduced climate impacts (SDG 13), and protection and avoidance of degradation of water sources, and water and land ecosystems (SDGs 6, 14, 15). A Sustainable FS also promotes decent working conditions and economic growth (SDGs 8) to help in ending poverty (SDG 1) (Independent Group of Scientists appointed by the Secretary-General, 2019).

Unfortunately, many current patterns in production and consumption in FS are unsustainable, causing externalities that range from air, water and soil pollution and degradation, to food losses and waste, food insecurity, and emissions that increase climate change (Accorsi & Manzini, 2019). Other effects are unfair working conditions for farmers and their employees (Mani, Agrawal, & Sharma, 2016), and price volatility of food products (Lanfranchi, Giannetto, Rotondo, Ivanova, & Dimitrova, 2019). In consequence, modern food supply chains require systemic and integrated approaches that address their complex dynamics among stakeholders, subsectors (García-Herrero, De Menna, & Vittuari, 2019), and stages of the life cycle of food products.

1.2. Sustainable food systems in developing countries

Global frameworks for more sustainable FS require adaptation to better tackle the challenges in different regions and contexts. Developing countries, as defined by the UN, entail a group of countries with particular socioeconomic conditions and usually lower income and GDP than developed nations and economies in transition (Altshuler, Holland, Hong, & Li, 2016) (UN, 2020); thus, specific policies that encompass their needs and resources are to be observed.

Most Latin American and Caribbean Region (LAC Region) nations belong in the developing countries typology. This Region is formed by 42 countries (PNUD, 2019), produces 14% of the world's agri-food supply and accounts for 23% of global exports (OCDE/FAO, 2019). Socioeconomic improvements of the past decade allowed LAC to become one of the regions able to reduce hunger and malnutrition (FAO, 2019); however, this condition is dramatically threatened by the effects of the Covid19 pandemics, particularly in rural areas where most agriculture and livestock production takes place (FAO, FIDA, OPS, WFP & UNICEF, 2020). Several international organisations are present in the LAC Region, and academic and public-private alliances begin tailoring many of the current policies towards sustainable FS. For instance, even when still at early stages, scientific production in circular economy topics (Martínez, Henríquez, & Freire, 2019), and policies dealing with food security and nutrition, rural development, urban-rural integration within food systems, and environmentally sustainable agriculture practices (Intini, Jacq, & Torres, 2019) are beginning to find a substrate to grow.

Despite its economic and food supply relevance, LAC countries present growing inequity (Kliksberg, 2000) and low investment in the agri-food sector. This situation causes challenges for achieving food security, nutrition, and health, and maintaining traditional livelihoods, exacerbating other problems such as migration and poverty, especially in rural areas (OCDE/FAO, 2019). In consequence, approaches to achieve sustainable FS must consider not only investments and economic indicators of these developing countries, but also the diverse cultural base and agro-ecosystems under which food is produced in the Region. This diversity includes a blend of modern, mixed and traditional FS, different access levels to education and food, pressures from global markets in regards to quality, environmental and social standards (Intini, Jacq, & Torres, 2019) and the imminent challenges caused by climate risks (UN DESA, 2019). Some of these disparities can be explained by the heterogeneous ecological and socio-economic conditions, printed by geography, ecosystems, and different culture blending among native inhabitants and immigrants from Europe, Asia and Africa. However, common traits can still be observed within subgroups of LAC nations, such as the Central or Meso American Subregion.

Costa Rica is one of the Meso American countries, and was of interest in this study. This is a democratic republic located in the Central American isthmus; sharing several agro-ecosystem similarities with neighbour countries. It is characterised as an upper middle-income country, with steady economic growth (strongly supported by agriculture), low poverty indicators (World Bank, 2020), and exemplary environmental, biodiversity and conservation standards (Rodríguez-Becerra & Espinoza, 2002). 5,2% of the Costa Rican GDP is based on the agri-food sector and 47,1% of the national territory is dedicated to agriculture activities; moreover, 12.3% of the jobs and 45.7% of the exports are grounded in agriculture (SEPSA, 2016). Currently, the country has one of the most dynamic approaches in the region for the achievement of the SDGs, after the declaration if the Sustainable Production and Consumption National Policy, and updated National Determined Contribution (NDC) under the Paris Agreement, and the National Bioeconomy Strategy 2020-2030 (MICITT, 2020) (MINAE-DIGECA, 2019) (MINAE-DCC, 2021). The foreseen bioeconomic Costa Rican model that integrates the triple-bottom dimensions of sustainability is expected to cause a convergence within biodiversity and conservation, food security, agriculture, traditional and science-based knowledge, innovation and adaptation to climate change (GBS, 2018 b).

Nevertheless, the Country still needs to overcome many sustainability challenges, some of them addressed in this research in regards to awareness and science-based decisions and policies. “Sustainable production” is often used in several studies and initiatives, but there is still scarcity of high impact scientific-literature production supporting the measurement and declaration of that condition through robust and systemic methods in the country. Even when the agriculture sector sustains essential indicators of the Costa Rican economy, it is continuously exposed to markets, prices and climate instability, and constrains in food security (OECD , 2017), especially in the case of farmers and workers who, ironically, produce that same food.

1.3. Assessment and decision-making for sustainable FS, a Life Cycle Thinking approach

Decision-makers need to be wary of the complexities, complementarities, interconnections and trade-offs within the triple bottom pillars of sustainable development. In the specific case of FS, sustainability assessments and interventions should also consider peculiar traits resulting from the involvement of natural processes and human management (Mensah & Ricart Casadevall, 2019) (Gulisano , y otros, 2018). In this sense, science-based evidence must help to identify critical points to target potential solutions to achieve SCP, and support decision-making processes at the product or FS policy level (EC, 2010).

A life cycle approach, already present at the adopted working definition of SCP in 1994, appears as the utmost opportunity to move towards more sustainable production and consumption in food systems. On one hand, the approach is supported by scientific processes, allowing the detection of priorities in more transparent and systemic manners. Moreover, it aids in effectively targeting decisions and policies (Sonnemann, et al., 2018), and maintaining the perspective of the interconnections and potential burden-shifts within the environmental, economic and social dimensions of sustainable FS.

Originated decades ago, Life Cycle Thinking (LCT) has evolved from an academic and private business application to a decision and policy support tool. LCT not only allows to debate about the results within practitioners, but it is also useful to communicate the outcomes (Sonnemann, et al., 2018) to users and non-users of LCT methods, entailing a paramount potential to trigger the needed transformations in FS. The life cycle vision widens the considerations of decision-makers to a supply/use/end-of-life perspective, and in this way, it allows the awareness of the benefits, impacts and potential trade-offs or a product or service through the lifespan of products (EC, 2010). Finally, this vision allows to better understand the potential outcomes of proposed interventions (De Menna, y otros, 2020).

LCT is defined by the European Commission (EC, 2010) as the "*the consideration of the potential environmental impacts that a product can have during its life cycle; from extraction and processing of raw materials, through manufacturing, distribution and use, to recovery or recycling and disposal of any remaining waste*". Moreover, quantitative methodologies like Life Cycle Assessment (LCA), as well as further extensions to the economic and social dimensions, allow to examine sustainability and bring LCT into practice (Sala & Castellani , 2019) (Manik, Leahy, & Halog, 2013) (UNEP/SETAC, 2009) (Parent , Cucuzzella , & Revéret, 2013). Depending on the intended perspective, LCT can provide a measurement of the sustainability of a product or service (in an attributional approach) or potential future impacts derived from interventions (in a consequential approach).

The three most developed LCT techniques consist of LCA, Life cycle costing (LCC) and Social Life Cycle Assessment (S-LCA). LCA analyses a product or service through its life cycle, quantifying its environmental impacts (INTECO, 2007); LCC quantifies the costs incurred during the life cycle of a product, by one or more actors in the entire product life cycle (Hunkeler, Lichtenvort, & Rebitz, 2008), and S-LCA informs of potential social footprints and handprints, and provide evidence for decision making and discussion, to advance towards improved social performance in the life cycle of products (UNEP, 2020) . LCA and LCC are well documented, robust and flexible in assessing environmental and cost dimensions; however, gaps among LCT and food system experts (Östergren, et al. , 2017), or between LCT and decision-makers are still present. Moreover, S-LCA is still considered at an early stage.

Even when LCA is widely used by policy makers in many countries (Sonnemann, et al., 2018), developing nations are only beginning to use them into decision-making processes. For instance, LAC countries, including Costa Rica, have decided to move towards SCP, decarbonisation, improved agriculture and rural development, and international markets participation, which demand environmental declarations (MICITT, 2020) (ICAFE (b), 2020) (MINAE, 2019), (Martínez, Henríquez, & Freire, 2019) (EC, 2010). Therefore, there is a growing pression and enabling environment to take advantage of LCT tools to successfully achieve these targets. The increase and improvement of knowledge, the closing of research gaps, and the encouragement of the application of LCT approaches in the Costa Rican and LAC context can result in the provision of diagnoses, scenario comparisons, and decision-making and policy frameworks to better address the challenges towards sustainable FS.

1.4. Aim and structure of the Thesis

With the interest to support the search of an increased and improved LCT approach in the Costa Rican FS that supports a more sustainable production, this thesis initiated with the following three research questions:

a) How to measure the environmental and economic sustainability of green coffee production, and waste-to-energy alternatives, considering that these two are key elements within the Costa Rican Agriculture and Sustainability Agendas?
b) How to assess social sustainability in selected Costa Rican agriculture-based products, given the overall recognized social characteristics of the country?
c) What could be the contribution and applicability of the performed assessments (a and b) to decision-making processes at the farm or sector level, in alignment to current market, policy and SCP trends?

The thesis aimed *to evaluate the sustainability of products from selected food supply chains in Costa Rica, aiding in the provision of inputs for further sustainable food system decision-making, through the application of the Life Cycle Thinking approach.*

Chapter 1 captures the main conceptual aspects that provided fundament to the aim and development of the thesis, while Chapters 2 to 4 entail the development of the case studies. Four case studies built the thesis, integrated in a logical collection of scientific papers to jointly answer the research questions and aim of the thesis.

Therefore, chapter 2 consists of a decision-making framework built in a university consortium (case study 1), through the combination of:

a) Literature reviews and linear programming to model food waste-to-energy scenarios
b) E-LCC and LCA to evaluate the scenarios, and
c) Analytic Hierarchy Process to undertake the outputs from the LCA and E-LCC as part of a decision-making process.

Chapter 3 focuses on the links between environmental, productive and socioeconomic aspects in green coffee production (case study 2) to suggest a model that considers the influencing factors in farmers' decisions to move towards more sustainable production. The followed multi-method approach in this chapter included:

a) a literature review to obtain possible related factors for sustainable shaded-coffee farming
b) the characterization of six small coffee farms through LCA, E-LCC and shaded-coffee systems evaluation, and
c) the application of the Interpretive Structural Modelling (ISM) method, supported by experts' consultations to define the model of the interlinked influencing factors for more sustainable coffee production.

Chapter 4 was dedicated to understand the potential social strengths and vulnerabilities of the production of green coffee (case study 2), raw milk (case study 3) and leafy vegetables (case study 4), in the particular context of Costa Rica. In this section, S-LCA was applied, through the definition of a goal and scope for the study, an inventory analysis, impact analysis and interpretation of results.

To finalize, Chapter 5 discusses and concludes on each paper regarding the research questions of the thesis, acknowledges the limitations, and suggests further research, presenting this investigation as a bridge to increase the application of LCT in the pursue of sustainable food systems in Costa Rica.

CHAPTER 2: Decision-Making Process in the Circular Economy: a Case Study on University Food Waste-to-Energy Actions in Latin America

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Abstract: Economies have begun to shift from linear to circular, adopting, among others, waste-to-energy approaches. Waste management is known to be a paramount challenge, and food waste (FW) in particular, has gained the interest of several actors due to its potential impacts and energy recovery opportunities. However, the selection of alternative valorization scenarios can pose several queries in certain contexts. This paper evaluates four FW valorization scenarios based on anaerobic digestion and composting, in comparison to landfilling, by applying a consistent decision-making framework through a combination of linear programming, Life Cycle Thinking (LCT), and Analytic Hierarchy Process (AHP). The evaluation was built upon a case study of five universities in Costa Rica and portrayed the trade-offs between environmental impacts and cost categories from the scenarios and their side flows. Results indicate that the landfill scenario entails higher Global Warming Potential and Fresh Water Eutrophication impacts than the valorization scenarios; however, other impact categories and costs are affected. Centralized recovery facilities can increase the Global Warming Potential and the Land Use compared to semi-centralized ones. Experts provided insights, regarding the ease of adoption of composting, in contrast to the potential of energy sources substitution and economic savings from anaerobic digestion.

Keywords: centralized waste valorization; lifecycle thinking; AHP; side flow; anaerobic digestion; composting

2.1. Introduction.

The circular economy is regarded as a sustainable economic system that reduces raw material extraction and recirculates resources, while creating benefits to society, industries, and the environment [1]. Strategies for its achievement include principles from various schools of thought, where designing out what is commonly observed as waste is fundamental [2] because of the value remaining in these materials. Waste, together with productive activities and transport, are relevant sources of environmental degradation and impacts, such as global warming, which involves a significant risk for humanity [3]. Ordinary waste entails almost 50% of organic sources approximately, and food waste (FW) is the highest contributor of that organic fraction [4]. Globally, it is accountable for 4.4 Gt CO2 eq per year [5]. Consequently, the disregard of FW causes economic, social, and environmental constraints [6,7].

Target 12.3 of the Sustainable Development Goals (SDG) aims to halve FW by 2030 [8], and in pursuit of that reduction, the "food use-not-waste" hierarchy embraces alternatives from most to less desirable, similar to the waste management hierarchy from the EU Waste Framework Directive 2008/98/EC [9,10]. FW management begins with the prevention and optimization of food use and supply. Actions include the avoidance of FW throughout the supply chain, as well as the donation and redistribution of surplus for human consumption when possible, and then the allocation to animal feed or non-food product transformation. Once FW occurs, it shall be valorized and treated through recycling and energy recovery, before landfilling [9,10,11]. That final disposal is commonly perceived as the least preferable option, due to its high environmental implications, such as emissions to soil, water, and air, occurring during biowaste degradation [10].

The interest in the circular economy and FW reduction in food systems rests, among other reasons, on the fact that this sector is high in energy demand, and suffers from intake-output energy imbalances [12]. Therefore, the recovery of currently wasted energy embodied in FW can represent an opportunity to recirculate energy into human activities again, thus aiding into more sustainable systems.

Depending on FW composition, anaerobic digestion and composting, are regarded as suitable options for energy recovery [12]. Anaerobic Digestion (AD) consists of the anaerobic degradation of the residues while generating biogas and digestate, which can be used as fertilizer with lower environmental impacts [13,14,15,16]. Even when suggesting the fittingness of the obtained by-products from this alternative, various authors recommend a close observation in regards to the source and composition of the FW and co-digesting materials, and the technical and economic potential challenges [17,18,19,20]. Composting (CP) is defined as the controlled organic waste degradation through biological agents, suitable to treat the biological fraction of ordinary waste [10], resulting in a rich soil substrate. Experiences using the Takakura composting method has proven it to be an efficient option for food and garden biowaste treatment [21], while remaining a relatively easy-to-adopt practice at domestic or larger scales [22,23].

Even when preferred over landfilling, FW valorization will also have recognized risks and embedded effects, due to emissions, transport, degradation, and labor [22,24]. Therefore, decision-making processes to support the selection of one option or another are not simple. Life Cycle Thinking (LCT) is considered to be an apt approach to evaluate food waste valorization alternatives through methods like Life Cycle Assessment (LCA) and Environmental Life Cycle Costing (E-LCC) [7,25,26,27]. In addition, multicriteria decision methods can aid managers and policy-makers from different levels to analyze the trade-offs offered by science-based evidence from the evaluation of different alternatives [28].

Several studies in certain regions such as Latin America and the Caribbean, focus on waste generation and composition analysis [4,29,30,31,32] and few of them directly involve LCT [33] or decision-making approaches for waste management, neither a combination of those. Therefore, gaps in literature availability and decisional frameworks, suggest integrated approaches are required [34]. Enormous amounts of biomass are possibly available for circular strategies in this Region, since 54% of the 160 million tons of its yearly waste belonging to biowaste, is generally disposed in landfills [31]. Even when a regional agreement or framework for bioeconomy is lacking, Latin American countries have recently begun to undertake specific policies towards a circular economy and food waste valorization [35]. Costa Rica, in particular, launched several initiatives on this matter, such as the inter-sectorial actions led by the Costa Rican Food Loss and Waste Network [36], the National Policy on Sustainable Production and Consumption [37], the National Decarbonization Strategy [38], and the Integrated Waste Management Law no.8839 [39]. On one hand, these policies motivate different stakeholders to pursue FW valorization actions; on the other, it enables actions that would directly support further steps into the achievement of the SDGs, such as less FW generation and waste management alternatives with lower emissions.

This paper evaluates FW valorization alternatives and compares them to the business-as-usual FW landfilling, through a combination of methods that includes linear programming to determine an optimal collection route for the waste, environmental and economic potential impacts analysis through a system-expanded LCA and E-LCC, and the prioritization of alternatives through an Analytic Hierarchy Process (AHP). The evaluation was built upon a case study of five universities, and it is one of the first assessments of this kind in Costa Rica and the Latin American region. The final aim is to contribute to decision-making processes to move into more circular approaches at the university consortium level, but also at the local level by offering a consistent framework to support actions to valorize FW. Potentially, the study can help other similar institutions, small communities or even small municipalities to plan for their biodegradable waste management in small centralized or semi-centralized units, and prioritize sustainable approaches to address food waste.

2.2. Materials and Methods

2.2.1. Methodological Framework and Case Description

This case study proposed a decision-making process for food waste-to-energy scenarios, through their evaluation and comparison to a business-as-usual scenario, landfill (LF).

It aggregated the FW from a consortium of five universities located in and nearby the Central Valley of Costa Rica, belonging to a national network of sustainable education institutions called REDIES. Rojas-Vargas et al. [30] determined the amount of FW generated in these university canteens using the standardized guidelines to measure FW in restaurants provided by the Costa Rican Food Loss and Waste Network [40]. That first and only available formal study on FW quantification for a group of universities in the country amounted 2.607 tons of FW per week, with an operative service of 45 weeks, given their academic calendar. There are different food waste definitions; and this paper adopts the FW conceptualization reported by the FUSIONS definitional framework that describes it as “any food, and inedible parts of food, removed from the food supply chain to be recovered or disposed” [41].

Being the landfilling disposal a common practice in Costa Rica, and generally in Latin America, this study proposed to follow the “food use-not-waste” hierarchy [9], which can be easily aligned to the Costa Rican Waste Management Law [39] and the REFRESH Generic strategy for LCA and LCC [42]. This study proposed to move from a situation where FW was disposed at the landfill, to a situation of valorization, or food waste-to-energy alternatives. This perspective was similar to the one described by the REFRESH strategy as REFRESH Situation (RS) RS 4 to RS 3, since the university consortium would agree to hand over the FW for valorization as part of their waste management (RS 3) instead of sending it to an end-of-life treatment or landfill (RS 4) as presented in Figure 1.

Anaerobic Digestion (AD) and Composting (CP) are among the alternatives to be considered, generating a side flow that has some value with the potential to replace a product on the market.

The overall methodological framework, accompanied by an iterative literature review, combined three methods (Figure 2) in a step-wise sequence.

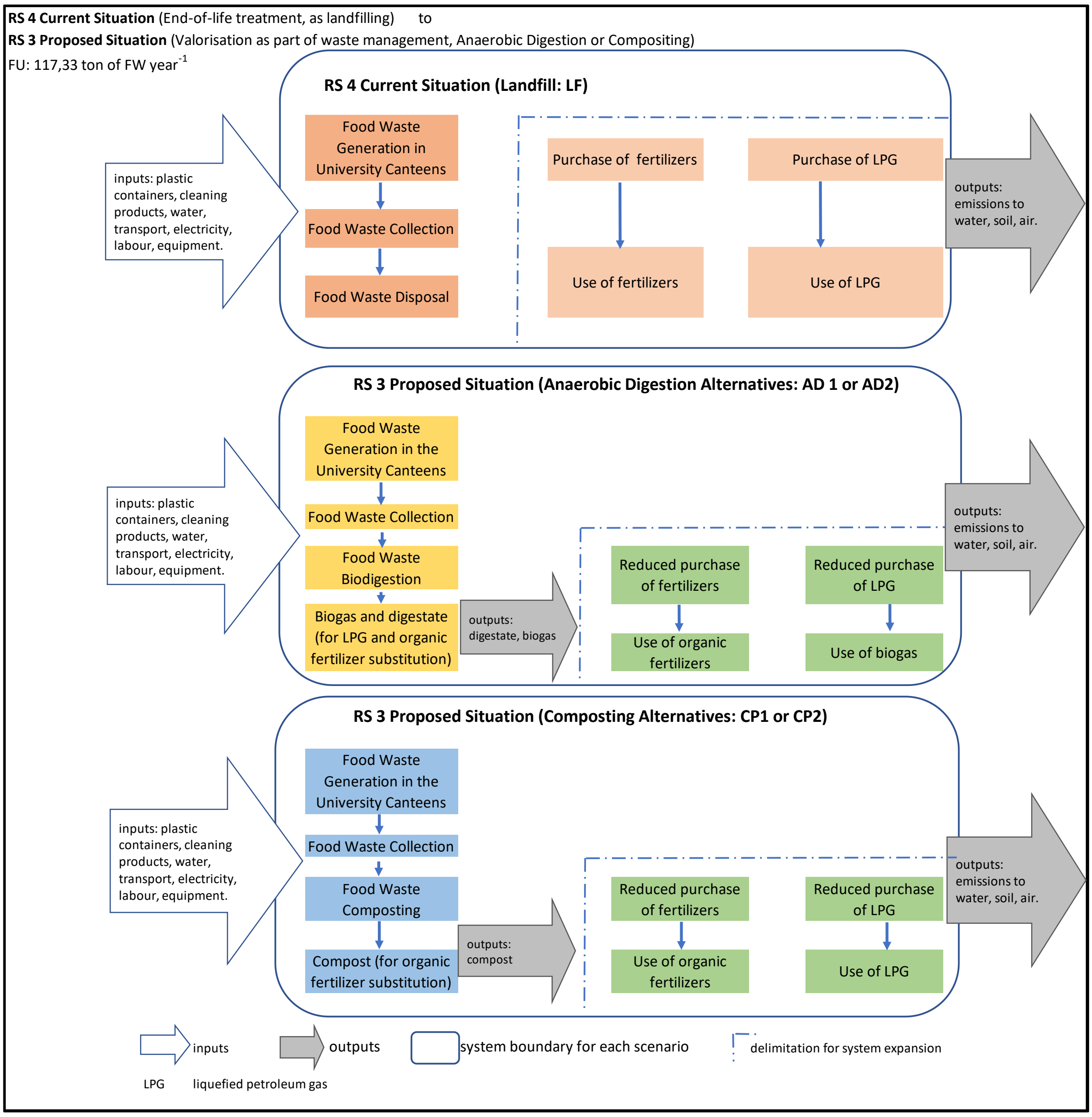

Figure 1 Flow diagram of proposed situations in the University Consortium, for valorisation through FW-to-energy alternatives. Source: adapted from J. Davis and authors, 2017.

The first method aimed to define the FW valorization sites and collection routes, through Linear programming. This led to two possible route designs that were used to model four FW valorization scenarios. Once the scenarios were defined and supported by literature reviews and by experts, a pre-selection of evaluation criteria was considered to later conduct a system-expanded LCA and E-LCC, which considered the impacts caused by the valorization scenarios, as well as the avoided impacts since FW would be diverted from LF and side flows would be utilized. LCA and E-LCC allowed to observe the performance of each scenario in terms of the environmental impacts and costs categories, offering relevant data for an experts' assessment developed through the third applied method of this framework: the AHP. This latter allowed to prioritize the scenarios within the local context and following a science-to-expert approach.

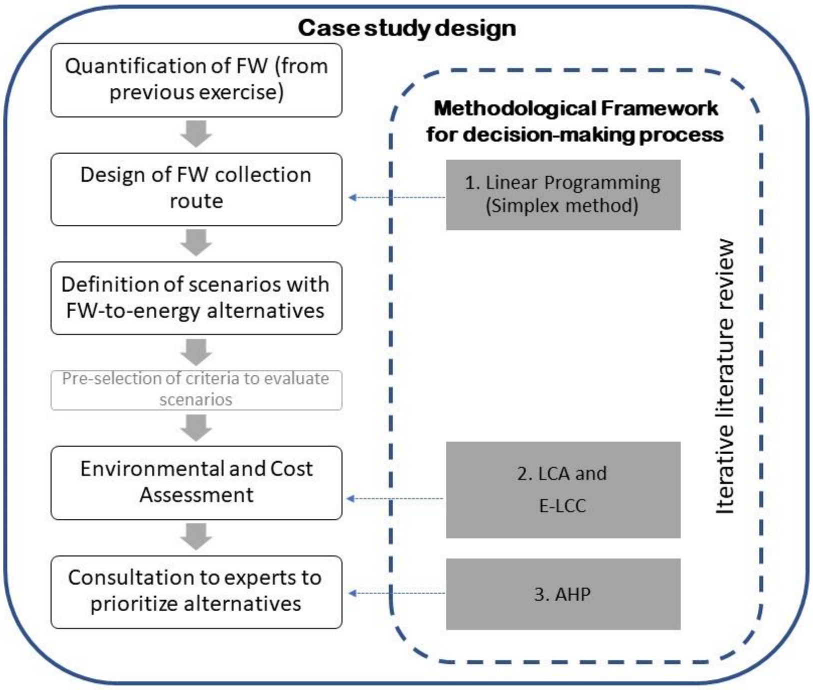

Figure 2 Methodological framework for a decision-making process of food waste (FW) valorization alternatives.

2.2.2. Route Optimization

Since the five universities have accredited environmental managers and operate under the university autonomy principle, it was assumed that they could potentially treat the FW and would agree on diverting the FW from a business-as-usual to a valorization scenario. Therefore, a simulation of an FW collection route was performed for this consortium. First, the FW valorization plant location was evaluated, through a decision matrix defined by the researchers, with four criteria and the following qualification scale and weight, based on similar techniques presented by various authors [43,44]:

1. Space availability to install the waste valorization plant: this criterium would receive a binomial response, where a value of 1 will be assigned if the campus had an available area of at least 250 m2 where a waste valorization plant can be established without negatively affecting the university activities, 0 would be given if that space was not available. This area (m^2) was selected base on the experience and observation of biowaste treatment facilities in municipalities and institutions;

2. Technical capacity to operate an FW treatment process: with a binomial response also, the site would receive a score of 1 if there was a minimum of one professional at campus capable and knowledgeable in waste management at least at the pilot scale, 0 if that kind of professional was unavailable;
3. Available infrastructure: the binomial qualification for this criterion would consist of assigning a value of 1 if the campus had at least one operative anaerobic digestor or composter to process the FW, 0 if they did not have any infrastructure for FW treatment
4. FW quantity: a 5-value scale was assigned in this criterion, where 5 corresponds to the highest FW quantity generated within the group of campuses, and 1 for the smallest amount of FW.

Each criterion was weighted [43,44,45,46] from a full score of 100%, as follows: a weight of 15% was assigned to technical capacity, supported by a law requirement in the country, a 25% weight was assigned to space availability and FW quantity, since they would have a higher impact than the previous criterion but in equal conditions among themselves. Finally, a 35% weight was assigned to available infrastructure, since it would have higher importance than the previous in terms of the possibility of short-term establishment of the valorization alternatives and budget implications. The location(s) with the highest score were to be selected to install the FW valorization facility since it would have available space, technical capacities, available infrastructure and higher amounts of FW to process.

Afterwards, the researchers calculated the average distances between each FW generation site (institutions) using Google maps. This allowed us to obtain the distance in kilometers between each two points, later used in the route design, with the assumption that budget constraints in the universities would only allow one truck for a weekly FW transportation. The five institutions were codified as A, B, C, D and E, corresponding to the five campuses of this study (Figure 3). A value matrix was set up with the average distances between each two points (Table 1) and modeled by linear programming, using the Simplex LP Method [47] and the Solver Tool from Microsoft ® Excel ® (2019 MSO Version, Microsoft Corporation ©, Redmond, WA, USA), to obtain the optimal route by minimizing the total distance.

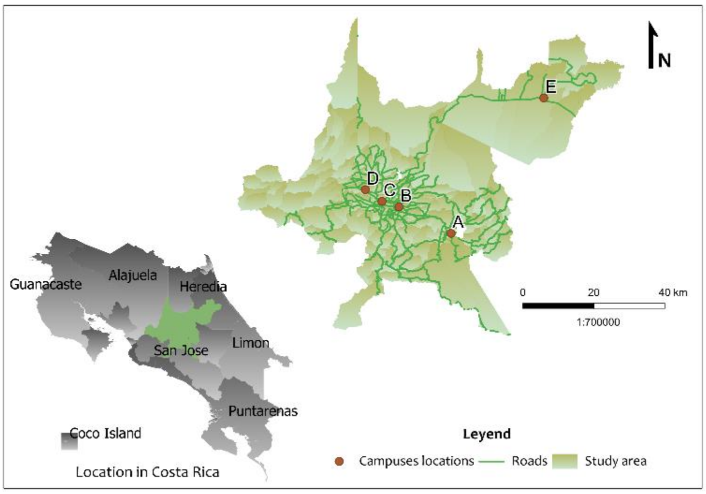

Figure 3 Location of the five campuses of the universities from the consortium (image developed by Mariajosé Esquivel, using Costa Rican Digital Atlas, 2014. Projection: CRTM05. Q GIS Software, Version V3.4, The Open Source Geospatial Foundation OSGeo, Chicago, IL, USA).

Table 1 Distance matrix among the five university campuses (sites) in kilometers (km).

SITES	A	B	C	D	E
A	0	22	40	34	104
B	22	0	16	11	86
C	40	16	0	11	82
D	34	11	11	0	95
E	104	86	82	95	0

Due to the farther distance from location E to the rest of the group, a second linear programming model was calculated (Table 2).

Table 2 Distance matrix among four of the university campuses (sites) in kilometers (km).

SITES	A	B	C	D
A	0	22	40	34
B	22	0	16	11
C	40	16	0	11
D	34	11	11	0

Two routes were calculated, one that would accept all the FW from the first four generation sites and deliver it at the fifth campus for centralized valorization (coded as 1), and a second route that would consist of a semi-centralized valorization where more than one campus would be in charge of processing the FW (coded as 2). The obtained data was later used in the LCA and E-LCC to compare the effect of the two routes on each FW valorization alternatives.

2.2.3. LCA and LCC

Goal and Scope

Following the ISO14040 Standard [48] and Hunkeler D., Lichtenvort K., and Rebitzer, G. [49] respectively, LCA and E-LCC were used to understand the environmental and economic effects the consortium of universities would have as a result of moving from a business-as-usual to an FW valorization scenario. This consortium with already well-established FW measurement and environmental management units, defined the system boundaries from gate to gate: from the FW generation point to the campus where the valorization facilities would be established and side flows would be obtained [42,50]. These side flows, have an already existing market value in Costa Rica [51] and could be used by the same university or a third party, who would collect them at the campus gate.

Reference Flows and Functional Unit

The study uses a reference flow that consists of a mass-based unit for the LCA and monetary-based units for the E-LCC, considering as functional unit (FU) the amount of treated FW per year: 117.3 t of FW per year.

Environmental Impact Categories, Cost Elements and Assessment Methods

Literature reviews, the criteria of the researchers and a set of three advisors with international, regional and national experience in FW and waste management suggested the main indicators to evaluate the alternatives. The two main environmental impacts were Global Warming Potential and Land-Use, both consistent with the recommended categories in FW LCA analysis, as well as with Costa Rican aim on decarbonization. Midpoint indicators were preferred by this study in order to observe particular impact categories for this type of FW valorizations processes. Therefore, the ReCiPe 2016 midpoint method, Hierarchic version (developed by RIVM, Radboud University Nijmegen, Leiden University and PRé Sustainability) was applied using SimaPro (Version 9.0.0.49, PRè Consultants ©, Amersfoort, The Netherlands). In general, the study calculated these potential environmental impacts, focusing mostly on the first two:

- Global Warming Potential (GWP), expressed in kg CO_2 eq;
- Land-Use (LU), expressed in m^2a crop;
- Terrestrial Acidification (TA), expressed in kg SO_2 eq;
- Freshwater Eutrophication (FE), expressed in kg P eq;
- Mineral Resource Scarcity (M-RS), expressed in kg Cu eq;
- Fossil Resource Scarcity (F-RS), expressed in kg oil eq;
- Water Consumption (WC), expressed in m^3.

The E-LCC included the following cost categories: inputs, labor, transport, public services and depreciation from equipment investments. They were categorized in four main groups: a-inputs and labor at the generation point, b-transport to the disposal or valorization site, c-valorization system (this one includes all operation elements such as inputs, labor, energy, water), and d-depreciation due to the use of the equipment in which the consortium shall invest. The depreciation cost related to the required investment and the net economic effect as a result of the overall operative costs and savings during the valorization of the FW, were selected as indicators in the economic dimension, expressed in American dollars (USD).

A category of social-oriented indicators, such as job generation and ease-of-implementation were considered as well. Job generation was calculated after the FW valorization labor requirement was inventoried for the E-LCC and then translated into the amount of new required full-time collaborators for each scenario. The ease-of-implementation was defined as the attribute that expresses how practical or less complex an alternative was in terms of technique, equipment and operation. Both indicators were assessed by the experts during the AHP implementation. Therefore, these indicators not only guided the proper data collection in the inventory phase of the LCA and E-LCC, but were the ones to be considered as criteria during the science-to-expert approach.

Scenarios and Inventory

The alternatives consisted of Anaerobic Digestion (AD) and Composting (CP) as seen in Figure 1 (more detailed information in the Supplementary Materials, Annex 1). The assessment comprised four FW valorization scenarios:

AD1: Anaerobic Digestion in a centralized plant and FW collection route design 1. It proposed the operation of a continuous-load digester, and considered there was an already existing and operational digester on the selected site that would have the capacity to process the annual amount of FW.

AD2: Anaerobic Digestion in a semi-centralized alternative of three valorization plants with route design 2. This scenario required three continuous-load digesters, one was already operating in one site, and new digesters would have to be set in two more valorization sites. It is assumed that the digestate from the already operative digestor would help to establish the microbiota in the other two locations.

CP1: Composting in a centralized plant and FW collection route design 1. This scenario anticipated a modified and scaled Takakura composting method, operated through a set of seven automatic composters (the Model JK5100 ®, Joraform, Laholm, Sweden) available in the market to manage 0,08 ton of FW per day each.

CP2: Composting in a semi-centralized alternative of three valorization plants with an FW collection route design 2. This scenario would also use a modified and scaled Takakura composting method, operated through a set of six new JK5100 ® automatic composters capable to process 0.08 tons of FW per day each and one already similar composter in one of the sites.

In the business-as-usual scenario, the FW was collected and disposed of in a landfill (LF) by an authorized third party. It was modeled upon national data regarding FW collection and disposal costs [52,53], and calculated distances in Google Maps, from the campus to the closest landfill where ordinary wastes would be usually directed to, according to the Environmental managers of these institutions.

An inventory of the inputs and outputs of each scenario was performed, with data gathered from previous experiments [22], literature and a questionnaire filled by the restaurant manager and operators. When necessary, the allocation of certain inputs based on the FW generation proportion of each campus was applied, due to a lack of primary data in some of the institutions. Inputs consisted of plastic containers to collect FW, products and water to clean (both the generation and valorization sites), transport of those inputs, and electricity to pre-condition FW, as well as the required labor to operate each stage. The FW transport was calculated regarding the FW mobilized mass and the FW transportation route; this meant that it considered the kilometers in the business-as-usual route for LF, as well as the kilometers for route 1 or route 2 obtained in the optimized route design. Outputs included the compost or digestate, biogas depending on the valorization alternative, the wastewater, as well as the correspondent emissions for the valorization process and expanded system. Packaging waste from inputs were not included since they would be considered to be outside the system boundaries of the present study. Finally, processes for the correspondent FW treatment or disposition were selected from the Ecoinvent database, whether it was a landfill for municipal solid waste, biowaste anaerobic digestion, or industrial composting on each scenario.

Assumptions and Data Sources

Several literatures present AD and CP as alternatives for FW valorization, and prior studies in one of the universities concluded that those were technically fit within the local conditions, which motivated further analysis and the assumption that these would be the valorization alternatives to be assessed in this study. Most inputs were considered as yearly consumables, except for the plastic containers for the FW, which were estimated to have a life of five years; therefore, the cost and mass for the yearly FW treatment was estimated. All alternative scenarios suppose that 50% of water consumption in cleaning operations would come from rainwater collection, a practice that is becoming more usual in the country. The compost yield was estimated to be 18.75% from the mass of the FW [22]. The biogas yield was obtained from literature reviews regarding biogas production, digestate production, technical characteristics, and calorific potentials, to assume a methane production of 53% of the produced biogas [13,54–57]. Distances from input suppliers as well as from the FW generation to valorization sites were calculated with Google Maps, and databases like Ecoinvent 3.4 were used for the inventoried processes on each scenario. The exchange rate to convert Costa Rican market prices (CRC) into American dollars (USD) was retrieved from the Costa Rican Central Bank at the moment of the study, at a rate of 596.18 CRC: 1 USD. Other information sources included scientific literature, environmental declarations, Costa Rican public services databases and market prices.

Interpretation

Critical stages or hotspots regarding environmental and economic data were identified in the business-as-usual and alternative scenarios, and an evaluation regarding the avoidance of certain impacts through a system expansion was used for a comparison among the four alternatives. A sensitivity analysis was conducted to observe the result of potential input changes suggested by experts during the exercise as well as contextual conditions. The summary of the LCA and E-LCC results was presented to a group of experts, to prioritize the option with more potential to be adopted by the consortium.

2.2.4. Multicriteria Decision Method: AHP

Saaty (2008) established the basis of a multicriteria decision-making approach named Analytic Hierarchy Process (AHP) [28], in which factors are arranged in a hierarchic structure. It follows a systematic set of steps, beginning with the definition of the problem. The second step sets a decision hierarchy structure where the goal of the process is placed at the first level of the structure, criteria on which subsequent elements depend are placed at the intermediate level and the alternatives to be considered in the decision process rest at the lowest level. A third step consists of the construction of pairwise comparison matrices, which are later normalized and an eigenvector is determined to later, in the fourth step, use the obtained priority vectors in the pairwise comparison to weigh the alternatives in the subsequent level. In this study, the goal was to select an FW valorization alternative for this University Consortium, based on pairwise comparisons of environmental, economic and social criteria to later prioritize the FW valorization alternatives.

This study considered six criteria from the environmental, economic and social dimensions (Figure 4), regarded as Global Warming Potential, Land-Use, depreciation cost (linked to the required investment), net economic effect, ease-of-implementation and job generation.

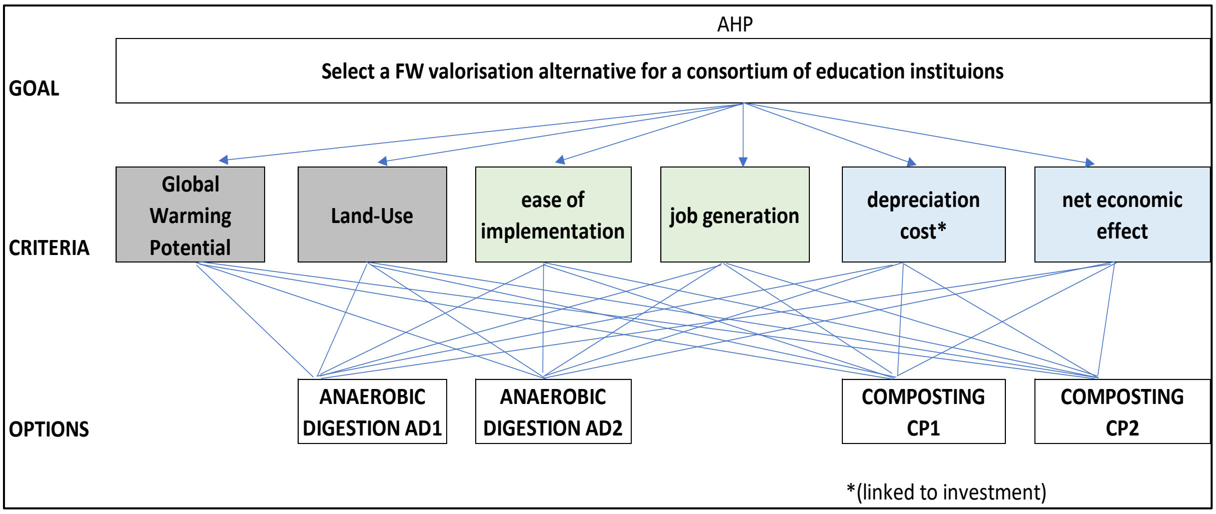

Figure 4 Analytic Hierarchy Process (AHP) structure to evaluate FW valorization alternatives for the university consortium.

A group of 10 experts was reached to provide a science-to-expert approach. The technical information from the description of the scenarios and the results of the LCA and E-LCC was offered to these professionals. The group of experts was gender-balanced and formed by professionals in environmental sciences, engineering and economics, most of them with postgraduate education and currently holding positions as environmental managers from education institutions or local governments, policy makers, academics, specialists in international/non-governmental organizations, or waste valorization entrepreneurs. The responses of the experts where registered in a data collection tool created for this purpose (validated and tested, Cronbach’s $\alpha = 0.93$).

They were asked first to prioritize each criterion versus the other and then to judge each FW-to-energy alternative versus the other regarding the mentioned criteria, using the fundamental scale for absolute numbers. This nine-point scale qualifies the alternatives in regards of the intensity of importance of one option over the other, assigning a value of 1 when there is equal importance, and up to a value of 9 when there is extreme importance [28]. The results were aggregated by a geometric mean, computed into a matrix, and later normalized using Microsoft ® Excel ®. The Eigenvector was calculated and used to weight the results for the four valorization alternatives. Then, the process allowed to prioritize the FW-to-energy or valorization alternatives for the consortium. A consistency check was performed for each matrix through the calculation of the Consistency Ratio ($CR \leq 0.10$). Finally, experts observed the overall results and offered feedback on the methodological framework in a single open-question section of the data collection tool.

2.3. Results

2.3.1. Selection of FW Valorization Facility and Route Optimization

The five campuses were evaluated to assess the possibility of establishing an FW valorization plant (Table 3).

Table 3 Evaluation matrix for the selection of the FW treatment site.

Site	Available Space	Technical Capacity	Available Infrastructure	FW Quantity	Score
A	25	15	0	25	65
B	0	15	0	5	20
C	25	15	35	15	90
D	0	15	0	10	25
E	25	15	35	20	95

As part of the design of the scenarios, this study qualified the capacity of the five campuses to implement FW valorization alternatives. Sites A, C and E had available space, and C and E would have already existing infrastructure and equipment for at least one of the valorization alternatives. Site A obtained the highest score due to the generation of 41.72 ton of FW per year, followed by E (26.51 ton FW year^{-1}), C (20.33 ton FW year^{-1}), B (20.32 ton FW year^{-1}) and D (8.45 ton FW year^{-1}). Consequently, after assigning the values and weight for each criterion, site E was defined as the site of preference to establish an FW valorization plant. Sites C and A would follow, one because of the existence of space and infrastructure, and the other because of the available space and amount of FW which could remain in place in order to avoid its transportation around the consortium. Sites B and D had limited capacities for the establishment of FW-to-energy alternatives.

Considering those results, there was a fist calculation of the best possible route design, named route 1. It consisted of 126 km and FW would be collected first at site A, and continue to point B, to D, to C and finalize in E where the valorization would take place.

The second route calculation proposed a collection route with four sites. In that case, the FW collection route 2 would consist of 33 km of FW transportation. It entailed a semi-centralized valorization system, where the sites that obtained the second and third highest scores in the site evaluation matrix for the plant selection (Table 3) would become FW treatment facilities as well. Therefore, FW from site B would be transported to site A, where FW valorization of both sites would take place; in parallel, site C would valorize its own FW and the one carried from site D; and site E would process its own waste. It would be still done with the restriction of one single truck for FW collection.

2.3.2. LCA and E-LCC

The second method of this framework, based on LCT allowed us to observe the different environmental and cost impacts of the evaluated scenarios.

Table 4 presents the LCA results, regarding the impact categories selected for this study, and from which the GWP and LU were considered for the further science-to-expert approach.

Table 4 Life Cycle Assessment (LCA) for the business as usual and alternative FW disposal or treatment scenarios.

Impact Category	Unit	LF	AD1	AD2	CP1	CP2
Global Warming	kg CO_2 eq	90,050.00	16,113.16	11,906.42	13,973.26	9376.31
Terrestrial Acidification	kg SO_2 eq	17.01	40.11	25.45	193.92	177.66
Freshwater Eutrophication	kg P eq	2.23	2.20	1.92	1.80	1.34
Land Use	m^2a crop eq	388.48	230.30	132.64	542.52	408.88
Mineral Resource Scarcity	kg Cu eq	6.84	16.80	11.68	29.92	16.41
Fossil Resource Scarcity	kg oil eq	1140.30	3034.22	1553.35	2992.81	1417.40
Water Consumption	m^3	58.22	59.74	88.57	55.53	80.32

The disposal of the FW in a business-as-usual scenario such as LF, presents higher Global Warming Potential and Freshwater Eutrophication impacts than the four valorization scenarios. However, CP1 and CP2 present a higher Land-Use than the rest, while AD1 and AD2, has the lowest Land-Use impact of the scenarios. LF has lower Acidification Potential than scenarios AD1, CP1 and CP2; and the four alternative scenarios would have higher Mineral Resources and Fossil Resources depletion than LF. Water Consumption is also increased in all valorization alternatives, except CP1.

Figures 5 to 12 summarize the environmental impacts, detailed in three phases or stages for each scenario: inputs, FW transport and FW disposal (or treatment).

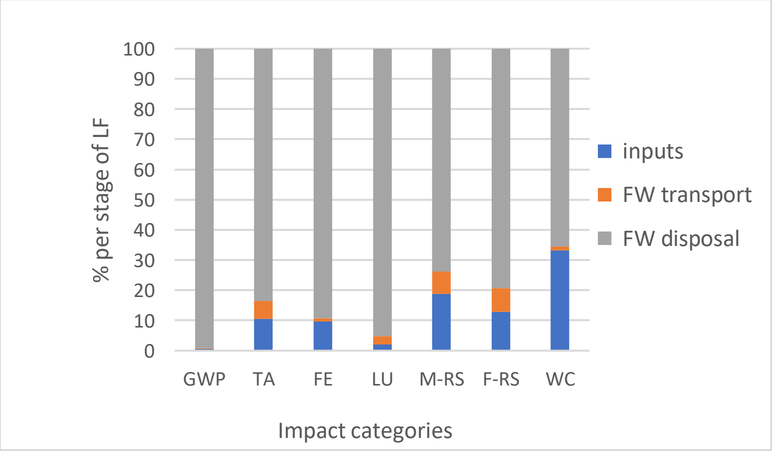

Figure 5 Impacts from FW landfilling disposal (LF).

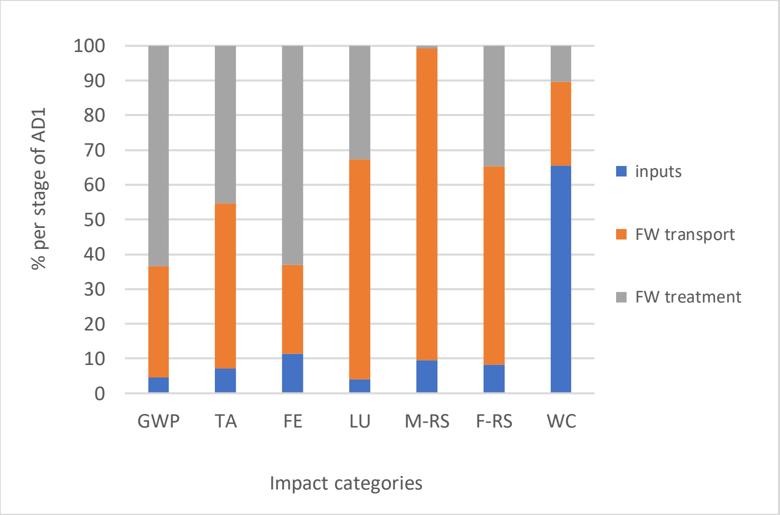

Figure 6 Impacts from FW Anaerobic Digestion in a centralized scenario (AD1).

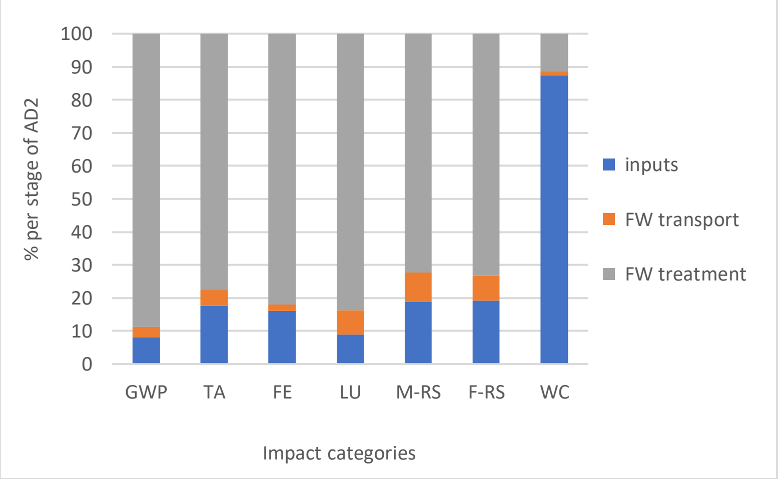

Figure 7 Impacts from FW Anaerobic Digestion in a semi-centralized scenario (AD2).

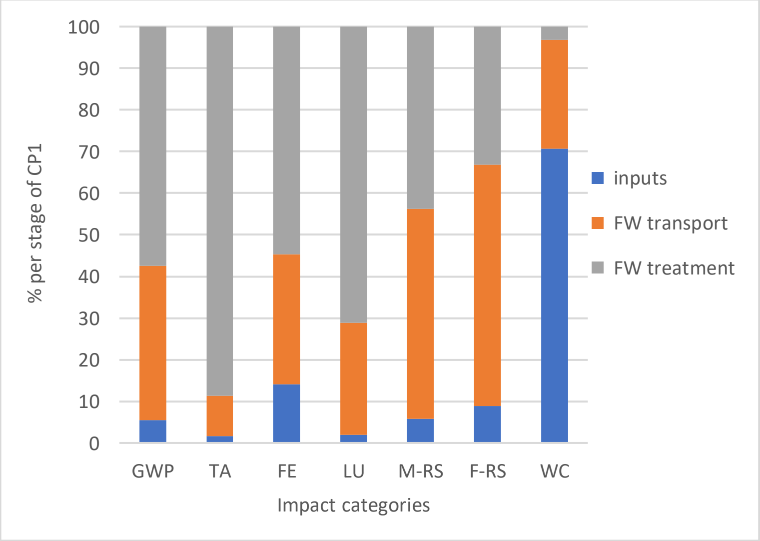

Figure 8 Impacts from FW Composting in a centralized scenario (CP1).

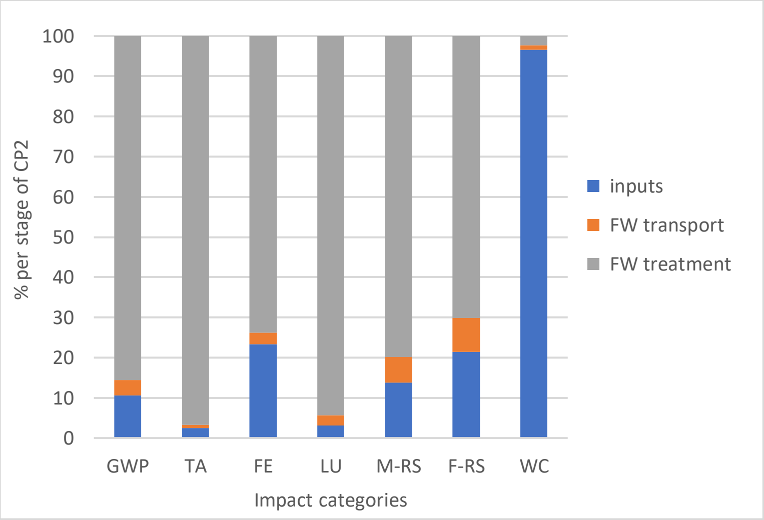

Figure 9 Impacts from FW Composting in a centralized scenario (CP2).

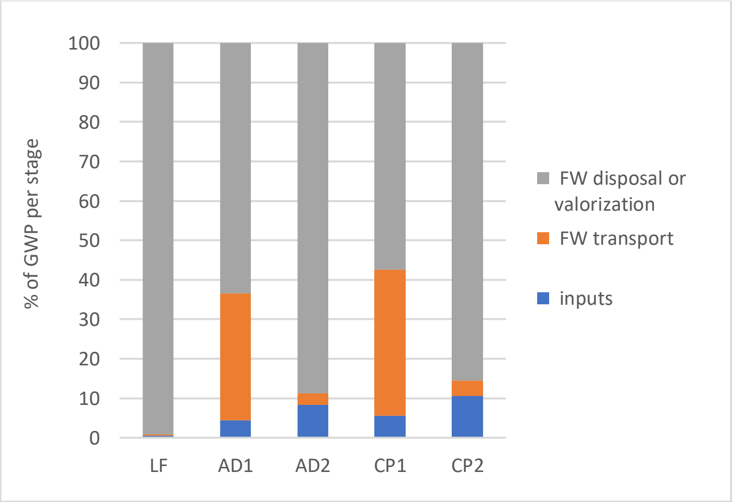

Figure 10 Contribution from each operation stage per FW treatment in the Global Warming Potential category.

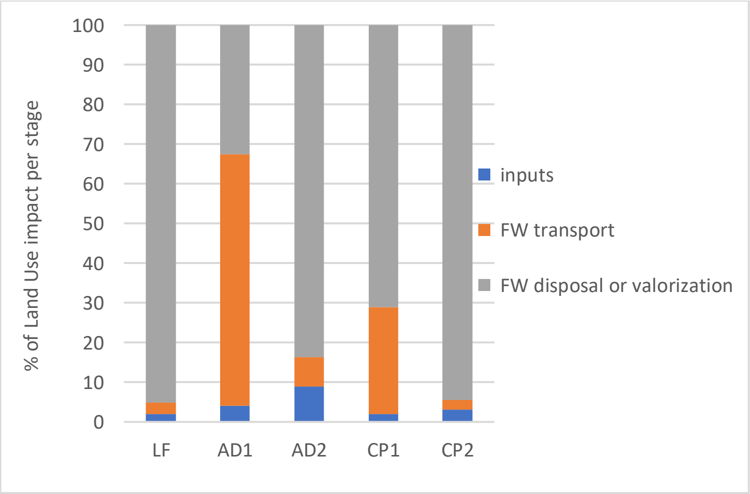

Figure 11 Contribution from each operation stage per FW treatment in the Land-Use impact category.

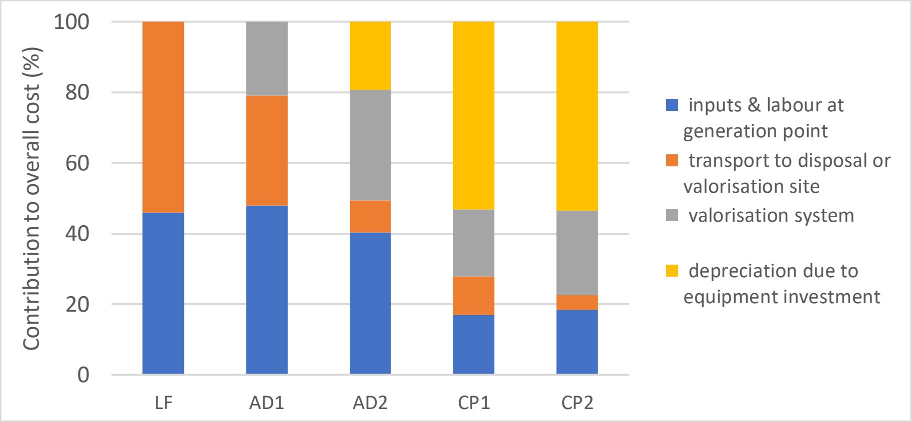

Figure 12 Proportion of each cost element within the E-LCC analysis.

Trade-offs among impact categories are observed. Transportation and the biodegradation process itself explains the higher Land-Use in CP1 and CP2; in contrast to AD1 and AD2, which would represent the least Land-Use impact of the scenarios. The Acidification Potential is influenced mostly by higher transport requirements and valorization processes. The higher potential impacts than LF for Mineral Resources and Fossil Resources depletion are attributable mostly to the increase in the FW transport. With the exception of scenario CP1, Water Consumption is also increased in all valorization alternatives, being the main reason, that now more cleaning operations would be mandatory both at generation point and in the valorization sites, while this latter was not required in the LF scenario. However, it should be observed that an approximately of 15% to 33% of this water would come from sustainable sources such as rainfall in alternative scenarios.

In summary, the FW treatment technique is the highest contributor to the Global Warming Potential, the Water Consumption and Land-Use impact categories (Figures 5 to 11); however, inputs would have higher proportional contributions in AD2 and CP2 scenarios, evidencing that transport becomes a hotspot.

GWP and LU are two relevant categories that would deserve in-depth observation (Figures 10 and 11), where the disposal or treatment practice plays a relevant role in the whole impact on both categories.

While transport of the FW is almost imperceptible in the overall LF Global Warming Potential (it is assumed the FW would be transported from the generation sites to closer landfills), the centralized alternatives AD1 and CP1 show a considerable increase due to the transport of the FW in route 1, accountable for a distance of 126km. This impact is lowered in the semi-centralized scenarios AD2 and CP2, where the FW transport is responsible for less than 4% of that impact, consequent with the 33km in route 2. Besides the treatment or valorization process, transport operations remain as one of the main contributors in the centralized scenarios (AD1 and CP1) for the impact category concerning Land-Use as well.

Regarding costs, the E-LCC showed that all valorization alternatives, except AD1, would result in higher yearly costs than LF (Table 5), and the contribution of the different elements of the cost will vary depending on each scenario (Figure 12).

Table 5 Cost of the business as usual and alternative FW treatment scenarios, expressed in USD.

Cost Category	LF	AD1	AD2	CP1	CP2
Inputs and labor at generation point	7635.32	7635.32	7635.32	7635.32	7635.32
Transport to disposal or valorization plant	8986.26	4938.27	1709.29	4938.27	1709.29
Valorization system	-	3334.81	5940.72	8562.19	9907.89
Depreciation due to equipment investment		-	3647.70	24,023.69	22,112.71
Total	16,621.58	15,908.41	18,933.03	45,159.47	41,365.21

Besides the already considered operators at the FW generation point to aid in cleaning and collection activities, AD1 and CP1 scenarios would require an estimate of 1.36 fulltime additional operators, while AD2 and CP2 would require 1.87 fulltime additional operators, with the correspondent calculation in monetary units and addition to the valorization system costs.

The increased yearly costs for most of the alternatives are attributed to a scale effect, the undertaking of new operations within the campus where the plant or plants would be established, and the depreciation of the required equipment were not previously available. LF does not incur in depreciation or valorization costs. In contrast, AD1, AD2, CP1 and CP2 would have new cost elements represented by the FW transport to the valorization site(s), and the FW processing operations, represented by materials, transport of those materials, and labor. In addition, the investment in new equipment will most definitely have economic impacts in the operation, as observed in the CP1 and CP2 scenarios in contrast to the AD1 and AD2 alternatives, or between AD1 and AD2 (for instance, AD1 would not require new investments because of an already existing and operational digestor). Similarly, CP2 would have a slightly lower depreciation cost since one of the campuses already has a composter.

The centralized scenarios such as CP1 have higher overall costs than AD2, CP2, and LF, attributable to the FW transport category; providing an important vision regarding the effects of centralization or semi-centralization of this type of recovery processes.

The study involved a system expansion, where market products were substituted by the side flows on each process, such as the biogas, digestate or compost (Table 6). For each alternative, a net effect was estimated, consisting of the impact that each new practice would suppose, the avoided impacts due to diverting the FW from the landfill, and the savings from substituting market products by the obtained side flows. In this case, liquified petroleum gas (LPG) would be substituted by biogas, and fertilizers, whether conventional or commercial compost bought by some of the universities or nearby farmers, would be substituted by the compost or digestate from the alternative scenarios.

Table 6 Net effect of FW valorization alternatives for GWP, LU and Economic effect.

Indicator		AD1	AD2	CP1	CP2
GWP **(CO_2 eq)**	new impact	16,113.16	11,906.42	13,973.26	9376.31
	avoided impact	1,260,078.39	1,219,486.49	91,012.29	90,050.00
	net effect	−1,243,965.24	−1,207,580.07	−7039.03	−80,673.69
LU **(m^2a crop eq)**	new impact	230.30	132.64	542.53	408.88
	avoided impact	13,391.95	12,248.63	417.27	388.48
	net effect	−13,161.65	−12,115.99	125.26	20.40
Net Economic effect **(USD)**	new cost	15,908.41	18,933.03	45,159.47	41,365.21
	avoided cost	729,659.58	729,05.66	19,985.77	20,016.95
	Net cost effect	−713,751.18	−710,772.63	25,173.70	21,348.26

The four FW-to-energy alternatives would suggest savings in CO_2 eq emissions in comparison to the business-as-usual practice. The net effect for Costs shows savings for AD1 and AD2, but avoided expenses do not make up for the potential new costs of valorizing FW in scenarios CP1 and CP2. There would be a substitution in the purchase of inputs, creating attractive yearly savings in scenarios AD1 and AD2. These savings are explained by the LPG substitution and smaller contribution from the substitution of commercial organic fertilizers once the universities use the digestate. In contrast, CP1 and CP2, even when substituting fertilizers by the obtained compost, will not represent yearly savings; instead, it will result in increased expenses because of higher depreciation costs and lower value products (compost) in regards to the AD alternatives.

A sensitivity analysis was conducted, observing effects in GWP and LU because of changes of certain inputs. On one hand, rice husk is one of the inputs for the adapted-Takakura compost method in the CP1 and CP2 alternatives, and would suppose an increased impact. However, the researchers decided to only account for its upstream transportation into the system. This was founded in the fact that the rice husk is a side flow of other processes, and the potential consumption of the input in the evaluated scenarios would not surpass 0.003% of the national inventory; therefore, competitive use of the husk or changes in the already existing local conditions are not expected to cause significant changes in the local market. Another input that deserved attention was the cleaning products, like chlorine, due to the contaminant power it is accounted for. Experts would suggest that quaternary ammonium and peracetic acid can be an effective option for disinfecting, besides the latter would be widely accepted to be used in food processing areas. Therefore, the analysis considered substituting sodium hypochlorite for acetic acids in one of the valorization scenarios, suggesting that this change would decrease the GWP by 180.976 kg CO_2 eq, and the LU by 4.224 m^2a crop eq. One additional concern in this last matter has to do with cost, since quaternary ammonium and peracetic acid can be more expensive than chlorine.

2.3.3. AHP Multicriteria Decision-Method

The science-to-expert approach indicated that, given the context where this case study was developed, the two most relevant criteria under which FW-to-energy alternatives should be evaluated are job generation and Land-Use (Table 7). Depreciation costs and Global Warming

Potential followed at an intermediate level of relevance, and finally, the ease of implementation and the net economic effect were the less relevant criteria for these experts.

Table 7 Evaluation criteria comparison matrix and priority vector.

Indicator	Global Warming Potential	Land-Use	Ease of implementation	Job generation	Depreciation cost	Net economic effect	Priority Vector
Global Warming Potential	0.130	0.136	0.194	0.115	0.124	0.120	0.136
Land-Use	0.235	0.245	0.152	0.313	0.239	0.221	0.234
Ease of implementation	0.057	0.138	0.085	0.071	0.087	0.095	0.089
Job generation	0.306	0.212	0.327	0.271	0.301	0.297	0.286
Depreciation cost	0.178	0.173	0.165	0.152	0.169	0.181	0.170
Net economic effect	0.093	0.095	0.077	0.078	0.080	0.086	0.085
						CR = 0.01 < 0.10	

Knowing the assigned priority to the criteria, comparison matrices are presented in Table 8, consisting of the judgment for the FW-to-energy scenarios under consideration, regarding each of the evaluation criteria. Afterwards, Table 9 presents the ranking for the scenarios that entailed different FW-to-energy alternatives for this university consortium according to the experts.

Table 8 FW-to-energy valorization alternatives comparison matrices for each evaluation criterion.

Global Warming Potential						Land-Use					
	AD1	AD2	CP1	CP2	priority vector		AD1	AD2	CP1	CP2	priority vector
AD1	0.201	0.278	0.204	0.163	0.211	AD1	0.266	0.391	0.255	0.176	0.272
AD2	0.107	0.149	0.166	0.169	0.148	AD2	0.108	0.159	0.285	0.110	0.166
CP1	0.405	0.368	0.411	0.435	0.405	CP1	0.360	0.194	0.346	0.538	0.360
CP2	0.287	0.205	0.220	0.233	0.236	CP2	0.266	0.256	0.113	0.176	0.203
					CR = 0.02						CR = 0.09

Table 8, continued.

Ease of Implementation

	AD1	AD2	CP1	CP2	priority vector
AD1	0.257	0.265	0.335	0.178	0.259
AD2	0.251	0.258	0.290	0.210	0.252
CP1	0.190	0.220	0.247	0.402	0.265
CP2	0.302	0.258	0.129	0.210	0.225
					CR = 0.05

Job Generation

	AD1	AD2	CP1	CP2	priority vector
AD1	0.542	0.540	0.576	0.484	0.535
AD2	0.187	0.186	0.179	0.189	0.185
CP1	0.163	0.180	0.173	0.230	0.186
CP2	0.108	0.094	0.072	0.096	0.093
					CR = 0.01

Depreciation Cost

	AD1	AD2	CP1	CP2	priority vector
AD1	0.199	0.110	0.268	0.208	0.196
AD2	0.331	0.182	0.233	0.095	0.210
CP1	0.246	0.260	0.332	0.464	0.325
CP2	0.224	0.447	0.167	0.234	0.268
					CR = 0.10

Net Economic Effect

	AD1	AD2	CP1	CP2	priority vector
AD1	0.221	0.385	0.191	0.186	0.246
AD2	0.093	0.161	0.254	0.156	0.166
CP1	0.443	0.242	0.382	0.453	0.380
CP2	0.243	0.211	0.173	0.205	0.208
					CR = 0.06

Table 9 Evaluation and ranking of the FW-to-energy alternatives under study.

	Global Warming Potential	**Land-Use**	**Ease of Implementation**	**Job Generation**	**Depreciation Cost**	**Net Economic Effect**	**Prioritization**	**Ranking**
(priority vector)	(0.136)	(0.234)	(0.089)	(0.286)	(0.170)	(0.085)		
AD1	0.029	0.064	0.023	0.153	0.033	0.021	0.323	1
AD2	0.020	0.039	0.022	0.053	0.036	0.014	0.184	4
CP1	0.055	0.084	0.024	0.053	0.055	0.032	0.304	2
CP2	0.032	0.048	0.020	0.026	0.046	0.018	0.189	3

2.4. Discussion

As a first method of the proposed methodological framework, the calculations through the site decision matrix and linear programming allowed the researchers to identify site E as the preferred to establish an FW valorization plant. However, it is observed that factors such as the integration of the consortium and the withdrawing of one of them from the route would account for a significant reduction of distance between one route and the other. Expected implications were observed in the results of CP or AD alternatives, entailing effects on the environmental and cost performance of the valorization alternatives, as well as in the decision in this study, of centralized FW valorization systems (with an FW collection route of 126 km) or semi-centralized ones (with FW collection route of 33km). In this sense, careful selection of parameters, weighting, and available information play a key role in the output of similar design of case studies.

As the second method of the framework, LCT proves to be clear and consistent in expressing the environmental and cost impacts of the evaluated scenarios. Previous sources indicate the fittingness of LCA [27,42] and E-LCC [15,25,42] to approach waste management situations, including FW. The stability of the LCT for the environmental and economic dimensions of sustainability studies, oriented by ISO14040 Standard [48] and Hunkeler D., Lichtenvort K., and Rebitzer, G [49] opens the possibility of comparability, perhaps not always among cases due to the diversity of elements of each scenario, but within cases as an improvement monitoring tool. However, the social dimension is still not addressed in the same manner, suggesting this to be a further area of research. Therefore, in this case, it was mostly evaluated by experts.

The LCA and E-LCC results of this study suggest AD to be the better performing FW-to-energy alternative, whether centralized or semi-centralized, being consistent with the municipal and experimental analysis that locates anaerobic digestion as a suitable treatment in terms of lower environmental impacts, side flow opportunities and economic perspectives [14,15,34]. Even when finding coincidence in hotspots such as the actual degradation technique, many of the consulted sources disregard transportation as a hotspot, reinforcing the need to observe system boundaries definitions when comparing studies and the relevance of centralization (or not) when proposing waste management systems [17].

The properties of the biomass to be valorized play a relevant role in the outcomes of each alternative. This study undertook valorization techniques already proven to work under the local conditions [21,22], based particularly in the balance of food groups comprised in FW. However, further experimentation based on properties regarding side flow production, calorific or nutritional potential and feedstock [17], as well as geographical origin, the type of collection source and the season of the collection [20] should be considered. In this sense, biomass characteristics could be included inside flow characterization experiments, or as a criterion to be assessed by the experts in decisional methods like the AHP.

The E-LCC also allowed to observe that the contribution of each element of the cost will vary with each scenario and more long-term and expanded perspectives must become part of these decisions. As an illustration of this argument, it is possible that if the decision was to rest uniquely upon the overall cost, FW treatment alternatives would not be of interest due to higher costs than the business-as-usual scenario. However, a wider comprehension of the circular economy principles, that considers the use and value of side flows [2,42] and performed by a system expansion in this study, allowed to understand that the AD scenarios would not only be avoiding environmental impacts but would be generating potential incomes.

Context-wise, it is relevant to highlight that the biogas was not considered in this case for electricity production, since the Costa Rican electricity grid is considered as already sustainable, and sufficient energy comes mostly from hydroelectric sources, followed by Eolic and geothermal sources [58]. Nonetheless, the country has an important consumption of fossil fuels such as LPG for combustion. For instance, universities would use liquefied petroleum gas (LPG) for their academic and research laboratories, and in their restaurants. In parallel, there is a relevant amount of Costa Ricans that would use LPG for cooking [56], consequently the study assumed the universities or nearby users can substitute LPG by biogas; however, acceptance rates were not inserted in this study. Another product would be the digestate from the AD1 and AD2 scenarios, as well as the compost in CP1 and CP2 scenarios. The selected valorization sites could use these products as a source of organic fertilizers in experimental fields where agricultural-related study programs or gardening activities are detected. Consequently, the costs and substitution preference cannot be considered as general for these valorization alternatives, but rather case-specific.

As a third and final step in the proposed decisional framework, the AHP method allowed the consulted experts to provide answers that were later computed to rank the alternatives. In this case, the two centralized alternatives ranked first (AD1 followed by CP1), then the semi-centralized composting scenario CP2 obtained the third place in the ranking and the AD2 alternative was placed fourth. Both the results of the pairwise comparisons and the open-question answers suggest AD1 would have a priority within the alternatives because of less Land-Use impact and lower Depreciation costs. However, when considering the rest of the criteria, CP1 was a second choice related to aspects such as the Ease-of-implementation. This last criterion, even when not highly prioritized, was usually present in the comments of the experts, mentioning that operating one facility might be easier than managing the simultaneous operation of several. In that sense, the comparison between the two semi-centralized alternatives, suggested composting in three plants was preferred to installing AD plants in three sites, therefore AD2 ranked the lowest from the four alternatives.

Feedback from the experts resulted in a positive overview of the proposed methodological framework for decision-making towards more circular approaches to manage FW, given the combination of methods and quantitative data that allowed to better understand the scenarios when supplied to the experts. They also expressed the sequence of methods allowed them to make an informed choice together with their experience and knowledge. Finally, they also found it to be innovative for the local context where decisions need to be more robust and consistent, since public policy creation, and implementation is considered by them to be a complex, multidisciplinary and dynamic process. Other experts suggested future scenarios to be evaluated as well, due to the scale of the consortium, where more artisanal composters were evaluated, and some presented a potential concern regarding the use of biogas and its acceptability at the consortium and local levels.

2.5. Conclusions

This paper evaluated four FW-to-energy alternatives and compared them to a landfill scenario through a system expanded LCA and E-LCC. The ultimate purpose was to contribute in decision-making processes related to FW valorization alternatives, and therefore it proposed an integrated methodological framework, combining LCT approaches with Linear programming and multicriteria decision methods such as (AHP).

From the environmental standpoint, main findings indicate that FW valorization alternatives in general, would entail reduced Global Warming Potential and Freshwater Eutrophication than the landfilling alternative; however, trade-offs are observed regarding other impact categories such as Terrestrial Acidification, Mineral Resource Scarcity and Fossil Resource Scarcity, where the potential impact from the valorization would be increased. Other environmental impact categories would perform differently when anaerobic digestion or composting were evaluated; nonetheless, it was clear that anaerobic digestion would entail lower Land-Use than composting and landfilling. Moreover, centralization or semi-centralization would also suggest different impacts, mostly in terms of the contribution that transportation would make to each impact category.

Regarding the economic and social dimensions, the findings conclude that, for the given circumstances and context, most of the FW-to-energy alternatives would have higher overall costs than the landfilling, something that is evidently reverted once a system expansion approach is considered. In this sense, when the valorization and the circular economy concepts are understood and explained through savings in products that can be substituted by side flows of the composting and the anaerobic digestion of the wastes, the proposed alternatives can become appealing for decision-makers. Besides, the valorization of the FW would require more labor, seen as an increased cost but also as an opportunity for job creation.

Further research and validation of the framework in different contexts are suggested, as well as the consideration of extended scopes where other criteria are evaluated, such as more in-depth biomass composition and energy properties, and the effects on the obtained side flows.

The trade-offs and potential interpretation of results will not always provide a straightforward selection of an alternative. Therefore, the proposed holistic methodological framework allowed a logical process of case definition and scenarios modelling, accompanied by scientifically-based assessment methods, together with a science-to-expert approach. This latter comprised a better understanding within this context, once experts offer their perspective by a well-structured and systematized method as the AHP.

Even with the limits of a case study, this research suggests that the circular economy is applicable for different activities. Evidence is always necessary to consider shifting from one scenario, as the usual and current landfilling one, to a more circular one where valorization of FW can improve not only the waste management within this university consortium, but the obtention of valuable products with the opportunity to positively affect environmental, social, and economic indicators.

Similar cases, such as small municipalities or groups of institutions, can benefit from a similar approach as the one presented in this research, since decisions can be guided in a systematic manner with already proven, sequential and steady methods like linear programming, LCA, LCC and AHP.

Supplementary Materials: The following are available online at https://www.mdpi.com/1996-1073/13/9/2291/s1 and include LCA and LCC information (Goal and Scope, system boundaries and flow diagram, inventories of LF, CP1, CP2, AD1 and AD2 scenarios, calculations and assumptions for inventories and generic information and sources used for those calculations (Also available in Annex 1 : supplementary materials from chapter 2).

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CHAPTER 3: Interlinked factors influencing decision-making processes for more sustainable coffee production

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Abstract: The coffee sector entails one of the top traded agricultural commodities worldwide; however, it struggles with socioeconomic and environmental challenges. There are different coffee production systems, and among those, shaded plantations represent an opportunity for sustainability. Many studies approach the agronomic and environmental performance of coffee production; however, there is a gap in understanding the factors that affect the farmer's decision-making processes towards sustainable practices. The aim of this study was to model the links among the characteristics of shaded-coffee systems with the economic and sector context, and environmental factors, through the application of the Interpretive Structural Modelling (ISM) method. As a result, a comprehensive representation of the interrelations and influence in sustainable coffee farming decisions was obtained. Main findings stress that the farm stage is the highest contributor to the cost and environmental impacts in the life cycle of green coffee, while different shade systems could mitigate negative impacts or increase productivity. The obtained model indicates that knowledge, tradition and training are the main factors to influence the farmers' decisions, followed by the emissions potential, biodiversity, and the services provided by the shade systems. Factors from the context, such as certifications, policies and the cooperative scheme sit at the intermediate level of the model, and the overall concept of environmental cost is one of the least influential but dependent factors. This research presents a first suggestion of model to address sustainable coffee production based on influencing factors in decisions from small-coffee farmers, and further research can allow for improved and tailored policies and interventions in this sector.

Keywords: coffee shade, Costa Rica, Life Cycle, ISM, sustainability

3.1. Introduction

Coffee is one of the most traded commodities worldwide (UN, 2019). Over 125 million people depend directly or indirectly on this commodity, and 25 million growers are disseminated among Central and South America, Africa, Asia and Oceania (Kuma, et al., 2019; Díaz, 2015). Central America (CA) is the second-highest growing subregion of the world in coffee exports (ICO, 2018), consisting of a group of countries that share common coffee varieties (Méndez, et al. 2013), as well as agroecological and climatic characteristics (Birkel, 2005).

Despite its importance, the crop is associated with economic, social and environmental constraints. Most environmental impacts concentrate at the farm level (Valenzuela-Vergara, 2016; Killian et al., 2013; Salomone, 2008), with hotspots usually related to soil erosion and excess nitrogen supply; non-point source pollution of water bodies, and greenhouse gas (GHG) emissions (Crespo et al., 20156; Ataroff and Monasterio, 1997; Babbar and Zak, 1994). Economic and social challenges involve price volatility; farmers food security and socio-economic conditions (Tschora and Cherubini, 2020; Díaz, 2015), together with strong climate change vulnerability that affects the stability of the yields and the farmers' income (Maplecroft, 2014).

Aware of these impacts, actors in the coffee sector have made efforts to incorporate more sustainable practices (ICO, 2007), including the production in shaded-coffee plantations. These are known for a reduced environmental footprint and similar yields in comparison to sun plantations (Schmidtt-Rivera, et al. 2020; Villareyna-Acuña, et al., 2016; Montagnini, et al. 2015; Méndez, et al., 2013). Moreover, the shade trees provide services consistent with climate change adaptation, soil health improvement, and biodiversity conservation, creating a positive effect on coffee productivity (Alline, et al., 2016). Some examples of services include the provision of soil coverage and increased organic matter in soils (Alulima, 2012), carbon sequestration, pollination, improved radiation conditions, potential income diversification, and conservation (Alline, et al., 2016; Rossi, et al., 2010; Méndez et al., 2009). In parallel, the international markets promote the compliance with several certification and labelling systems that often entail the expression of sustainability, and even when they not always reinforce true fair-marketing practices (Andreotti, et al., 2020), they demand additional efforts from the farmers and the subsector, and create a premise for improved profitability and market access.

Studies already begin to portray the effect of certifications and interventions in coffee production, as well as the need to quantify the contribution of shade systems to the overall environmental performance of the crop (Acosta-Alba, et al., 2020; Cabrera, et al., 2020; Hindsley, et al., 2020; Vogt, 2020). However, most available literature for coffee studies in CA widely focuses on the agronomic or the agroforestry perspectives (Rakocevic, et al., 2017; Montagnini, et al., 2015; Méndez, et al., 2013), as well as in environmental evaluations (Birkenberg and Birner, 2018; Killian, et al., 2013), neglecting the understanding of decision-making and policy processes in this sector.

The limited literature availability and the detected gaps (Courville, 2003) related to integrated influencing factors in the farmers' sustainability decision-making processes motivated this study. Consequently, this research aimed to recognize the links between environmental, productive and socioeconomic factors obtained in literature reviews, and a case study performed in six small coffee farms, providing a comprehensive model of the interrelations of these factors in coffee farming sustainable decisions. Life Cycle Assessment (LCA), Environmental Life Cycle Costing (E-LCC) and shaded-coffee systems evaluation were applied to characterise the farms of the case study, and Interpretive Structural Modelling (ISM) posed as an appropriate method to aid in better understanding how the relations among factors could support decisions at the farmer level and graphically representing the model of those interactions. Further use and adaptation of the model can assist related stakeholders as well as policymakers to understand key entry points and hotspots to be addressed in the pursue of more sustainable coffee-farming practices in similar contexts as the one studied in this case.

3.2. Materials and methods

3.2.1. Case description

Costa Rica belongs to the Central American coffee production subregion, with 93 697.32 ha dedicated to coffee production, grown mostly in small farms. Hand-picked coffee cherries are delivered to the processing plants for wet milling, and over 80% of the national production is exported, mostly to North America and the European Union (ICAFE, 2020). The research was conducted in the Tarrazú canton (9°36'18.55"N, 84°2'16.40"W) in Los Santos Region of Costa Rica, considered the most productive location in the country. The average annual rainfall is 2400 mm, and the mean annual temperature is 19 °C (Banks, et al., 2013). The soil, typically acid, with low base content and steep slopes (30 - 60%), belongs to the ultisols / inceptisols order (Chinchilla, et al., 2011; Crespo, et al., 2016).

This case study consisted of six small coffee farms (figure 13) affiliated to Coopetarrazú, the most representative coffee productive unit in Costa Rica. Farms were selected in collaboration with the cooperative technicians, following representative selection criteria for this productive landscape, such as farm size (94% of farms are less than 10 ha), altitude (1320-1550 m.a.s.l.), varieties (Caturra and Catuai), and productive practices (conventional shaded coffee production).

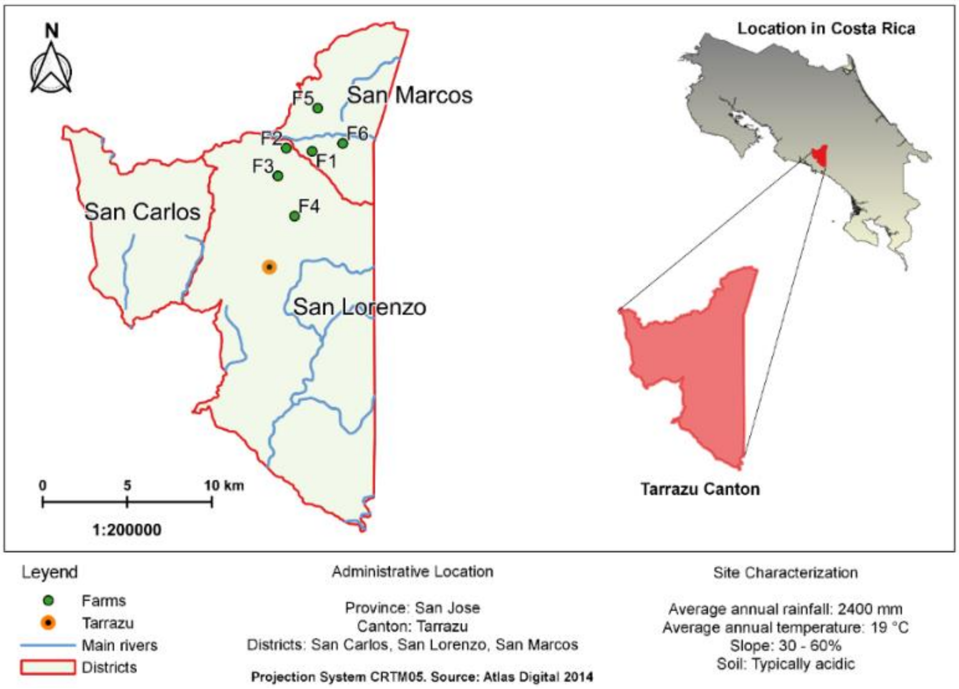

Figure 13 Case study Location, Tarrazú Canton in Costa Rica, Central America

3.2.2. Methods:

The study was developed following a multi-method framework (figure 14) that began with a literature review to detect possible influencing decision-factors for more sustainable coffee production. In a second phase, field work allowed to obtain a characterization of the six farms, including environmental and cost indicators (through LCA and E-LCC), as well as a description of the shade system (through agroforestry evaluation methods). Finally, as one of the main adaptations to the ISM method, this research used both the outputs of steps 1 (literature review) and 2 (farm characterization) to obtain the graphical representation of a model that explains the relations among factors, their levels of influence and typology (through MICMAC) in the decision-making process of farmers in regards to more sustainable coffee production.

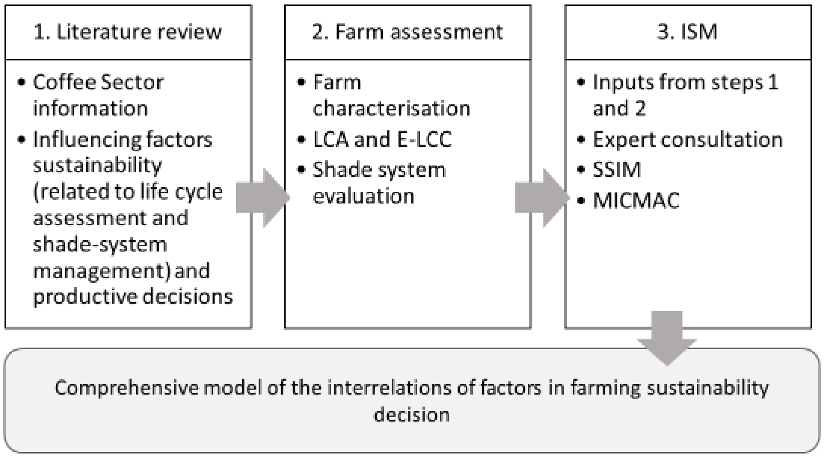

Figure 14 Methodological framework based on ISM to provide a model of linked factors for sustainable decisions in small-coffee farming

Literature review

A literature review was conducted to obtain an overview of the coffee sector and the possible factors related to sustainability decisions and practices. The Scopus search engine was used, focusing in scientific articles written in English language, published within the past five years and containing key words such as coffee, sustainability, life cycle, shade, and decision, and their combinations. A total of 54 documents were located, and after careful revision of the relevance to the research aim, 34 papers provided the relevant factors considered in this study (table 10; literature sources are summarized in Annex 2: supplementary materials from chapter 3).

Farm characterisation

This section allowed an overview of the farms involved in the study and their productive practices, environmental and cost indicators and shade system characteristics. Varied data collection methods were applied at the farm level, using mostly structured and semi-structured questionnaires, non-participatory observation, in-site sampling methods, and when available, on-site registers.

Overall characteristics:

Each farmer was asked to describe the productive practices and to provide a common set of data: farm size, yield (mean kg of green coffee per year; calculated with two productive cycles to avoid biennality bias), and type and amount of inputs. The measurement unit for coffee in Costa Rica is the “fanega” (ff), a volumetric measure equivalent to 2 double hectolitres, which was converted in this case to kg of green coffee using empirical estimations of the efficiency rate of the milling process (1 ff = 44.85kg of green coffee). A representative soil sample of 0.5 kg was obtained per farm to perform a complete soil chemical analysis. Subsamples were taken first using a one-piece auger and following with a quartering technique; the sampling process took place before the fertilization operations. Foliage samples were extracted as well to determine the nutritional condition of the plantations. They consisted of 60 expanded leaves randomly collected from the productive section of the coffee bushes, after the pruning and first soil fertilization, once vegetative growth was observed, avoiding very young or very mature leaves, and then submitted for a full digestion analysis. Both analyses were performed at INTA (Instituto Nacional de Innovación y Transferencia de Tecnología Agropecuaria) laboratories in Costa Rica.

Environmental and cost indicators:

The study performed an attributional LCA following the ISO 14040:2007 standard (INTECO, 2007), as well as an E-LCC based on Hunkeler et al. (2008) guidelines. The goal was to evaluate the environmental and cost impacts of producing 1 kg of green coffee beans[2] at 11,5% of humidity content (functional unit FU) with system boundaries from cradle (coffee plantation establishment) to gate (milled green coffee delivered at the entrance of the export docks), and included the yearly operations and inputs for the 2019/2020 coffee harvest, entailing upstream, core and downstream processes. The assessed system included four life cycle stages: 1) establishment (seed, nursery and plant growth operations), 2) production (fertilization, pest management, weed control, harvest and harvest delivery operations), 3) mill (coffee beans reception, wet milling, drying and packing operations), and 4) transport (from the cooperative to the export dock operations) (Detailed information and data of the inventory of the LCA and E-LCC are available at Annex 2: supplementary materials from chapter 3). Selected midpoint impact categories for the LCA were based on the Costa Rican main agro-environmental goals (ICAFE, 2020; NAMA Café de Costa Rica, 2020; MINAE-DIGECA, 2019; Presidencia, 2019), using the ReCiPe 2016 Midpoint (H) V1.02 method (Huijbregts, et al. 2017). Hence, the assessment involved the following categories per FU: Global Warming potential (GWP, kg CO_2 eq), Freshwater Eutrophication (FE, k P eq), Freshwater Ecotoxicity (FW-ecotox, kg 1,4-DCB) and Water consumption (WC, m^3). The inventory was built in Microsoft Excel ® and then computed in SimaPro 9.0.0.49 with the aid of Ecoinvent v3 and Agri-Footprint databases, and emissions were calculated according to the World Food LCA Database (Bengoa, et al., 2015). Assumptions include a lifespan of the coffee plantation of 25 years, and since farms have been settled since more than 50 years ago, emissions from land use change were excluded, as in the study of Birkenberg & Birner (2018). The transport distances were averaged from the source of inputs to the farms through the use of Google Maps, accounting only for terrestrial transportation of inputs at country level. Processes regarding the seedling and nursery operations, bioinputs production, and treatment of wastewater and coffee brush were modelled for this specific case.

Following the same goal and scope, system boundaries and functional unit, the E-LCC provided the impacts in monetary units (USD) of the relevant costs per kg of green coffee (inputs, water, energy, fuels, labour, transport), according to each life cycle stage. Data sources for costing included local market prices at the currency exchange rate for the studied harvest year, provided by the Costa Rican Central Bank.

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[2] The concept of green coffee does not refer to a ripening aspect, but to the stage within the processing of coffee cherries where the external peel, pulp and mucilage has been removed, obtaining a greenish-coloured coffee bean, at 11,% humidity content. The green coffee beans will then be roasted and grounded to obtain the usual commercial presentation of coffee.

Shade System description:

Rectangular-shaped, semi-permanent plots were stablished in the farms, consisting of 1000 m^2 (25 m x 40 cm) with East-West orientation, avoiding steep slopes (> 30%), drainage areas, floodable lands and uneven or irregular sites. Data on the shade system density, composition (popular and scientific name) and dasometric characteristics of the shade individuals were collected, such as diameter at breast high or DBH following Sanchez-Monge (2013), total height, crown diameter, and crown height. This allowed to evaluate three variables of interest to describe the shade systems:

a) Shade coverage: with the information of the composition and dimension data from shade individuals, the indicator was expressed as a percentage of shade coverage (Somarriba, 2002).
b) Biodiversity: the biodiversity of each plot was analysed through the Importance Value Index (IVI) and the Shannon diversity index (H') (Somarriba, 1999).
c) Carbon storage: this variable represented the amount of stored carbon in the shade species in the farms. The calculation was based on the IPCC guidelines (IPCC, 2006), considering the biomass of the shade individuals above ground level and conversion rates to CO2 eq.

More detailed information about the soil, foliage and shade system evaluating methods and formulas are available in Annex 2: supplementary materials from chapter 3.

Interpretive Structuring Modelling (ISM)

ISM has been used by many authors due to its applicability at early stages of research and when experts' judgment is of interest to explain the outcomes of research in regards to a certain context (Xu and Zou, 2020; Awan, et al., 2018; Mani, et al., 2016). Moreover, it has been considered as an effective method to investigate the relationships, directions of those relationships and hierarchy among factors of a complex system, including those to address decisions related to sustainability in different activities. For instance, it has been used to analyse strategies in end-of life tire management (Shankar, et al., 2016); selection of suppliers (Karimi-Gavare, et al., 2017), campus sustainable operations (Gholami, et al., 2020), construction and energy performance (Xu and Zou, 2020); or supply chains in the manufacturing sector (Mani, et al., 2016). Consequently, these experiences suggest that ISM fits the aim of the present study where there is still scarce literature to link sustainability multicriteria for the coffee sector that incise in decision-making processes.

The ISM is considered a well-established method, proposed since 1973 by John N. Warfield, developed through a series of steps consisting of: 1) identification and listing of main factors to be linked to the issue of interest; this is usually supported by literature and was adapted in this study to include specific factors resulting from the executed case study, 2) establishment of contextual relationship between each pair of factors, with support from expert opinion, 3), formulation of a structural self-interaction matrix (SSIM), 4) development of a reachability matrix after checking for transitivity, 5), partitioning of the reachability matrix into different levels, 6) representation of the final reachability matrix through a graph, 7) development of the interpretive structural model, 8) checking for conceptual inconsistencies, and iterative expert opinion if inconsistencies are detected (Karimi-Gavare, et al., 2017; Attri, et al., 2012).

ISM can also be accompanied by MICMAC (*Matrice d'impacts croisés multiplication appliquée á un classment*), in order to classify the factors of the ISM in four clusters or types: autonomous (cluster I), dependent (cluster II), driving (cluster III) and linkage (cluster IV) factors (Xu and Zou, 2020). MICMAC was introduced by Duperrin and Godet in 1973, and it is used to classify and validate the ISM factors in the study to reach further conclusions (Ahmad, et al., 2019).

The possible factors (table 10) obtained from the literature review and farm characteristics, were used in a structured questionnaire to validate them or suggest new ones with the help of 17 stakeholders (farmers, institutional, academic and cooperative experts). A second questionnaire was used to conduct a pair-wise judgment with 15 experts in coffee production due to their roles as institutional agents (Ministry of Agriculture, the Costa Rican Coffee Institute-ICAFE); specialized academics in agroforestry, agronomy, agricultural extension, and productive sector representatives (Cooperative technicians and producers).

An example of the used tools available at Annex 2: supplementary materials from chapter 3 .

Table 10 List of relevant factors related to sustainable decisions in small coffee farms.

Category	**Relevant factor**
LCT-Related	1. Amount of GHG emissions 2. Possible water pollution 3. Water consumption 4. Environmental costs
Shade system-related	5. Conservation and/or enhancement of biodiversity 6. Climate change adaptation and resilience, including the provision of adequate microclimate conditions (water availability, temperature, pollinators and biocontrollers enabling environment) 7. Improvement of pre-existing soil conditions (fertility organic matter deficiencies, erosion propensity) 8. Adoption of certification schemes and their requirements as well as benefits (price premium, market access and distinctions) 9. Investment and operative costs of shade-system 10. Possibility of income diversification 11. Possibility of food supply diversification for the family 12. Incentives per adopted practices (such as payments for ecosystem services or conservation) 13. Previous knowledge, tradition, cultural perspectives and sustainability commitment
Sector and farm-related	14. Results related to productivity, yield, price and final cup quality 15. Preference and access to coffee varieties 16. Use and cost of inputs, such as fertilizers, pesticides, herbicides and alternative ones (compost, bioinputs, biochar) 17. Conditions of coffee plant nutrition 18. Training and capacity building needs and availability 19. Existing Policies (enabling or disenabling the adoption of practices) 20. Support, requirements and/or motivation from Cooperative schemes they belong to 21. Easiness of sustainable production practices (fertilization, pest, disease and weed management, input application, pruning, harvesting)

3.3. Results

3.3.1. Farm characterisation

These farms were considered to be typical, shaded coffee plantations from the Tarrazú Canton in Costa Rica. The common practices from these rainfed farms include the use of synthetic fertilizers, and pest and disease control products, which are applied either to soil or plants. Farmers have planted shade trees within the coffee bushes, and they practice coffee and shade pruning (manually or with the help of motor-saws), as well as mechanic and chemical weed control. Most input applications are done manually with the help of mechanical or motor back-pumps. All farmers own their land and participate directly in the primary production activities, supported by one or two permanent workers, and a higher number of temporary collaborators to manually harvest the coffee; which is transported in light trucks to local reception points or to the central milling plant from the Cooperative. Table 11 presents the most relevant characteristics of the studied farms.

Table 11 Characterisation of the studied farms

Criteria	**Unit**	**Farm**					
		1	**2**	**3**	**4**	**5**	**6**
General characteristics							
farm size	ha	2,61	3,53	7,58	6,35	3,17	4,23
coffee bush density	bush ha^{-1}	3 180	4 640	3 480	3 410	3 910	4 570
green coffee production	kg	5 977,37	10 054,98	15 986,91	13 829,96	6 351,84	14 135,10
productivity	kg ha^{-1}	2 291,50	2 852,48	2 109,44	2 179,66	2 002,15	3 341,63
Inputs at farm level							
N	kg N kg coffee^{-1}	0,23	0,16	0,13	0,15	0,20	0,10
P	kg P kg coffee^{-1}	0,13	0,04	0,02	0,02	0,05	0,02
water	L water kg coffee^{-1}	1,34	1,93	1,64	1,43	1,64	1,19
Diesel fuel	L diesel kg coffee^{-1}	0,01	0,02	-	0,00	0,26	0,00
Permanent workers cost	USD kg coffee^{-1}	0,84	0,72	1,06	0,27	0,75	0,25
Harvest workers cost	USD kg coffee^{-1}	1,02	0,81	0,97	0,84	0,77	0,77
Soil conditions							
pH		4,81	4,80	4,80	4,77	4,77	4,82
element deficiencies		Ca, Mg, P	Ca, Mg, P	Ca, Mg, P	Ca, Mg, P	Ca, Mg, P	Ca, Mg, P
element excess		Fe	Fe	Fe	Fe	Fe	Fe
Plant nutrition							
element deficiencies		Zn	Zn	Ca	Ca, K, Zn	Ca, Zn	Zn
element excess		N, Cu	N, Cu	N	N, Fe, Cu	N, Cu, Mn	N, Cu

Critical range based on the Soil and Foliage Laboratory recommendations of the University of Costa Rica–CIA/UCR (Molina & Meléndez, 2002).

The obtained characteristics indicate these are high-yield farms, that use different amounts of inputs per FU and share similar soil conditions; however, element balance is expressed differently in some famrs, either at soil level or in the plant nutrition.

3.3.2. Environmental and cost assessment through the LCT approach

The LCA and E-LCC identified the environmental impacts and cost per FU (kg of green coffee) produced by the farms in the study, as seen in Table 12.

Table 12 Environmental and cost assessment per FU in the farms of the study

Impact category	**Unit**	**Farm**					
		1	**2**	**3**	**4**	**5**	**6**
GWP	kg CO_2 eq	2,174	1,649	1,273	1,465	2,632	2,236
FE	kg P eq	0,013	0,002	0,001	0,001	0,003	0,001
FW-ecotox	kg 1,4-DCB	0,137	0,051	0,035	0,044	0,299	0,033
WC	m^3	0,048	0,035	0,072	0,031	0,215	0,044
Cost	USD	3,358	5,127	4,877	3,734	4,863	3,132

Potential trade-offs among impact categories are observed; however, it is common to detect highest impact in comparison to the group from farms 1 and 5. Moreover, the LCT approach that was applied, highlighted the contributions of the life cycle stages of green coffee production. A mean calculation within the six farms of the study can be observed in figure 15.

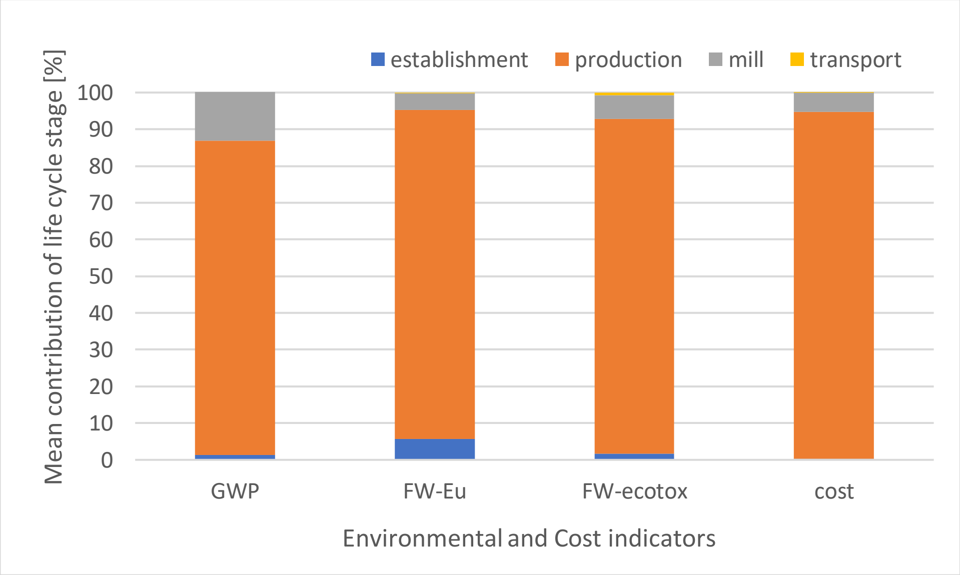

Figure 15 Contribution of the life cycle stage to the environmental impact categories and cost.

The production stage taking place at the farms, is the highest contributor to all environmental impact categories and cost, suggesting that most interventions to mitigate or reduce environmental impacts and cost of coffee production should be addressed at this stage, followed by the mill stage. Therefore, further discussion in this study was centred at the production, hence the linkage of the shade system in the farms and sustainable decisions were of interest.

3.3.3. Shade System evaluation

The six farms consisted of shaded-coffee plantations (table 13). Four main types of shade species were detected, grouped as service trees (*Erythrina* spp, *Grevillea* spp, *Inga* spp, and others), fruit trees (*Persea* spp, *Eriobothrya* spp y *Psidium* spp), timber trees (*Eucalyptus* spp y *Quercus* spp), and a group of *Musaceae* family individuals commonly found in the Costa Rican rural landscapes.

Table 13 Shade system characterization and shade coverage

Criteria	**Unit**	**Farms**					
		1	**2**	**3**	**4**	**5**	**6**
Density of service trees	Individuals ha^{-1}	440	437 ± 76	200	285 ± 92	278 ± 32	463 ± 225
Density of fruit trees	Individuals ha^{-1}	30	N/A	10	30	10	10
Density of timber trees	Individuals ha^{-1}	N/A	N/A	N/A	20	10	10
Density of Musaceae plants	Individuals ha^{-1}	350	537 ± 67	310	265 ± 78	310 ± 311	223 ± 123
Shade coverage	%	43±17	33±15	29±11	17±10	29±12	30±16

(N/A no individuals found in for those shade species groups)

The six farms have a mixed species shade system, represented mostly by two typologies, as defined by De Melo (2005) and Pico-Mendoza et al (2020): mixed with *Erythrina* spp dominated arrangements (a) and *Erythrina* spp with Musaceae arrangements (b), as seen in table 14.

Table 14 Shade system biodiversity assessment from the studied farms

Criteria	**Farms**					
	1	**2**	**3**	**4**	**5**	**6**
Typology of shade arrangement	a	b	a	a	a	a
IVI Musaceae	43	39	43	32	29	27
IVI *Erythrina* spp	50	60	48	44	32	41
Quantity of species	4	3	5	8	9	6
Quantity of families	3	2	3	3	7	4
H’	0.90	1.02	1.09	1.54	1.61	1.60

Most of the farms range within optimal shade coverage (20-40%) to allow proper coffee production (De Melo, 2005), and data shows that the identified species are consistent with the regional context. Farms 5 and 6 account for the highest diversity (H’) of the studied farms, and farm 1 has the highest shade coverage. In regards to the stored carbon, table 15 summarizes the estimation of the stored carbon in the present biomass above the ground.

Table 15 Estimation of stored carbon in the shade systems of the studied farms

Criteria	**Unit**	**Farms**					
		1	**2**	**3**	**4**	**5**	**6**
Biomass above the ground	ton ha^{-1}	2,52 ± 0,61	3,53 ± 1,72	1,95 ± 0,43	1,26 ± 0,86	1,89 ± 1,23	1,04 ± 0,68
Stored carbon	ton ha^{-1}	1,11 ± 0,27	1,55 ± 0,76	0,86 ± 0,19	0,55 ± 0,38	0,83 ± 0,54	0,46 ± 0,30
CO_2 eq	ton ha^{-1}	4,07 ± 0,98	5,70 ± 2,77	3,15 ± 0,69	2,03 ± 1,39	3,06 ± 1,99	1,68 ± 1,09

Even when Product Category Rules (PCR) for environmental product declarations or footprints do not usually consider emission balances (International EPD system, 2013), and the presented calculations account for the current stored carbon from trees of different age, this section expresses the potential mitigation of emissions these farms could have in time. In this case, farms 1 and 2 present the highest storage.

3.3.4 Interrelations of factors for sustainable decisions in small coffee farms.

The 21 proposed factors were validated; consulted experts suggested to maintain them in the assessment. Afterwards, experts provided their judgment for each pair of factors, indicating the relations among each two. First, they would graphically indicate the relation, and then the answer as codified as V (factor *i* influences *j*), A (factor *j* influences *i*), X (factors reciprocally influence each other) and O (factors are not related). These relations are observed in the SSIM (Table 16).

Table 16 Structural self-interaction matrix for the selected factors (SSIM)

FACTOR	F21	F20	F19	F18	F17	F16	F15	F14	F13	F12	F11	F10	F9	F8	F7	F6	F5	F4	F3	F2
F1	O	O	O	O	A	A	O	O	A	O	O	O	A	O	A	X	X	V	O	O
F2	A	A	A	A	O	O	O	O	A	O	O	O	O	A	A	O	A	V	X	
F3	O	O	O	A	O	O	O	O	A	O	O	O	O	A	O	O	O	O		
F4	A	O	A	O	A	A	O	A	A	A	O	O	O	A	O	O	O			
F5	O	A	O	A	O	A	O	X	A	O	V	O	X	O	X	X				
F6	O	A	O	O	V	V	V	X	A	O	O	O	X	O	X					
F7	O	A	O	A	V	V	O	X	A	O	O	O	X	O						
F8	X	X	X	O	O	O	O	O	A	X	O	V	O							
F9	O	A	O	A	O	O	O	x	A	O	O	O								
F10	O	A	A	A	O	A	O	O	A	A	O									
F11	O	O	A	O	O	O	O	O	A	O										
F12	X	X	X	A	O	O	O	O	A											
F13	V	A	O	X	O	V	V	V												
F14	A	V	O	A	O	O	O													
F15	A	A	O	O	X	X														
F16	A	A	O	O	X															
F17	A	A	O	O																
F18	V	V	O																	
F19	X	X																		
F20	X																			
F21																				

The obtained relations were introduced in the Adjency matrix, substituting the Boolean relations by binomial values as indicated in the ISM method, which consisted of transforming A and O into a 0 (zero) value, and V and X into a 1(one) value(table 17).

The matrix was checked for transitivity, resulting in the Reachability matrix (table 18), also presenting the driving power (sum of rows) and dependence power (sum of columns) of each factor.

Table 17 Adjency matrix of the selected factors

FACTOR	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10	F11	F12	F13	F14	F15	F16	F17	F18	F19	F20	F21
F1	1	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
F2	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
F3	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
F4	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
F5	1	1	0	0	1	1	1	0	1	0	1	0	0	1	0	0	0	0	0	0	0
F6	1	0	0	0	1	1	1	0	1	0	0	0	0	1	1	1	1	0	0	0	0
F7	1	1	0	0	1	1	1	0	1	0	0	0	0	1	0	1	1	0	0	0	0
F8	0	1	1	1	0	0	0	1	0	1	0	1	0	0	0	0	0	0	1	1	1
F9	1	0	0	0	1	1	1	0	1	0	0	0	0	1	0	0	0	0	0	0	0
F10	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
F11	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
F12	0	0	0	1	0	0	0	1	0	1	0	1	0	0	0	0	0	0	1	1	1
F13	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	1	0	0	1
F14	0	0	0	1	1	1	1	0	1	0	0	0	0	1	0	0	0	0	0	1	0
F15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	0	0	0	0
F16	1	0	0	1	1	0	0	0	0	1	0	0	0	0	1	1	1	0	0	0	0
F17	1	0	0	1	0	0	0	0	0	0	0	0	0	0	1	1	1	0	0	0	0
F18	0	1	1	0	1	0	1	0	1	1	0	1	1	1	0	0	0	1	0	1	1
F19	0	1	0	1	0	0	0	1	0	1	1	1	0	0	0	0	0	0	1	1	1
F20	0	1	0	0	1	1	1	1	1	1	0	1	1	0	1	1	1	0	1	1	1
F21	0	1	0	1	0	0	0	1	0	0	0	1	0	1	1	1	1	0	1	1	1

Table 18 Reachability matrix of the selected factors

FACTOR	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10	F11	F12	F13	F14	F15	F16	F17	F18	F19	F20	F21	**Driving power**
F1	1	0	0	1	1	1	1*	0	1*	0	1*	0	0	1*	0	1*	1*	0	0	0	0	**10**
F2	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**3**
F3	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**2**
F4	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**1**
F5	1	1	0	0	1	1	1	0	1	0	1	0	0	1	1*	1*	1*	0	0	1*	0	**12**
F6	1	0	0	0	1	1	1	0	1	0	0	0	0	1	1	1	1	0	0	1*	0	**10**
F7	1	1	0	0	1	1	1	0	1	0	0	0	0	1	0	1	1	0	0	1*	0	**10**
F8	0	1	1	1	0	0	0	1	0	1	0	1	0	0	0	0	0	0	1	1*	1*	**9**
F9	1	0	0	0	1	1	1	0	1	0	0	0	0	1	0	0	0	0	0	1*	0	**7**
F10	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	**1**
F11	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	**1**
F12	0	0	0	1	0	0	0	1	0	1	0	1	0	0	0	0	0	0	1	1	1	**7**
F13	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1*	1	0	1*	1	**20**
F14	1	0	0	1	1	1	1	0	1	0	0	0	0	1	0	0	0	0	0	1	1*	**9**
F15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	0	0	0	0	**3**
F16	0	0	0	1	0	0	0	0	0	1	0	0	0	0	1	1	1	0	0	0	0	**5**
F17	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1	1	1	0	0	0	0	**4**
F18	0	1	1	0	1	0	1	0	1	1	0	1	1	1	0	0	0	1	0	1	1	**12**
F19	0	1	0	1	0	0	0	1	0	1	1	1	0	0	0	0	0	0	1	1	1	**9**
F20	0	1	0	0	0	0	0	1	0	1	0	1	0	0	1	1	1	0	1	1	1	**10**
F21	0	1	0	1	0	0	0	1	0	0	0	1	0	0	1	1	1	0	1	1	1	**10**
Dependence power	**7**	**10**	**5**	**11**	**8**	**7**	**8**	**6**	**8**	**8**	**5**	**7**	**2**	**8**	**8**	**10**	**10**	**2**	**5**	**12**	**8**	

*(*after transitivity check)*

The reachability, antecedent and intersection sets were extracted from table 18 to finalize with the level partitioning process (table 19), used afterwards in the graphical representation of the model (figure 16).

Table 19 Level partinioning of factors and rank vectors

Factor	Reachability set	Antecedent set	Intersection set	Level
F1	1, 4,5,6,7,9,11,14,16,17	1,5,6,7,9,13,14,20,21	1,5,6,7,9,14	V
F2	2,3,4	2,3,5,7,8,13,18,19,20,21	2,3	II
F3	2,3	2,3,8,13,18	2,3	II
F4	4	1,2,4,8,12,13,14,16,17,19,21	4	I
F5	1,2,5,6,7,9,11,14,15,16,17,20	1,5,6,7,9,13,14,18	1,5,6,7,9,14	V
F6	1,5,6,7,9,14,15,16,17,20	1,5,6,7,9,13,14,21	1,5,6,7,9,14	V
F7	1,2,5,6,7,9,14,16,17,20	1,5,6,7,9,13,14,18	1,5,6,7,9,14	V
F8	2,3,4,8,10,12,19,20,21	8,12,13,19,20,21	8,12,19,20,21	IV
F9	1,5,6,7,9,14,20	1,5,6,7,9,13,14,18	1,5,6,7,9,14	V
F10	10	8,10,12,13,16,18,19,20	10	I
F11	11	1,5,11,13,19	11	I
F12	4,8,10,12,19,20,21	8,12,13,18,19,20,21	8,12,19,20,21	IV
F13	1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,20,21	13,18	13,18	VI
F14	1,4,5,6,7,9,14,20,21	1,5,6,7,9,13,14,18	1,5,6,7,9,14	V
F15	15,16,17	5,6,13,15,16,17,20,21	15,16,17	III
F16	4,10,15,16,17	1,5,6,7,13,15,16,17,20,21	15,16,17	III
F17	4,15,16,17	1,5,6,7,13,15,16,17,20,21	15,16,17	III
F18	2,3,5,7,9,10,12,13,14,18,20,21	13,18	13,18	VI
F19	2,4,8,10,11,12,19,20,21	8,12,19,20,21	8,12,19,20,21	IV
F20	2,8,10,12,15,16,17,19,20,21	1,5,6,7,8,9,12,13,14,18,19,20,21	8,12,19,20,21	IV
F21	2,4,8,12,15,16,17,19,20,21	8,12,13,14,18,19,20,21	88,12,19,20,2	IV

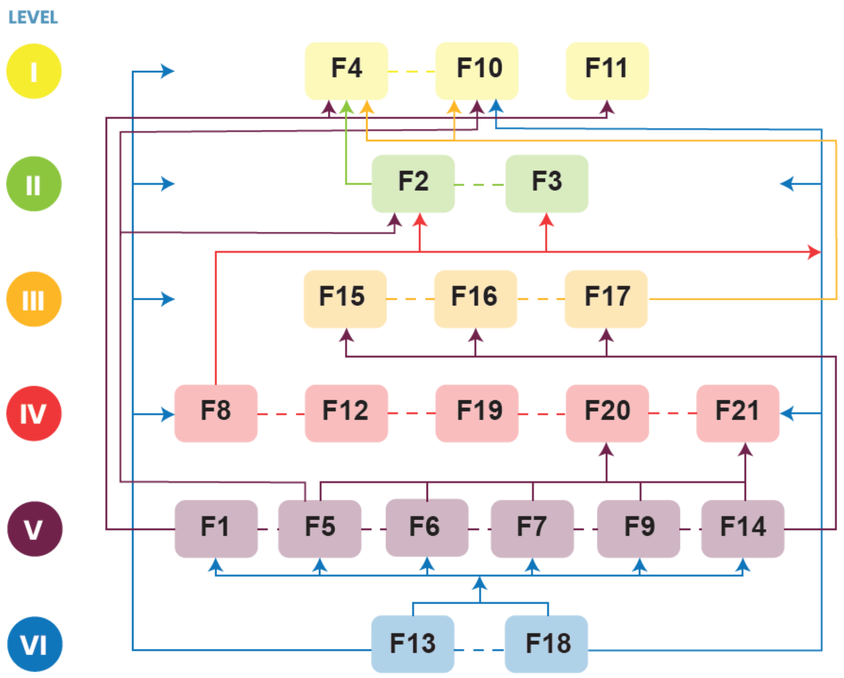

Figure 16 Comprehensive model of the factors that influence more sustainable decisions in small coffee farms (- - - relation among factors of same level, → relation among factors of different levels, factor number in reference to the list of table 10)

Finally, the MICMAC allowed to cluster the factors regarding their characteristics.

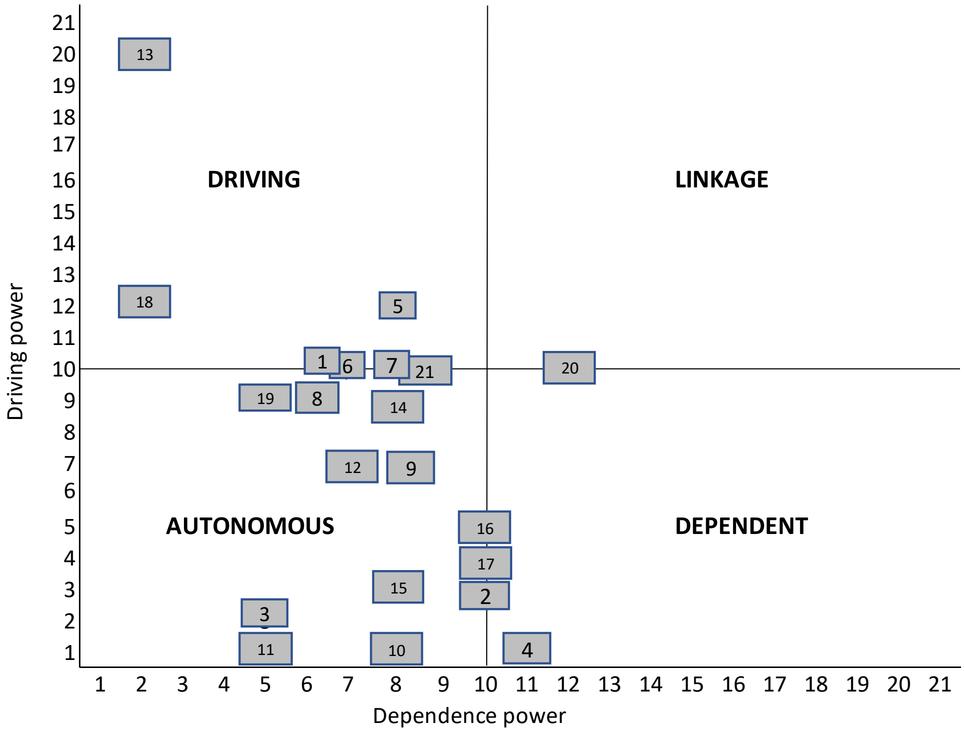

Figure 17 Driving and dependence power diagram based on MICMAC analysis

3.4. Discussion

3.4.1 Farm characteristics

The studied farms belong to a representative group in regards to productive area and practices, yet classified as high-yield farms according to the Costa Rican coffee sector (ICAFE, 2020). The environmental indicators provided by the LCA were consistent with other studies that place the farming stage as the main contributor to the life cycle impacts, (Birkenberg and Birner, 2018; Valenzuela-Vergara, 2016; Killian, et al., 2013; Noponen, et al., 2012; Salomone, 2008). One of the most reported impact categories in green coffee production is the GWP, and the results of the present study indicate that these farms are among the usual ranges, oscillating from 3.14 to 1.10 kg CO_2 eq (Birkenberg and Birner, 2018; Killian, et al., 2013).

In regards to the cost, provided by the E-LCC, it was determined that farms with the highest use of inputs had the highest cost /FU. It is relevant to highlight that the E-LCC, not only accounts for the conventional costs; therefore, even when this study does not fully internalize all externalities, it included the water cost as a consideration of the consumed water throughout the life cycle of green coffee production (using the market value of local water suppliers). As a result, elements such as water, labour and inputs entail the highest contribution to the environmental-cost of coffee production.

Fertilization practices are key to explain part of the productivity, environmental and cost indicators in these farms results (Noponen, et al., 2012). Due to limitations in soil fertility and accentuated acidity (Sadeghian, 2016), producers in CA and Costa Rica particularly, provide large quantities of fertilizer to coffee plantations (Babbar and Zak, 1994), and a fraction of this input would be furtherly leached or volatilized. N is a critical element in coffee production; however, all farms appeared to have coffee plants with excess N.

Shade systems entail the potential of mitigating environmental impacts as the ones considered in this study, or provide services that better balance the agroecosystem where coffee is produced (Nesper, et al., 2019) (De Melo, 2005) (Méndez, et al., 2013). Altogether, the six farms accounted for 19 different shade tree and plant species. The IVI and H' calculations suggest the diversity of species in the farms can be improved, since the diversity index (H´) in CA agroforestry systems ranges from 1.57 and 3.08 (Somarriba, 1999), while the farms of the study oscillate only from 0.90 to 1.61. The increase in diversity can potentially enhance ecosystem services that could positively relate to higher soil pH (critical in these farms) and consequently to affect soil fertility and plant nutrition in a positive manner (Montagnini, et al, 2015; Méndez, et al., 2013; Méndez, et al., 2009; Ataroff and Monasterio, 1997). Moreover, even when carbon storage was only considered in the study to express the potential of mitigation these systems would have, improvements in the variety of trees, as well as their health, age and selection can provide efficient carbon sequestration. This last aspect is currently foreseen in the Cooperative and coffee sector plans through the payment of ecosystem services and low carbon emissions (NAMA Café de Costa Rica, 2020).

After observing the results of the characterisation of each farm, it is evident that farm 5 presents the highest impact for global warming, which coincided to be the farm to apply the second highest amount of N from the group (in the form of Ammonium Nitrate). Farm 5 also accounts for the highest freshwater ecotoxicity impact, mostly associated to the supply of Mo. This element was also present in the inventory of farm 1, which has the second highest impact in this category. Farm 1 also applies the largest amount of N /FU and of P/FU, this later mostly consisting of poultry manure. Moreover, Farm 1 accounts for the highest freshwater eutrophication impact as well, attributable mostly to phosphate fertilizers, Cu and Mo.

Farm 3 had fewer nutritional imbalances in the coffee plants, followed by farms 1, 2 and 6. Farms 2 and 6 also entail the highest productivity of the group. Producers of farms 3 and 6 accounted for less N and P applications, and they also present lower global warming and freshwater eutrophication impacts in comparison to other farms, without compromising productivity, cost and the possible return (Courville, 2003), which are key competitiveness and economic sustainability goals in the sector.

Particularly farm 6, was both the most productive farm, and the most efficient in N use. In addition, it has the second highest H´ of the group and the lowest cost per kg of green coffee in the group, being efficient in the use of certain inputs, such as fertilizers and pest control products. Literature indicates productivity can be positively affected by the appropriate shade system arrangement, which can directly influence the farm profitability due to balanced nutrients and enhanced N soil dynamics (Acosta-Alba et al., 2020).

3.4.2. Interlinked factors for sustainable decisions in small coffee farms.

Previous studies partially address the decision-making considerations towards the use of diverse shade species in coffee plantations, the related livelihoods and production (Vignola, et al., 2015; Méndez, et al., 2013; De Melo, 2005), but not strictly in regards to sustainability-sensitive decision models by farmers.

The literature review allowed to extract factors that could relate to these decisions, and recognized relevant environmental factors to be addressed in order to promote sustainability, considering that shade-systems could aid in that purpose, even when not usually relating it directly to coffee productivity. Contained factors of the literature review were also considered in the six farms or the case study, observing similarities among the literature and the assessed farms, as well as within the farm production techniques. However, the way in which producers manage specific input amounts and types, and arrange the shade system, was not always the same in the six productive units. Therefore, this study took a step forward and aimed to explore the links between these elements, and a broader perspective towards decisions that result in improved sustainable farming practices.

The obtained model suggests that knowledge, tradition, culture and commitment towards sustainability, as well as training entail driving factors. These are the most relevant drivers for more sustainable coffee farming, as observed in the ISM graph where these factors sit at the bottom of the model (level VI). In consequence, any attempt to improve sustainability, through the adoption of positive features present in the farm characterization, such as the use of more diverse shade trees, technical and economic management of inputs (specially fertilizers), environmental impact mitigation, or yield and productivity, should begin with proper intervention of knowledge-related aspects, as these are the most capable factors to influence the rest. In parallel, this could also partially explain why the farmers from these case study, even when being in the same Canton; belonging to the same Cooperative, and sharing edaphoclimatic conditions and coffee varieties, would have different farm characterisations. In other words, their decisions are mostly influenced by their knowledge, culture and commitment, suggesting that interventions should reinforce capacity building, extension and training services, recognizing particular culture and tradition traits.

GHG emissions, services provided by the shade system (climate change adaptation and resilience, improvement of soil conditions), and conservation of biodiversity were the next factors to influence sustainability-related decisions, since they locate at the V Level of the model and sit inside or closer to the driving cluster of the MIMCAC. The cost of shade system management and the productivity-price-quality results also belong to this level in the model, however, they are located in the autonomous cluster of the MICMAC, presenting intermediate dependence and driving power than the rest of factors in this level, suggesting they might slightly influence other factors and be slightly influenced by others. Biodiversity in particular, held a relevant place for farmers, and is typified as a driving factor. Similar as in the study of De Melo (2005), farmers decide in relation to the links they identify between the use of diverse shade trees and the provision of improved environmental conditions for the coffee production. Moreover, farmers from our study even mentioned they enjoyed the view of a shaded-coffee plantation and the amount of birds these trees attract, which was coincident with the expert's judgment. This finding entails an opportunity to increase biodiversity in these farms, as farmers consider this a relevant factor. It is also important to maintain attention on the fact that knowledge (level VI) together with biodiversity (Level V) are powerful drivers to trigger more sustainable decisions, since they also present further relations with other environmental and productive factors from the subsequent levels of the model.

Existing policies, the cooperative scheme, certification schemes and incentives (such as ecosystem service payments), together with the easiness of the cropping practices are related among themselves, and receive influence from both precedent levels, specifically by level V factors such as the climate change adaptation/resilience, and production-related results. Even when most of these factors present lower dependence and driving power, the easiness of the cropping practices is closer to the driving cluster, which means it can still generate influence in other factors. Moreover, support, motivation and requirements from the cooperative scheme should be carefully planned, since it is typified as a linking factor, suggesting that actions on this factor will create effects on other factors as well as in itself. For instance, these context factors would mostly influence the ones in levels II and I of the model.

Level III factors include preference and access to different coffee varieties, the use and cost of inputs, and the nutrition condition of the coffee bush (level III). They do not receive direct influence from the precedent level suggesting that direct outcomes from the existing policies and schemes do not influence the farmers' decisions in this study in regards to the selection of coffee varieties, the use of inputs or the conditions of plant nutrition. In contrast, they respond to knowledge, shade-system services and productivity-related factors. One interesting observation relates to the circumstance that as the factor related to variety selection seems to be more autonomous than the others of this level, as both the cost of inputs and the conditions of the coffee plant nutrition move closer to the dependent cluster of factors; which suggests by definition that factors of this type can be properly addressed if linking and driving factors are addressed. In other words, when knowledge and tradition, training and capacity building, biodiversity conservation, and the support from the cooperative scheme are aligned and improved, the use and cost of inputs as well as the condition of plants can become improved too, connecting to other factors they influence such as the overall environmental cost of coffee production (Level I).

Impacts related to water degradation are of special interest worldwide as well as in the productive area where the farms sit. The geography, topography and soil characteristics of these farms predetermine a high potential for non-point source pollution (Crespo, et al, 2016); however, the factors of water pollution and consumption situated at level II; suggesting that even when necessary to address, they were not driving factors for sustainable decisions for farmers. Explicit intervention through driving factors that would result in a more sustainable management of the water resources are urgent, and can be motivated by certification schemes that take into account the sustainable use of this resource, as observed in the model.

Finally, two of the level I factors contrast to previous related the use of shade as a driver for income or food supply diversification studies (Vignola, et al., 2015; Méndez, et al., 2013). Farmers usually claim to use *Musaseae* species due to the shade it provides and the pruning easiness and not for feeding reasons, which is something in which most experts coincided, leading to the classification of these factors as autonomous. The environmental costs, however, are evidently linked to all of the precedent levels of the model, and locate in the dependent cluster, expressing the possibility to be properly addressed when other factors are addressed, whether they relate to LCT factors, context or shade factors.

3.5. Conclusions and recommendations

The production practices at the farm level of the life cycle of green coffee production contribute to the highest share of environmental and cost impacts. Hotspots are explained by the use of inputs, such as fertilizers, which can be managed in terms of fertilization programme and techniques, type, and amount. Moreover, studies suggest the inputs performance can be improved by provided services from shade trees. The literature supports the fact that introduction of shade trees in the plantations entail paramount opportunities to mitigate environmental impacts and improve production conditions, as observed in some of the farms of the study with higher biodiversity indicators, carbon storage potential, more efficient use of inputs and higher productivity. However, even when sharing similar conditions, not all farmers make the same decisions in regards to fertilization and shade-tree management, unveiling different sustainability performances in their farms.

Productive, commercial and environmental relations are still blurry for many stakeholders, and even when environmental protection is at the heart of many policies and agendas (Díaz Porras, Hernández, Romero Padilla, & Salazar, 2000), the direct link and guidance for the productive sector still needs more support and evidence. Therefore, decisions from productive actors, particularly farmers can only be consciously adopted when linked to effective training, knowledge and capacity building. Scientific-evidence based policies, extension and co-learning experiences in consequence, can trigger more sustainable decisions regarding lower emissions to water, soil or air, biodiversity and climate change adaptation and resilience.

Future assessment regarding the use of different varieties and inputs, and their relation to production, productivity, quality and income is required to support decisions for improved sustainability indicators as well, since they would also have effects in overall environmental costs.

Engagement of stakeholders and particularly participatory approaches for farmers are key to reveal their knowledge, perception and understanding of the related factors among environmental and economic indicators, together with shade system co-benefits. These considerations can properly aid in addressing decision and policy processes towards more sustainable coffee production.

Finally, even when ISM is particularly useful at early stages of research as in this case, agro-ecosystem similarities to other Costa Rican and Central American productive areas together with larger farm samples, can allow the coffee-sector policy makers to build-in from this study to support and tailor programmes and policies that result sensitive to the observed driving, dependent and autonomous factors that influence decision-making processes in farms when addressing sustainability.

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CHAPTER 4: Unveiling social hotspots in selected agri-food chains in Costa Rica: the case of green coffee, raw milk, and leafy vegetables

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Abstract:

Scientific literature suggests a growing consensus about the importance of addressing social impacts to ensure sustainability. At the same time, there are important sectors as the agri-food where the identification of social hotspots is largely neglected. This work intends to unveil social hotspots and strengths in three agricultural products from a Latin American and Caribbean developing country as Costa Rica, while recognizing the challenges of Social-Life Cycle Assessment (S-LCA) application in this context.

METHODS: S-LCA represents a powerful technique to evaluate the potential social impacts of a product. A set of three case studies were analysed through S-LCA, using the Subcategory Assessment Method (SAM) to characterize the impacts and detect hotspots in the production of green coffee, raw milk and leafy vegetables. Primary data collection consisted of observations questionnaires applied to key informants and, together with secondary data collection, eight impact subcategories were assessed for two groups of stakeholders (farmers and workers), and nine subcategories for a third group (local community).

RESULTS AND DISCUSSION: Main results suggest that there is a satisfactory social performance, possible enabled by the local setting surrounding studied cases. The assessed stakeholders appeared to be able to fulfil basic needs through access to inputs and services; there were fair-trading conditions, absence of child labor or forced labor, and no evidence of environmental or health risks for the nearby communities. Important efforts were observed to address the delocalization and migration subcategory, as well as indigenous rights when applicable. However, farmers and workers entail hotspots regarding social security and women´s empowerment, mostly in the farming operations.

CONCLUSIONS: S-LCA was useful to identify relevant areas of intervention in the context of these particular case studies; considering farmers and workers as one of the most vulnerable groups. Further research and capacity building is recommended in order to tackle the detected challenges in the use of the technique, since most stakeholders were not fully aware of its existence and applications.

Keywords: S-LCA, agri-food system, Costa Rica, social impact, coffee, vegetable, raw milk, SAM

4.1. Introduction

Sustainable development has been part of international and national policies for several decades. Although a formal definition by the Brundtland Commission's report in 1987 was adopted (UNEP/SETAC, 2009), and frameworks such as the Sustainable Development Goals (SDGs) promote an integration among the environmental, economic and social dimensions (Manik, Leahy, & Halog, 2013), many efforts and studies usually focus on the environmental challenges (Fauzi et al., 2019), neglecting the social perspective. This occurs in spite of the acknowledgment of human well-being as a crucial aspect of sustainable growth (Mani, Agrawal, & Sharma, 2016). Moreover, the evaluation of social sustainability is intricate since it involves different stakeholders and areas of attention entailed in modern and complex food supply chains (García-Herrero, De Menna, & Vittuari, 2019).

SDG 12 for Sustainable Production and Consumption demands a systemic change, decoupling economic growth from environmental degradation in all phases of the life cycle of products. In consequence, the Life Cycle Thinking (LCT) approach has been recognized as powerful to examine sustainability beyond the sole the environmental standpoint (Salla & Castellani, 2019; Manik, Leahy, & Halog, 2013; Parent, Cucuzzella, & Revéret, 2013; UNEP/SETAC, 2009). As part of the LCT approach, Social Life Cycle Assessment (S-LCA) is defined as a technique that evaluates the social impacts, actual or potential, positive or negative, in relation to a stakeholder over the life cycle of a product (UNEP/SETAC, 2009). Most S-LCA case studies located in literature are focused on the manufacturing or the agricultural sectors, and almost half of them have been implemented in developing countries. Even when increasing publications ground S-LCA as the main methodology to assess social sustainability, and an update of the S-LCA Guidelines was introduced in 2020 by UNEP (UNEP, 2020), there are still gaps in its implementation. Some of these relate to the inventory methods and analysis, the definition of the goal and scope, the scales and type of assessment, the definition of acceptable and non-acceptable outcomes and its geographical relativity (Sureau, Neugebauer, & Achten, 2020; Tokede & Traverso, 2020; Fauzi et al., 2019; Lucchetti et al., 2018; Petti, Serreli, & Di Cesare, 2018).

A relevant region to study regarding overall sustainability is Latin America and the Caribbean (LAC) since it is responsible for 14% of the world's agri-food production and 23% of global exports, enclosing an outstanding natural capital and a high reliance upon family farming activities to support rural economies and food security (OCDE/FAO, 2019; MAG, 2020). However, investment in the LAC agri-food sector is still lower than the OECD and global averages, potentially causing constrains in food security and nutrition, health, poverty (mainly rural), permanence of traditional livelihoods, and migration (OCDE/FAO, 2019). The social challenges in this region and sector, call for actions in policies, investment, and research, including the use of S-LCA as it is still scarce in the region (Cornejo & Orner, 2019; Du et al., 2019; Du, Dias & Freire, 2019). The results obtained from this type of research are crucial both for improved inclusiveness within the agri-food sector, and to remain a key player in the global food markets (OCDE/FAO, 2019). One particular country of interest within this Region, is Costa Rica, a developing country with appealing socio-economic and environmental traits (SEPSA, 2016; Rodríguez-Becerra & Espinoza, 2002).

Given the mentioned context, the purpose of this paper is to aid in understanding the vulnerabilities and strengths of the social dimension of three selected agricultural Costa Rican products. To accomplish this purpose, the paper collects three case studies: green coffee, raw-milk and leafy vegetables production, using a reference scale approach for the intended social impact categories, aggregated under a theme for each assessed stakeholder, with the support of the Subcategory Assessment Method (SAM). The interpretation of hotspots and potential trade-offs could guide public policy processes, and showcase the prospects of S-LCA application in this particular context.

4.2. Materials and methods

4.2.1. Case studies description

Costa Rica is a democratic LAC country, with relevant sustainability indicators. It has had steady economic growth and one of the lowest poverty indicators in the region; however, recent conditions related to the Covid19 pandemic are pressing into increased inequality and fiscal constraints (World Bank, 2020).

The agri-food sector generates 12.3% of the jobs in the country, and supports 5.2% of the national economy and 45.7% of exports (SEPSA, 2016). Almost half of the national territory is dedicated to agriculture (47.1%), and a similar proportion is for conservation, with increased urbanization processes in concentrated areas (PNUD, 2019). The activities from the case studies (Table 1) were selected due to their relative contribution to the national economy and food security, as well as their local relevance. For instance, the dairy sector farms represent 28.5% of the national agricultural coverage; coffee production represents 24.3% and vegetables 4.8% (INEC, 2018). A more specific description of the cases is also provided in the results section.

2.2. Social-Life Cycle Assessment

The first guidelines to perform S-LCA were published in 2009 by UNEP and SETAC, and evaluations using them have increased in the past decade (Fauzi et al., 2019). S-LCA informs of incremental improvements and provides evidence for decision making and discussion to advance towards an enhanced social performance in the life cycle of the assessed good. It does not provide particular solutions nor is defined by a standardized method, but follows the same steps from the (environmental) LCA (UNEP/SETAC, 2009), facilitating the detection of hotspots and trade-offs. Moreover, it allows the expression of social footprints (negative impact) and social handprints (positive impacts caused by changes applied to the business-as-usual production) (UNEP, 2020).

There are several approaches to address social assessments; in this case, the interpretivist paradigm was followed, therefore formerly known as Type I impact categories (Iofrida et al., 2017) were evaluated through reference points, scored and aggregated under themes for each assessed stakeholder. This paradigm contrasts with the positivist one, which relies on type II categories that model the results through causal links (Russo-Garrido et al., 2018) and a pathway perspective.

Goal and scope:

The study had the purpose to assess the potential social impacts and detect main hotspots of the production of 1 functional unit (FU) of three selected agri-food goods, produced in 2019, in life cycle stages with system boundaries from cradle to gate (table 20). Production was located in the central zone of Costa Rica (figure 18). Through the assessment different opportunities, good practices and improvement needs in the studied subsectors were to be observed.

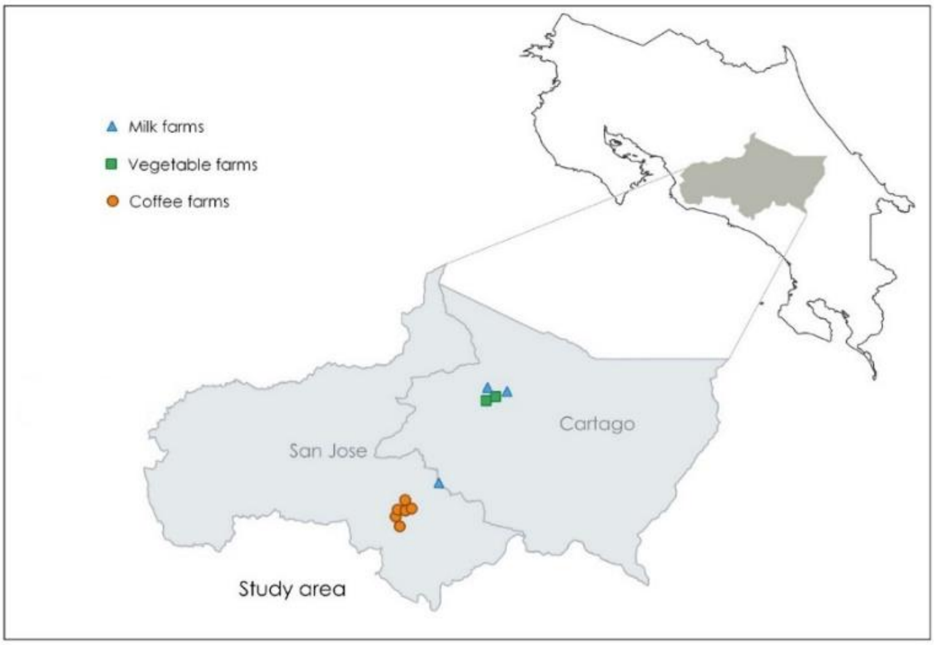

Figure 18 Location of the three case studies in Costa Rica

Table 20 Summarized case description for S-LCA in selected agri-food chains from Costa Rica

Crop	**Green Coffee**	**Raw milk**	**Leafy vegetables**
Farms	6	4	3
Functional unit	1 kg of green coffee	1 kg of raw milk	1kg of lettuce
System boundaries	Cradle to farm gate	Cradle to farm gate	Cradle to market entry gate
Considered stakeholders	Workers, local community and value chain actors (farmers)		
Interviewed key informants	12	11	5
Key informants	The group included farmers, Cooperative agents, and institutional actors	The group included farmers, workers, sectoral representatives, and institutional actors	The group included farmers, workers, members of the farmers' association and institutional actors

This research assessed three of the stakeholders referred by the UNEP/SETAC Guidelines (2009) and Methodological Sheets (2013) (figure 19), and the value chain actors' group was modified placing special emphasis on farmers, as addressed in the small-entrepreneurs stakeholder category in the S-LCA methodology by Goedkoop, Indrane, & de Beer (2018). This is due to the fact that most agricultural activities in the Region, in Costa Rica, and particularly in the three case studies, are developed by medium or small family farmers (OECD , 2017; MAG, 2020).

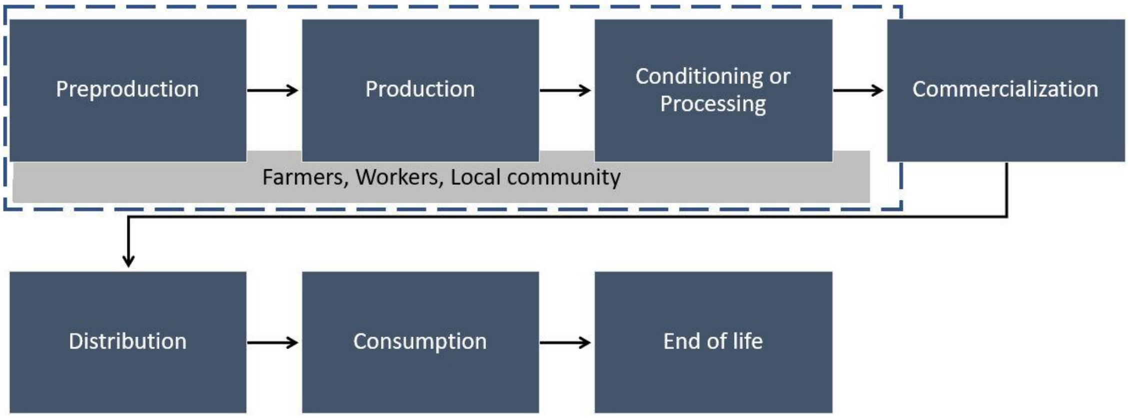

Figure 19 System boundaries and stakeholders defined in this S-LCA

Inventory analysis:

This phase was the result of the collection of data through applied questionnaires to a non-representative sample of farmers, workers, and sector experts, and focus groups (guided by the same questionnaires). Due to the novel application of S-LCA in this country, a case-study approach was followed, and interviewees were approached based on their relation to each case and willingness to participate. On-site observations and primary documentation when existing was also considered, as well as secondary national or sectoral information, related to legislation on labour rights (MTSS, 2018; 2019), child labour (FAO, 2020; PANI, 2020) and migrant working permits and social security coverage (MAG, 2020; ICAFE, 2019; Loría-Bolaños, 2012); national and agriculture-sector statistics and analysis (INEC, 2015; 2018; MTSS/CSO, 2018; OECD, 2017; SEPSA, 2016; INDER, 2016; de la Garza Toledo, 2001), and subsector statistics and reports (ICAFE 2020a, b; CoopeTarrazú R.L., 2019; Coto-Keith, 2019; CNPL, 2019; 2018; 2017; MEIC, 2017; Barboza-Arias, 2016).

Impact assessment:

The impact assessment phase consisted of the application of the SAM as characterization method, expressing the performance of the system to be evaluated through four levels (D'Eusanio et al., 2018; Petti et al., 2018; Sanchez-Ramirez et al., 2014):

- level A (value of 4) is obtained when the system or the organization responsible for the assessed product shows a proactive attitude, surpassing Basic Requirements (BR),
- level B (value of 3) indicates the fulfilment of the BRs,
- level C (value of 2) is assigned when BRs are not met, similar to peers or the local context,
- level D (value of 1) is assigned when BRs are not fulfilled, while the sector or context usually does or is close to compliance.

The BRs were established according to national legislation (aligned with international dispositions) and context conditions. Answers from the different interviewees were registered in Microsoft Excel ® spreadsheets, and a descriptive analysis was conducted, using the median as the obtained value for the assessed impact subcategory, since results are presented as ordinal data (Harpe, 2015). The study included a total of 114 indicators in relation to the impact subcategories observed in table 21 (indicators can be seen in Annex 3: supplementary materials from chapter 4).

Table 21 Stakeholder groups and impact subcategories

Stakeholder	Source of evidence	Impact subcategory
Farmers **(Value Chain actors)**	Questionnaire, interviews, non-participatory observation, secondary data	Meeting basic needs Access to services and inputs Women´s empowerment, inclusion and no discrimination practices Child labor Health and safety Land rights Corporate Responsibility Fair Competition
Workers	Questionnaire, interviews, non-participatory observation, secondary data	Freedom of Association and collective bargaining Child Labor Fair Salary Hours of Work Forced Labor Equal Opportunities /no- discrimination Health and Safety Social Benefits / Social Security
Local Community	Questionnaire, interviews, non-participatory observation, secondary data	Delocalization and Migration Community Engagement Cultural Heritage Respect of Indigenous Rights Local Employment Access to Immaterial Resources Access to Material Resources Safe and Healthy Living Conditions Secure Living Conditions

(most impact subcategories are based on UNEP/SETAC (2013) *and UNEP (2020), except the ones for farmers as value chain actors based on Goedkpp, Indrane and de Beer* (2018).

A triangulation of the obtained assessment, secondary data and observations was integrated to present the social performance of the studied cases. This was first done to observe each category per stakeholder, and afterwards, it was aggregated to observe the overall social performance per studied crop. This latter was executed through equal weighting among subcategories [(obtained points / possible maximum points)*100], and supported the detection of hotspots and trade-offs in the production of these goods; later.

Interpretation:

In order to carry out this phase, a revision was included for completeness and consistency in regards to the goal and scope, as well as for the inventory and impact assessment. An additional discussion was presented, regarding the most relevant subcategories in light of social risks and strengths from the cases, as well as limitations and applications of S-LCA in the studied agricultural context.

4.3. Results

3.1. Green coffee

This case study, consisting of six small coffee farms located in the Tarrazú canton in Los Santos Region, included conventional shaded coffee production systems that use coffee-brush compost and bioinputs (CoopeTarrazú R.L., 2019). Farmers send the harvested coffee beans to be processed and commercialized through the local cooperative named Coopetarrazú. Most of the tasks are manual, with an increased number of workers during harvest season, similar to the rest of the national coffee sector (ICAFE, 2020 a).

The farmers stakeholder group assessment (figure 20) indicated that the subcategories of *access to services and inputs; health and safety; land rights,* and *fair-trading conditions* obtained a Level A score with value of 4 points, while the remaining social impact subcategories obtained level B scores, meaning they complied with BRs but did not surpass them.

The assessment for the workers' stakeholder group was positive (figure 21), since five subcategories obtained a proactive performance score (level A, 4 points), namely *child labor, fair salary, hours of work, forced labor,* and *health and security*; the remaining three subcategories obtained a level B score.

A third assessed stakeholder group was the local community, where the following subcategories obtained level A scores (figure 22): *delocalization and migration; cultural heritage; respect to indigenous rights; access to material resources; access to immaterial resources*, and *safe and healthy living conditions*; in contrast to *community involvement, local employment* and *secure living conditions* that obtained level B (3 points) scores.

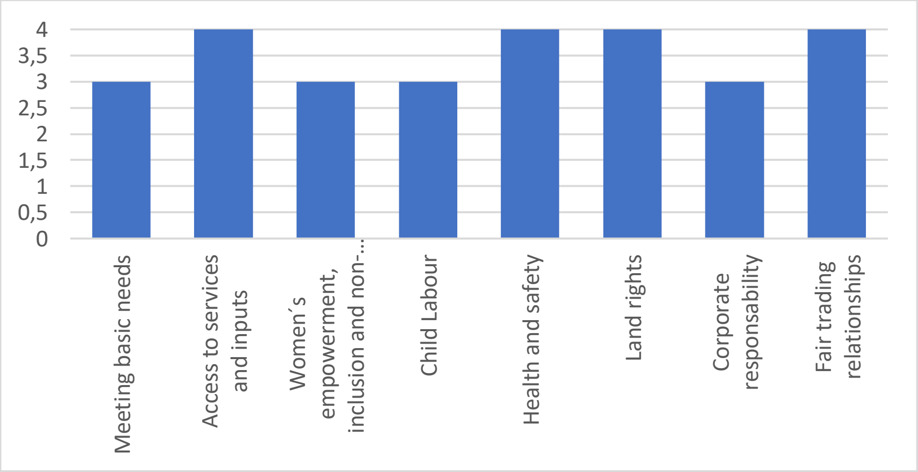

Figure 20 Farmer stakeholder subcategory assessment results in the green coffee case study

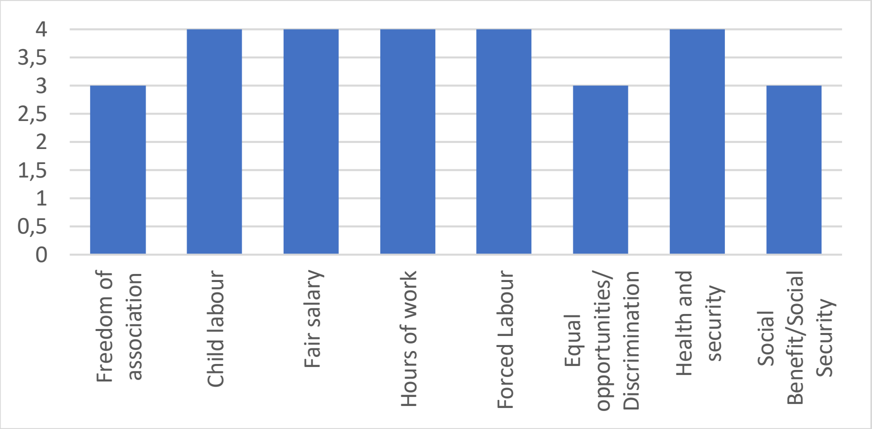

Figure 21 Worker stakeholder subcategory assessment results in the green coffee case study

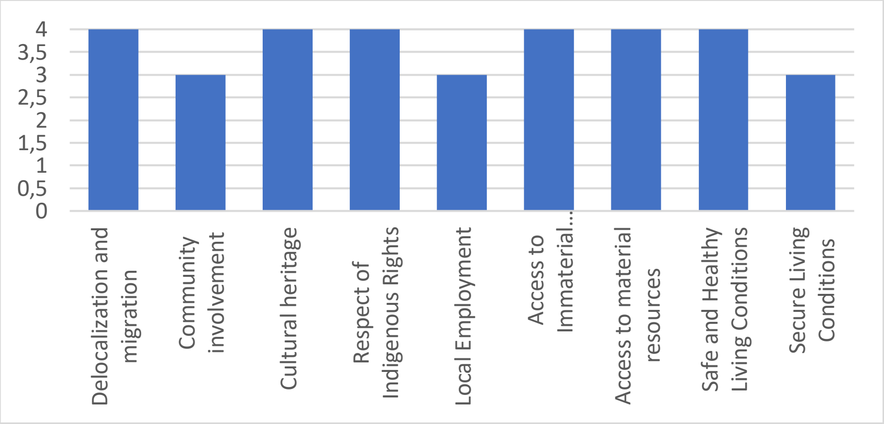

Figure 22 Local community stakeholder subcategory assessment results in the green coffee case study

3.2. Raw milk

This case study included specialized high-land dairy farms in the Cantons of Alvarado, Oreamuno and Tarrazú, belonging to two of the largest milk producing provinces in Costa Rica (Arndt et al. 2020). These are characterized as commercial farms that turn their milk output to their own cooperative for industrialization, with high quality milk production, specialized dairy breeds and feeding strategies. The following subcategories assessed for farmers obtained level A scores: *meeting basic needs, access to services and inputs, health and safety, land rights* and *fair-trade relationships* (figure 23); *child labour* and *corporate responsibility* subcategories obtained a B score, and *women´s empowerment, inclusion and non-discrimination practices* scored at C level, mostly due to the absence of female workers or farmers.

Figure 24 presents the social impact subcategories assessed for the workers stakeholder group; where *freedom of association, child labour, fair salary, forced labour*, and *health and safety* obtained a level A; *hours of work* and *equal opportunities* subcategories ranked at B level, and *social benefits and security* obtained a C level score. The last stakeholder group assessment of social impact subcategories in the raw milk production case was for the local community, presented in figure 25, where subcategories related to *safe and healthy living conditions* and *secure living conditions* in regards to the local community stakeholder group obtained a level A score, and the remaining a B score, except *delocalization and migration* (C level) and *indigenous rights* which was not applicable to the case.

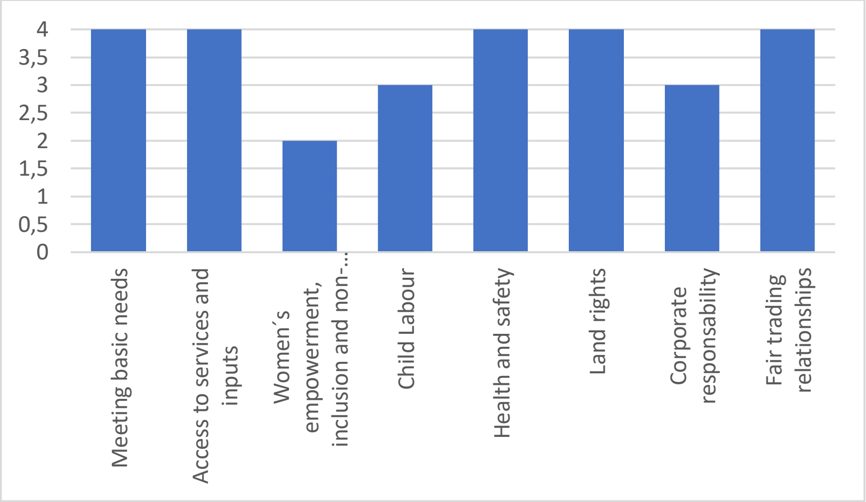

Figure 23 Farmer stakeholder subcategory assessment results in the raw milk case study

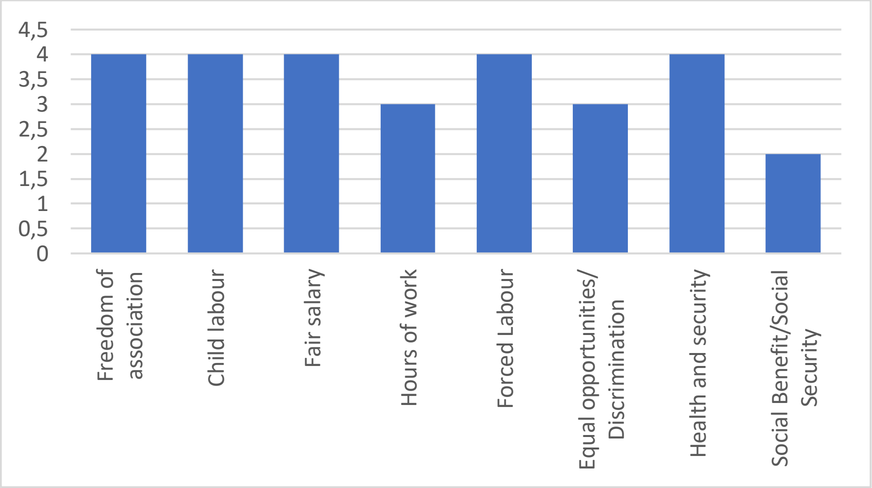

Figure 24 Worker stakeholder subcategory assessment results in the raw milk case study

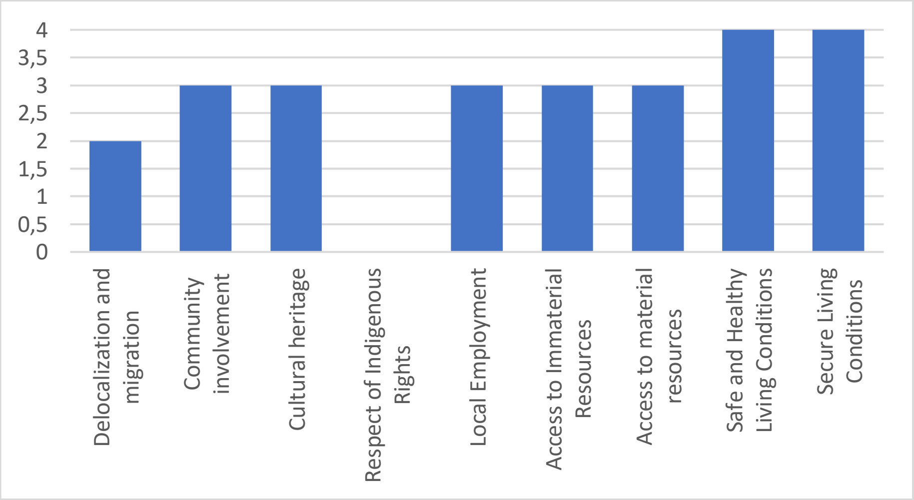

Figure 25 Local Community stakeholder subcategory assessment results in the raw milk case study

3.3. Leafy vegetables

The leafy vegetables case study was built on three farms that operate within a local organic farmers association in the northern part of the province of Cartago called APROZONOC. They qualify as small family farms with improved environmental sustainability performance according to the "Bandera Azul" award and the Primus Lab Organic certification scheme (PBAE, 2017) (Pacheco-Rodríguez, Borrero-González, & Villalobos-Rodríguez, 2017. Their product is commercialized in farmers markets during the weekends, or through personalized delivery during weekdays.

The following social impact subcategories were assessed as A level or proactive (value of 4 points) for the farmers' stakeholder group (figure 26): *access to services and inputs; women´s empowerment, inclusion and non-discrimination practices; child labour; land rights*, and *corporate responsibility*. Subcategories regarding *meeting basic needs; health and safety*, and *fair-trade conditions* were assessed at B level. In regard to the workers stakeholder group (figure 27), indicators for the subcategories of *child labour; fair salary; hours of work; forced labour*, and *equal opportunities and non-discrimination* obtained a score of A; while *freedom of association; health and security*, and *social benefits/social security* obtained a level B score. Finally, the assessment of the social impact categories for the local community stakeholder group is presented in figure 28, where most of the subcategories are assessed as proactive (level A), two categories complied with BRs (level B), and the one regarding *indigenous rights* does not apply since indigenous peoples are not present in this activity or location.

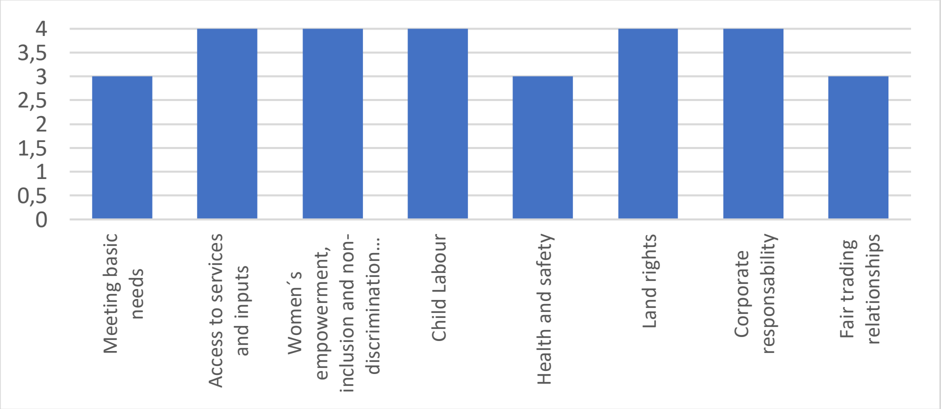

Figure 26 Farmer stakeholder subcategory assessment results in the leafy vegetables case study

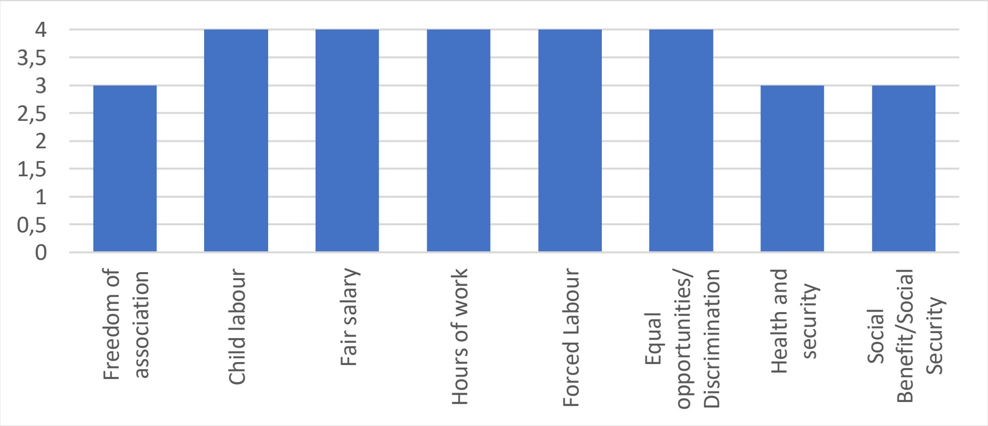

Figure 27 Worker stakeholder subcategory assessment results in the leafy vegetables case study

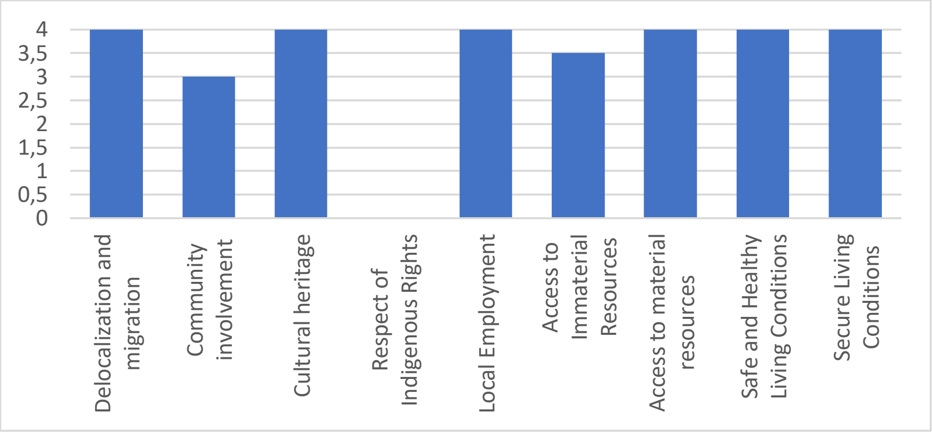

Figure 28 Local community stakeholder subcategory assessment results in the leafy vegetables case study

A summary of the aggregated assessment from each of the studied cases (figure 29), presents the overall performance per stakeholder, namely farmers, workers and local community.

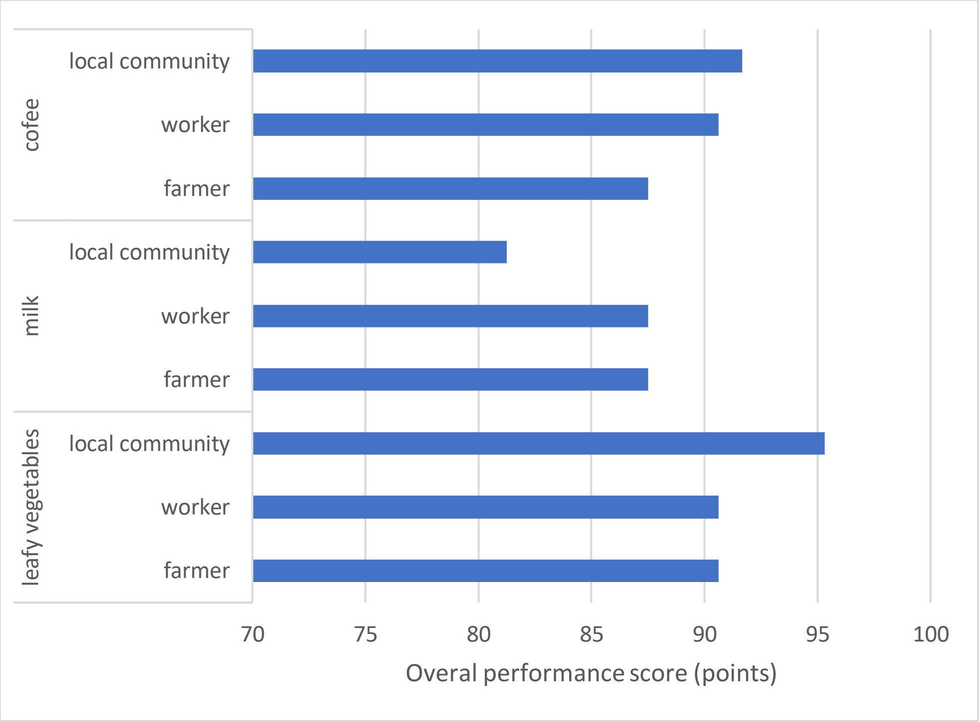

Figure 29 Local community stakeholder subcategory assessment results in the leafy vegetables case study

4.4. Discussion

4.1. Main strengths of the studied products

The general assessment for the potential social impacts in the three case studies are perceived as positive, since most of them ranked between level A and level B scores, in response to a generally enabling environment provided through a robust social and institutional system. This condition is expressed in the country through the existence of work-legislation and policies that foster decent work hours, minimum wages, avoidance of child and forced labour, freedom of association, and collective bargaining. There are accessible public services for extension and training, transportation, and many basic services in the studied farms. There are good commercial conditions for the provision of a variety of inputs and input-suppliers in the market. Telephone, credit and insurance services, both from public and private operators are also widely spread (Loría-Bolaños, 2012; INDER, 2016; OECD, 2017; World Bank, 2020).

Within basic conditions, all the cases presented compliance with BRs, since farmers, their families and workers were able to access safe drinking water, electricity and the products from the Costa Rican basic food-basket. However, some farmers claimed to be unable to surpass basic needs, confirming that even when they situate above the line of poverty (INEC, 2018), rural families in certain activities tend to be at risk of food insecurity (Intini, Jacq, & Torres, 2019), an aspect that is most certainly increased by crisis such as the one caused by the Covid-19 pandemic.

The environmental and health-related legislation and standards in the country, in companionship of academic, research and training institutions (OECD, 2017) have also played a key role in preventing risks and fostering safe and healthy living conditions. In fact, even when agriculture activities are in the top-three positions for work related injuries according to national statistics (MTSS/CSO, 2018), the studied cases presented a low accident rate or illnesses related to chores in the farms and the absence of fatalities. Moreover, stakeholders coincided on the fact that workers are always provided with safety equipment and encouraged to work carefully to avoid accidents, acting as an alternate mechanism to explicit policies or work safety departments (as they are not required by law due to the amount of workers per farm, less than 20persons/ year) (MTTS, 2018).

Even when not conducting a social hand-printing exercise in this study, future comparisons between business-as-usual (past) production and current performance can allow the correspondent calculations (UNEP, 2020). This possibility relies in the important improvements that have been seen in the past two decades in regards to waste management, environment and health regulations. These aspects were established at constitutional level and operatized through ministerial rectories that have promoted decisions at policy level, private-public alliances and citizen participation (Rodríguez-Becerra & Espinoza, 2002). Moreover, the farms from the cases have been proactive in the application of these improvements. For instance, the coffee and dairy sectors have been subject to close monitoring to improve working conditions and waste treatment, currently resulting in two of the most highlighted showcases for biocircular economy approaches in the country (MICITT, 2020). From a voluntary perspective, the leafy vegetables farms operating under organic agriculture would not only comply with pest-control products residue standards, but they also show a high commitment to comply with other normative to certificate their production as organic (PBAE, 2017; Pacheco-Rodríguez, Borrero-González, &Villalobos-Rodríguez, 2017). This suggests lower pollution risks and health risks due to chemical fertilizers or pest control inputs in the produce they sell and their surroundings. This argument is supported by similar perception studies, such as the one developed by Racines, Isaías-Acuna & Varela (2021), in which consumers of organic vegetables preferred these produces based on health, protection to the land and sensitivity to farmers.

Additional and extraordinary measures have been observed in the case of the coffee production, in which besides of the existence of specific representation of indigenous population in the locality, mostly due to the interaction with the Ngäbe-Buglé indigenous community (Morales-Gamboa, Lobo-Montoya, & Jiménez-Herrera, 2014), an important investment has been made in a social project called “Casas de la Alegría”. This initiative aims to provide children and minors that move with their parents during the harvest season, indigenous or not, with proper attention while the parents are in the farms (UNICEF/IMAS, 2019; (CoopeTarrazú R.L., 2019). In this sense, even when further assessment to define the metrics for this aspect, potential social handprint inputs are observed in these practices, as the Costa Rican agriculture sector, and particularly actors from these case studies, have been evolving from business-as-usual operations, to more aware and social-sensitive ones; creating additional benefits or conditions than other activities for workers, farmers or the local community.

It is worth to mention that two of the cases operate under cooperative schemes (coffee and dairy), which seem to constantly support farmers in fair trading conditions, training and services access, and usually improved health, environment and safety circumstances (Barboza-Arias, 2016). These conditions are enabled through different value chain alliances promoted by the cooperatives with private, public or academic organizations (CNPL, 2017; ICAFE, 2020b), fair-trade certifications (CoopeTarrazú R.L., 2019), and regulations that support quality standards definitions and product categorizations at national or regional levels (MEIC, 2017; CNPL, 2019). This was not the same for the case of leafy vegetables, due to the fact that although organic associations, national programmes and organizations were identified, farmers regretted the actual support for transparent and fair conditions in the local trade of organic products. The farmers claim that even after all the efforts they put into producing organically, policies have not been reinforced to consistently request evidence and certifications of this trait in some markets. In parallel, it is also perceived that farmers who are grouped in cooperatives tend to receive slightly more profits at the end of the fiscal period (through a cooperative surplus distribution, due to quality or certification prizes achievement), and be more involved, directly or indirectly, in the communities. As an example, Coopetarrazú registered contributions of over 90 000 USD/year to the surrounding districts (CoopeTarrazú R.L., 2019), and even when farmers would not directly organize the activities, they usually participate and provide their support.

4.2. Opportunities for improvement unveiled by S-LCA

Hotspots were located mostly at the production operations in the farms, particularly in the workers and farmers groups whether they dealt with preproduction, production or harvesting (or milking in due case), consistent with the observed lower overall scores in two of the cases. Those hotspots were detected after observing certain impact subcategories and indicators, which if not properly addressed, could result in evident constrains. The following impact subcategories and aspects can be considered as entry points to conduct future diagnoses or interventions for policy-making processes or adaptations to existing ones.

Observations and interviews suggested social security performance is at risk in these farms. Despite the widely spread coverage and access for health insurances, the affiliation to this system is reported as expensive by the farmers. This condition has sometimes pushed workers to resort to a social security coverage payed by him or herself. This is possible under the national legislation if a worker is freelance; however, it was not possible to determine if this was the situation at all times in three case studies.

This condition is quite relevant from different perspectives, as it becomes the most evident trade-off observed in the assessment as well. On one hand, most health and social security infractions in Costa Rica respond to enrolment and payment of social security, as well as to salary registers, showing a slight increase in the past years (MTSS/CSO, 2018). Coincidently, farmers, who stated that the cost of social security is high for them, might not enrol the worker since it might affect their income and profit. However, if farmers keep enrolling their workers at the current cost, it might suppose a decrease in their profits and consequently, it can result in potential reduction of hired workforce and job generation. On the other hand, the agriculture sector is the fourth highest contributor from private economic activities to the social security system in Costa Rica (MTSS/CSO, 2018); thus, the contraction in contributions could severely impact the sustainability of the national system.

Women´s empowerment is another aspect that still requires close observation, as most decision-making processes from the studied farms still lack the full and equitable involvement of women. National statistics indicate 15,6% of farmers are women and 37% of the national occupied workforce is female (INEC, 2015; 2018), and even when these thresholds were closely met in the coffee and leafy vegetable cases, the raw milk case lacked of female participation according to observations and consulted key informants. Even when interviewees of all cases expressed absence of discrimination, certain aspects related to gender, sexual orientation and diversity were not fully discussed, or understood in the assessment process.

Local employment is another aspect that is very relevant to be addressed in the Costa Rican agriculture sector, considered as a second socio-economic vs. productive trade-off. This is evident in the coffee production, since even when there might be an interest to hire local workers, these would not be enough as most harvest operations are dependent on migrant workforce (Loría-Bolaños, 2012). This represents a high risk to maintain economic and productive indicators, which almost became true during the borders shut-down because of the Covid19 pandemic, as many migrants seem to be unable to enter national territory and work in the coffee harvest. Cooperative managers and statistics claimed that even if all the Tarrazú canton inhabitants would have worked harvesting coffee, more than half of the output would have still been lost because of insufficient workforce. At the end special measures were introduced and the harvest season was not as badly affected as expected. In parallel, the volume of migrant workers can potentially remain in irregular migratory conditions for a period of time, which could limit their access to social security and health coverage. The awareness of the situation, both productively and socially, has motivated a set of alternatives that entail the chance to normalize or obtain temporary work permits for immigrants, in order to be subjected to social security and verified decent working conditions (MAG, 2020).

Finally, there were two indicators that even when not significantly affecting the overall score of subcategories such as freedom of association, hours of work and fair salary, need to be addressed. One has to do with the documentation processes of the working relations on the farms, since most of contracts were verbal and few farms (only from the raw milk case) indicated they provided payment slips or made bank deposits, which also creates evidence of the salary payment. This is already pointed in national statistics where receipt or pay-slips absence are one of the most common infractions in the social security evaluations (MTSS/CSO, 2018). Moreover, current Costa Rican legislation requires the creation of contracts, but allows verbal typologies when the working relation is of less than three months (MTSS, 2018); in this sense, few farms evidenced some form of information systems (notebook, bank deposits or computer information systems) to keep track of their working relations, payment conditions and track of incidents. The second indicator had to do with the fact that, since some productive sectors in Costa Rica have had harsh encounters with the operation of workers unions, a worn-out image is perceived towards this type of worker association (de la Garza Toledo, 2001). Despite the assessment of the subcategory that suggested there was freedom of association, there is no encouragement to formally establish certain union typologies in the farms. Indirectly, this could mean working relations are mostly harmonious for the studied cases (as expressed by workers), but on the other hand, if conflicts arrive, workers have little chance to collectively bargain for their conditions and would need to resort to the Labour Ministry: this is a relevant support for their right, but usually an intricate way to follow.

4.3. Prospects of S-LCA in the Costa Rican and LAC context

While conducting the assessment, challenges for data collection were encountered, since registers at these small-scale operations are not always common. This is not only a challenge for the research and S-LCA method application, but for the transparency and monitoring of the activities themselves. Data based on questionnaires, which would entail testimonies of the interviewees as inputs, as well as observations were required. This could suggest a certain degree of subjectivity in the study, being one of the weak aspects of the assessment itself. Even when expressions of different stakeholders and key informants were taken into consideration, and contrasted with secondary data, questionnaires and interpretation of the answers is a delicate matter which will have to be improved in future studies, both in terms of representativeness, and in terms of standardization. The researchers also perceived some questions caused uneasiness to certain parties, producing a lack of answer or the preference of omission of those in the data collection process, and there is little understanding of the S-LCA method within some informants.

LCT is not widely applied yet in the Costa Rican agricultural sector. Studies in the environmental dimension through LCA are beginning to increase in the LAC Region and in Costa Rica; however, when conducting searches on databases as Scopus, the keywords “Life Cycle Assessment Costa Rica” provided 16 documents, and not all of them referred to agriculture or food products, and only one paper regarding the inclusion of LCT approaches in tertiary educational contexts in Costa Rica was located. That study suggested there are needed improvements in all the areas of LCT, but particular emphasis was placed on the need to improve the accounting for social implications (Cornejo & Orner, 2019). In summary, LCA studies are still scarce, and S-LCA are almost non-existent, and even through different techniques, most social assessments focus on few stakeholder groups as stated also by Sharaai & Mokti (2020).

The selection of a characterization method was another point of debate for the researchers; and SAM was to be considered a suitable one for the clearness of results and the possibility of having formal sources to provide fundament for the scale of values. It also eliminated the constrain of the cost of acquisition of databases, as in other alternatives, but then potential bias could always be present.

A systematic review on the evolution of the guidelines for S-LCA by Tokede & Traverso (2020), covered many of the above-mentioned challenges, and suggestions included the need to evaluate the actors of the value chain in more consistent ways, together with a more robust theoretical orientation for the assessments. Context also has a significant role that needs to be considered in terms of the selection of indicators, the need for inclusive and flexible studies, and context-oriented choices of functional units. This was evident in sections of the studied cases in our research, where the selection of value chain actors rested mostly on farmers (event when not present explicitly in the UNEP Guidelines of 2020 as a separate group of stakeholders), and the observation of certain indicators would not be applicable in certain cases (indigenous rights for instance in all the three cases). This means that in the process of defining the iterative steps for a S-LCA, previous inquiries are needed and research should be context-sensitive.

Strict comparison with other S-LCA studies was not considered feasible due to the case-study nature of our research and differences in terms of functional units, system boundaries, context and products (Tokede & Traverso, 2020); however, certain similar traits suggest further attention and policy efforts are required in particular social areas in agriculture-based products, consistent with some of the findings of the studied cases in our research. Impact subcategories regarding the promotion of social security, local employment, delocalization and migration as well as transparency are critical aspects to be addressed in the honey production (D'Eusanio et al., 2018), while most worker related subcategories achieved basic requirements level, but not proactive in the 'Cuore di Bue' tomato S-LCA by Petti and authors. With a similar scaling system as the one provided by SAM, other studies also suggest that in the Canadian dairy sector, subcategories relate to farmers (workday length, work load, and professional development, among others) were complaint with the local context regulations, as well as certain local community relate subcategories (Revéret, Couture & Parent, 2015). Hence, these are indicators that suggest close observations and potential policy interventions in regards of social-related aspects in the studied cases.

Finally, the S-LCA method is considered by researchers and sectoral actors who were involved in the process and keener to understand more about it, as a powerful tool to register the social performance of their sector and trigger improvements in agricultural subsectors or production systems within a wider scope based on sustainable production and consumption approaches. The detection of hotspots and prioritisation aligned with local, regional or global policies and goals (Soltanpour, Peri, & Temri, 2019; Di Noi et al., 2020) result in an opportunity for future improvement and potential communication of outputs. The step-wise procedures based on the standardized process for LCA brought into the S-LCA seem to clearly present a path to be followed, and even when several aspects entailed in the UNEP Guidelines are already considered in different certification schemes, the researchers found that the S-LCA basis can provide clearer and systematized suggestions of evidences to respond not only to S-LCA itself and to other schemes as well.

4.5. Conclusions and recommendations

The research allowed to have a better understanding of the potential social opportunities and vulnerabilities of the agri-food sector for public policy orientation, presented through three cases studied in a LAC developing country, Costa Rica. Cases belonging to the coffee, dairy and vegetable subsectors suggest hotspot can be located mostly at the farm level operations, and within impact subcategories related to social security, women´s empowerment and documentation processes of the working relations.

SAM seems as an efficient and clear way to conduct the assessment; however, careful and robust documentation of BRs is required, together with detailed data collection tools, to assure objective assessments.

The use of the case studies also allowed the researchers to conduct the first formal S-LCA in these agriculture subsectors of Costa Rica, unveiling challenges in regards to the knowledge of S-LCA and LCT in general by institutional and productive actors, but presenting paramount opportunities to register, track and document the social performance of this type of productive activities. Further research where more stakeholders are considered, increased number of interviewees and representative samples of farms are considered, would allow more robust assessments that better support decision-making processes derived from hotspots detection and policy interventions priorisation.

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Author Contributions: conceptualization: Laura Brenes-Peralta, María Fernanda Jiménez-Morales, Rooel Campos-Rodríguez and Matteo Vittuari; methodology: Laura Brenes-Peralta; validation, Rooel Campos-Rodríguez and Matteo Vittuari; formal analysis, Laura Brenes-Peralta and María Fernanda Jiménez-Morales; writing—original draft preparation Laura Brenes-Peralta; writing—review and editing: Laura Brenes-Peralta and Matteo Vittuari; supervision, Matteo Vittuari. All authors have read and agreed to the published version of the manuscript.

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CHAPTER 5: Conclusions

5.1. Sustainability assessment and decision-making in food systems through LCT

LCT has been recognized as a powerful aid for decision-making processes at different organization and governance levels. This research used LCT in different case studies and for different purposes, proving its versatility and usefulness to assess the three dimensions of sustainability and to guide decisions.

Whether it was used as a decision instrument itself, or in combination with other methods, it allowed to provide insights of the opportunities and challenges that each case study would face to contribute in the pursue of more sustainable FS, since it was possible to:

a) address the first research question in regards of measuring the environmental and economic sustainability of circular approaches within waste-to-energy alternatives and green coffee production; this was presented in Chapters 2 and 3, taking advance of LCT outcomes in both cases to apply additional decision-making and modelling methods
b) evaluate the social performance of the production of coffee, milk and vegetables, portraying potential social impacts in these agri-food chains, hence offering a diagnosis of this performance as a first decision-making step to correct, improve or promote key social aspects
c) observe that the obtained products (or answers) of each of the previous questions constitute a significant contribution to decision-making and policy-making processes occurring at the farm or sectoral level, as they highlight hotspots and trade-offs to address, or explain relevant factors and context-sensitive considerations in regards to a more sustainable production pattern in these supply chains. Ultimately, the reduction and attention to those hotspots, and the way in which they can be addressed, are part of the path to achieve sustainable FS as suggested in the SCP concept.

5.1.1. An assessment of environmental and economic sustainability in waste-to-energy alternatives

This case, besides measuring environmental and economic sustainability of FW valorisation alternatives, allowed several developments. On one hand, LCT undertook previous existing knowledge in the studied context related to FW quantification, composting and anaerobic digestion of FW, and assessed each scenario through different environmental impact categories and cost. On the other hand, in companionship of other methods, LCT permitted to scale-up that knowledge into a decision-making framework and concluded in a prioritized group of FW-to-energy alternatives for the case of the university consortium. Linear Programming was used to define FW collection routes, being an important aspect to address since many discussions concerning waste valorisation scenarios often centre in the possibilities of centralized or semi-centralized systems. The results of this method functioned as an input for the modelling of the scenarios, which were then evaluated with LCA and LCC. These methods depicted the environmental impact categories, as well as the cost of each scenario, evidencing hotspots and trade-offs.

The previous outcomes would have been useful to conduct particular actions regarding the use of certain raw materials or valorisation options, but from the consortium perspective, it would have been difficult to select an alternative. In consequence, the inclusion in the study of the fourth method called 'Analytic Hierarchy Process' or AHP, to prioritize the alternatives according to the given context and included a social perspective within the criteria was advantageous. At this stage of the research, the outcomes of the LCA and LCC became useful to conduct pair-wise comparisons with a group of experts during the AHP.

As final feedback of this section of the research, The consulted experts considered that integration of Linear Programming, LCA, LCC and AHP into a methodological framework was a valuable step-by-step guide to support the process of decision-making in businesses of similar scale, institutions and even local governments. Moreover, the framework allowed the possibility of using criteria from the environmental, economic, and social perspectives with contextual considerations as a pathway for FW valorisation decisions, aligned with the sustainability approaches contained in the SCP concept. LCT was versatile enough to include context traits, such as the route optimization or the interest of using FW valorisation by-products for certain purposes in a system expansion approach (i.e. the Costa Rican electric grid is composed of over 90% renewable sources; therefore, biogas from the anaerobic digestion was not attractive for electricity production; in contrast, the country shows high dependence on imported fertilizers and fossil sources for transportation and cooking at the house-hold level, and the LCT methods were flexible enough to account for the net effects of using potential by-products to reduce that input dependence).

Finally, high-level Government advisors developed an interest in the paper, currently shared with a “NAMA-Residuos” (or NAMA-Waste in English) working group in the country, to consider this methodological framework in future analysis of the waste-to-energy research, projects and proposals in this sector.

5.1.2. Green coffee production: sustainability and its relation to decision-making processes

In regards to the green coffee sustainability evaluation, the LCT approach permitted to assess the environmental and economic impacts of 1kg of green coffee produced in the six Coopetarrazú farms of the case study. Consistent with literature, the farm level of the life cycle of green coffee was the stage to contribute the most to the environmental impacts and cost. In further examination of the cases, the inventory analysis confirmed that fertilizers were the most significant input causing those impacts, hence interventions should focus in a more efficient fertilization management, together with agroecosystem management that would allow better performance of the inputs, as suggested in many studies that address the benefits of shade systems in coffee plantations. This assessment constitutes a relevant base for farmers and the Cooperative to move towards more sustainable coffee production once this hotspot was detected. In addition, farmers usually point out challenges regarding their costs. Therefore. the opportunity to act in regards to this critical point affecting cost and environmental indicators is supreme in terms of effective solutions.

Price can be improved when quality is recognized, either through cup parameters or sustainability traits. In this sense, the assessment allowed a second output which seem to deeply interest the Cooperative managers. Coopetarrazú is recognized for solid efforts and commitments in sustainability; however, these are not always successfully presented to clients and customers. One alternative to formally do this could be the environmental product declarations (EPDs) and ecolabelling, which can later differentiate the product in the market with improved sustainability practices portrayed in the resulting environmental footprint of the coffee. Managers expressed this research was an initial encounter with the LCA technique for the Cooperative, acting as a step to advance in these declarations. In fact, during the last year of the research project, a client requested for a preliminary footprint of the coffee sold by Coopetarrazú, and the organization was able to answer due to the growing culture of data collection during the LCA and LCC carried out through this research. Besides being of interest for the Cooperative, the research supports the actions that the coffee sector has been implementing for some years now in Costa Rica, as part of its plans for competitiveness and sustainability, which entails the reduction of the carbon footprint, the management of production costs, and the creation of a Product Category Rule (PCR) with the final goal to maintain a distinguished participation in markets that begin demanding for EPDs.

The reality of the landscape and current trends in coffee research, suggested to pay special attention to the shade system in the coffee plantations of the study. The consideration to this topic during the development of the research allowed to observe differences within the farms in productivity, input use (in quantity and type), environmental and cost indicators, and shade-system configurations. It was the interaction with farmers and technicians from this sector that permitted to understand that efforts for improved sustainability do not rest in a stand-alone solution. Therefore, while conducting interviews and visits, and performing literature reviews for the application of LCA, LCC and the ISM, it was evident that decisions towards more sustainable farms were depending on many aspects −at least 21 factors were detected−. Agronomic and agroecosystem interrelations, soil and productivity elements, variety preferences, policies and associativity affect the decisions farmers take, and specially knowledge, tradition, culture are to be regarded.

In conclusion, the consideration of the LCT approach in combination with other methods and assessments, including the ISM, introduced a first model in the Costa Rican coffee sector that suggests, at least for this case study, that knowledge, tradition, training and culture are entry points to drive farmers to take more sustainable decisions. Together with biodiversity, climate change adaptation and mitigation, and enabling policies, farmers can keep moving forward to more sustainable paths, inducing real and positive transformations at other levels of the model, which are crucial factors for actual sustainability. Among those further levels, the selection of more efficient coffee varieties and inputs, the sustainable management of water and the overall environmental costs of coffee farming must also be considered.

Moreover, the LCT approach not only allowed the measurement of sustainability through environmental or cost indicators in the two of the case studies of this thesis, but particularly in the green coffee case, it opened a whole new perspective for the involved researcher to better understand the productive system and explore the linkages between factors that affect decisions towards more sustainable production. In this sense, it was possible to reach a point of acknowledgement of the complexities, complementarities, interconnections and trade-offs related to sustainable development of FS.

5.1.3. The social dimension in sustainable food systems

The second question addressed by this thesis looked upon ways to assess the social sustainability in three selected products: green coffee, raw milk and leafy vegetables. To do this, S-LCA became the avenue to detect social hotspots, strengths and challenges in this type of assessment for the Costa Rican agri-food context.

In general terms, S-LCA provided a framework that guided the assessment of the social dimension that is usually neglected in many sustainability studies when contrasted to the environmental dimension. Although S-LCA is still in a young stage in comparison to other LCT techniques, the advancements by the UNEP Guidelines as well as other publications provided a useful outline to conduct the assessment, based on stakeholder groups, impact subcategories for each group, and indicators. However, this case evidenced once more in similarity to other publications, the need to be flexible in regards to the context where assessments take places without loosing the aim of moving towards more sustainable patterns. For instance, some subcategories seemed to be commonly addressed and almost solved in the Costa Rican context (e.g. forced labour), others would not always apply (e.g. indigenous rights), and others would rise the need to carefully address the scope and definition of the indicators, as in the case of child labour vs family agriculture, which is very common in Costa Rica. In the latter children are part of the farm actors attending some chores, in special ways so that their health, their possibility of accessing education and their opportunity of "just being kids" are not threaten, at the same time they grow interest in agriculture and generational integration.

Characterization methods seem to still be a relevant limitation of S-LCA, besides other aspects already mentioned by several authors, in terms of definition of the goal and scope (functional unit, system boundaries) and even type of indicators. The formal and theoretical study of S-LCA appears to be a necessary first step for any researcher interested in this assessment, since the selection of a paradigm or another would deeply influence the course of the study. Due to the novelty of S-LCA in this Costa Rican context, type I indicators were selected to provide a score of the social performance of the cases; instead of type II indicators that would explore the causality of the outcomes and integrated social effects.

The choice of databases would also be relevant, and budget constrains as well as macro-level or aggregated indicators present in databases as the Social Hotspot Database (SHDB) suggested the research could focus on more locally-available data and methods to conduct the study. In consequence, and supported by literature, the impact assessment was executed through the 'subcategory assessment method' or SAM. The method seemed to be efficient in providing a measurement of the performance of the product per each subcategory of interest for the selected stakeholder group, and communicated the results in a simple, descriptive and clear manner. Even when conducted in a descriptive style and no direct comparisons or co-relations were made among the three cases, they all rested upon common ground, expressed in the results of certain social impact subcategories related to access of farmers to production inputs, services and their meeting of basic needs, as well as workers basic conditions, and the avoidance of child labour. It is believed that Costa Rican socio-economic frameworks pose an influence so that these subcategories were satisfactory, and most of the time above basic requirements (BRs). The observation of particular associativity structures in these subsectors of the Costa Rican FS also seem to relate to other impact subcategories, such as input access, fair-trade conditions, local community involvement and workers conditions.

Few hot-spots were found, some already being addressed by policy makers, such as the dependence of immigrant workers, the documentation of worker-employer relations, and the attention to gender balance. This latter still has links to more conservative approaches in the rural sector; however more women´s involvement was present in cases where family agriculture was entrenched at the farmer or worker level. Another relevant hot-spot dealt with the potential infraction of social security and passiveness in the quest of supplementary social benefits for workers. It was observed that most cases would somehow comply with the affiliation of the workers to the Costa Rican social security system, but farmers claimed this was expensive and sometimes unfeasible for them, expressing a trade-off with the economic dimension with deep social implications in the availability of further job generation, fulfilment of basic needs for farmers and workers, and potentially food security. This potential risk is already a reality in many locations of the LAC region, presented in the recently released Regional Overview of Food Security and Nutrition in Latin America and the Caribbean 2020 that indicates hunger, poverty and inequity is growing, particularly in rural areas. Decisions directly taken by farmers in this dimension may be triggered through the results of this social sustainability measurement; however, the observed hotspots and trade-offs require deep systemic analysis and interventions with policy involvement as well.

5.2. LCT in the Costa Rican and regional context, inputs for policy frameworks

This research contributed to the dissemination and increase in knowledge related to the use of the LCT approach in the measurement of sustainability of products in Costa Rica and the LAC region. The definition of the four case studies, and the methods required first, of a deep understanding of LCT, and related techniques and tools, such as the LCA corresponding ISO standard, as well as literature and guidelines. Subsequently, the mapping of the supply chain, the subsector, and the pre-existing research and findings was a compulsory step in order to define the goal and scope, and the creation appropriate data collection tools to initiate with the inventory creation and further inventory assessment, impact assessment and interpretation. These last three steps brought up the need to validate the outputs with experts in an iterative process as described by ISO14040, realizing that in terms of LCT, there are some proficient experts in Costa Rica and the region; however, a more profound understanding, capacity building and application of LCT is needed as not all consulted sources were aware of it, even when extremely capable in their technical area of expertise. Although LCA and LCC are robust and proven techniques, high-indexed literature is still scarce in the studied context; for instance, searches in the Scopus database including specific cases of Costa Rica are limited, and when some available studies are detected, the number of local co-authors is rare. Perhaps other countries have had a more intense use of LCT, usually conducted by non-LAC researchers, presenting the need to address the current understanding and limitations of stakeholders regarding the LCT approach, and particularly its use as input for decision making processes.

In summary, it can be considered that it was possible to evaluate the sustainability of the selected cases belonging to food supply chains in Costa Rica, through a Life Cycle Thinking approach. In the process, LCT provided sufficient and effective elements to aid in the provision of inputs for decision making processes that could lead FS into more sustainable practices and decisions. The agroecosystem similarities and some shared traits of FS with other LAC countries or Central American countries can suggest the applicability of developed frameworks, data collection tools and approaches from these researches in similar contexts.

5.3. Limitations and recommendations for future research

Based on the execution of the research, still considered novel in the LAC region and Costa Rican context, limitations arose from the availability of primary data and data collection culture to allow the building of inventories to perform the LCA and LCC in the case studies. Production, input, waste, cost, and incidents registers are not common in farms, in contrast to the university consortium case; therefore, the study had to begin with the creation of tools to collect that data, and training on its use to be able to create inventories that were later fed in specialized software like Simapro or in assessment forms created in Microsoft ® Excel.

Another limitation had to do with the fact that there is still a lack of local databases to conduct the impact assessment. This generated time constrains and the need to conduct the research based on case studies and not through wider samples, limiting also the possibilities of statistical inferences and further development. However, it allowed a first encounter for several stakeholders with the LCT approach and specific techniques, opening the possibilities for future research. On the other hand, first assessments might have to be adjusted to locally-tailored databases once they begin to be available (e.g. some authors begin to question CO_2 eq estimations by IPCC modelled in specific geographic contexts, when contrasted with on-site measures in the tropics, such as in the dairy case presented by Arndt and others in 2020.)

Temporary limitations, particularly towards the end of the research were present as well, due to the Covid-19 pandemics, which affected the frequency and format of the field work and expert consultation activities. This situation required modifications so that meetings were held with less participants or on-line, and sanitary protection equipment as well as approved protocols during visits to farms and meetings were always met (especially when a relevant number of farmers are above 55 years old). Still the research was managed to comply with timeframes and proposed aim.

Recommendations and future research alternatives are presented in the next lines, calling for potential follow-up and expansion of the results observed in this thesis:

a) There is need to consider the discussion, research and analysis of possible integration of the three dimensions in a sustainability assessment or LCSA. This can be done by the collection of the four case studies from this research and the modelling of integrated studies with experts' consultations to evaluate its interest, comprehension applicability. In this sense, the interaction of the researcher with local experts and stakeholders to measure the outcomes in regards to national goals (already aligned with the international SCP goal) will be required, together with the observation of already performed LCSA experiences available in scientific literature and international researchers. New research in this aspect would suggest the need of developing excel or specially-dedicated applications to integrate LCA, LCC and S-LCA. Also, the suggestion to convert these applications into calculators for non-experienced LCT professionals can support an improved understanding of the usefulness of LCT. A project like this, considering the inputs from this thesis could at least consider a year of execution; however, since representativeness is also a suggestion, the recovery of data for more robust inventories and statistical analysis, validation, impact analysis and output of results shall not consider less than a two-year project. It is believed that more stakeholders are becoming interested in LCT in the country; therefore, it is worth to explore potential funding at the university level, but also with ministerial and productive actors. For instance, Coopetarrazú and the Costa Rican Dairy Chamber are already considering projects related to capacity building and PCR standardization, and new agri-food chains like pineapple are beginning to grow interest; therefore, shared inputs, resources and experiences can aid into the development of a LCSA.

b) Other recommendations rest on the need to surpass the experienced limitations in terms of creating a more stable culture of data collection and registers in farms, as well as the obtention of primary representative data for the studied subsectors of Costa Rican FS to feed local databases. One possibility to address this, is the already presented proposal in a national research call to aid in the transference of technology and capacity building for more sustainable production in coffee, using as a baseline this research. These proposals aims at co-learning and demonstrating in collaboration of stakeholders the benefits of certain practices through quantitative assessments as those contained in the LCT approach. This proposal is foreseen as a two year project that would require funding from a Costa Rican organisation (FITTACORI), two public universities (TEC and UCR) and Coopetarrazú, which together with its research unit and farmers, would provide the experimental areas to conduct trials and capacity building activities.

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ANNEXES

Annex 1 : supplementary materials from chapter 2

Evaluation of FW valorisation alternatives: the case of consortium of educational institutions moving towards more sustainable practices

GOAL AND SCOPE	Following the ISO14040 Standard [48] and Hunkeler D., Lichtenvort K., and Rebitzer, G. [49] respectively, a LCA and an E-LCC were used to understand the environmental and economic effects the consortium of universities would have as a result of moving from a business-as-usual scenario consisting of FW landfilling, to a FW valorization alternative scenario, such as Composting-CP and Anaerobic Digestion-AD in two FW collection route designs. This consortium with already well-established FW measurement and environmental management units, defined the system boundaries from gate to gate: from the FW generation point to the campus where the valorization facilities would be established and side flows would be obtained [42] [50]. These side flows have an already existing market value in Costa Rica [51] and could be used by the same university or a third party, who would collect them at the campus gate.

System boundaries	The system has boundaries from gate to gate: from the FW collection point to the sideflows use in local facilities. It is expected to generate sideflows with an already established market value in Costa Rica.

Functional unit	117,33 ton of treated FW per year

Reference flow	The study uses a reference flow that consists of a mass-based unit for the LCA and the value represented in monetary units for the E-LCC.

Evaluation methods	Midpoint indicators were preferred by this study in order to present particular environmental impact categories for this type of FW valorization processes. Therefore, the ReCiPe 2016 midpoint method, Hierarchic version was applied in SimaPro 9.0.0.49.

Environmental impact categories	In general, the study calculated these potential environmental impacts, focusing mostly on the first two: • Global Warming Potential (GWP), expressed in kg CO2eq • Land-Use (LU), expressed in m2a crop • Terrestrial acidification (TA), expressed in kg SO2 eq • Freshwater eutrophication (FE), expressed in kg P eq • Mineral resource scarcity (M-RS), expressed in in kg Cu eq • Fossil resource scarcity (F-RS), expressed in kg oil eq • Water consumption (WC), expressed in m3.

Cost categories	The E-LCC included the following cost categories: inputs, labour, transport, public services and depreciation from equipment investments. They were categorized in four main groups: a-inputs and labour at generation point, b-transport to disposal or valorisation site, c-valorisation system (this one includes all operation elements such as inputs, labour, energy, water), and d-depreciation due to the use of the equipment in which the consortium shall invest. The Depreciation Cost related to the required investment and the Net economic effect as a result of the overall operative costs and savings during the valorisation of the FW, were selected as indicators in the economic dimension, expressed in American dollars (USD)
Social-oriented categories	Two categories were considered: Job generation and Ease-of-implementation were considered as well. Job generation was calculated after the FW valorisation labour requirement was inventoried for the E-LCC and then translated into amount of new required full-time collaborators for each scenario. The Ease-of-implementation was defined as the attribute that expresses how practical or less complex an alternative was in terms of technique, equipment and operation.
Interpretation	Critical stages regarding environmental and economic data were identified in the current and proposed scenarios, and an evaluation regarding the avoidance of certain impacts in comparison among them was carried out to present a summary to a group of experts, where an assessment through Analytic Hierarchy Process was execute to prioritize the option that would suggest more potential to be adopted by the consortium.
Assumptions and Limitations	Literature as well as previous experimental data from the research group were used. Most inputs were considered as yearly consumables, except for the plastic containers for the FW, which were estimated to have an economic life of five years. All alternative scenarios suppose that 50% of water consumption in cleaning operations would come from rainwater collection, a practice that is becoming more usual in the country. The compost yield was estimated to be 18,75% from the mass of the FW [22]. The biogas yield was obtained from literature reviews regarding biogas production, digestate production, technical characteristics, and calorific potentials, to assume a methane production of 53% of the produced biogas [13] [54] [55] [56] [57]. Distances from input suppliers as well as from the FW generation to valorization sites were calculated with Google Maps, and databases like Ecoinvent 3.4 were used for the inventoried processes on each scenario. The exchange rate to convert Costa Rican market prices (CRC) into American Dollars (USD) was retrieved from the Costa Rican Central Bank at the moment of the study, at a rate of 596,18 CRC: 1USD. Other information sources included scientific literature, environmental declarations, Costa Rican public services databases and market prices.

Flow of operations

LF Inventory

INVENTORY					
	cost				
product/service	Q	unit	cost CRC/unit	cost USD	
food waste	117,33	ton			Food Waste Generation
					Food Waste collection at generation point (restaurant)
plastic containers	3,60	un	38,52	138,67	
mass of plastic containers	0,03	ton			
transport plastic containers	0,68	tkm	0,36	44,26	
operator	1 125,00	hrs/year	2,32	2 605,69	
operator 1	1 125,00	hrs/year	2,32	2 605,69	Cleaning and desinfection
chlorine	584,72	L /year	3,53	2 064,84	
chlorine mass	135,95	kg			
desinfectant	-	L /year	-	-	
transport inputs	2,35	tkm	0,36	35,59	
water	8,15	m3	13,43	140,59	
water	8 152,91	L o kg			
FW transport	1 541,91	tkm			FW collection by authorised third party
FW disposal	117,33		1,00	8 986,26	Landfill disposal
waste water	8,15	m3			
				16 622	

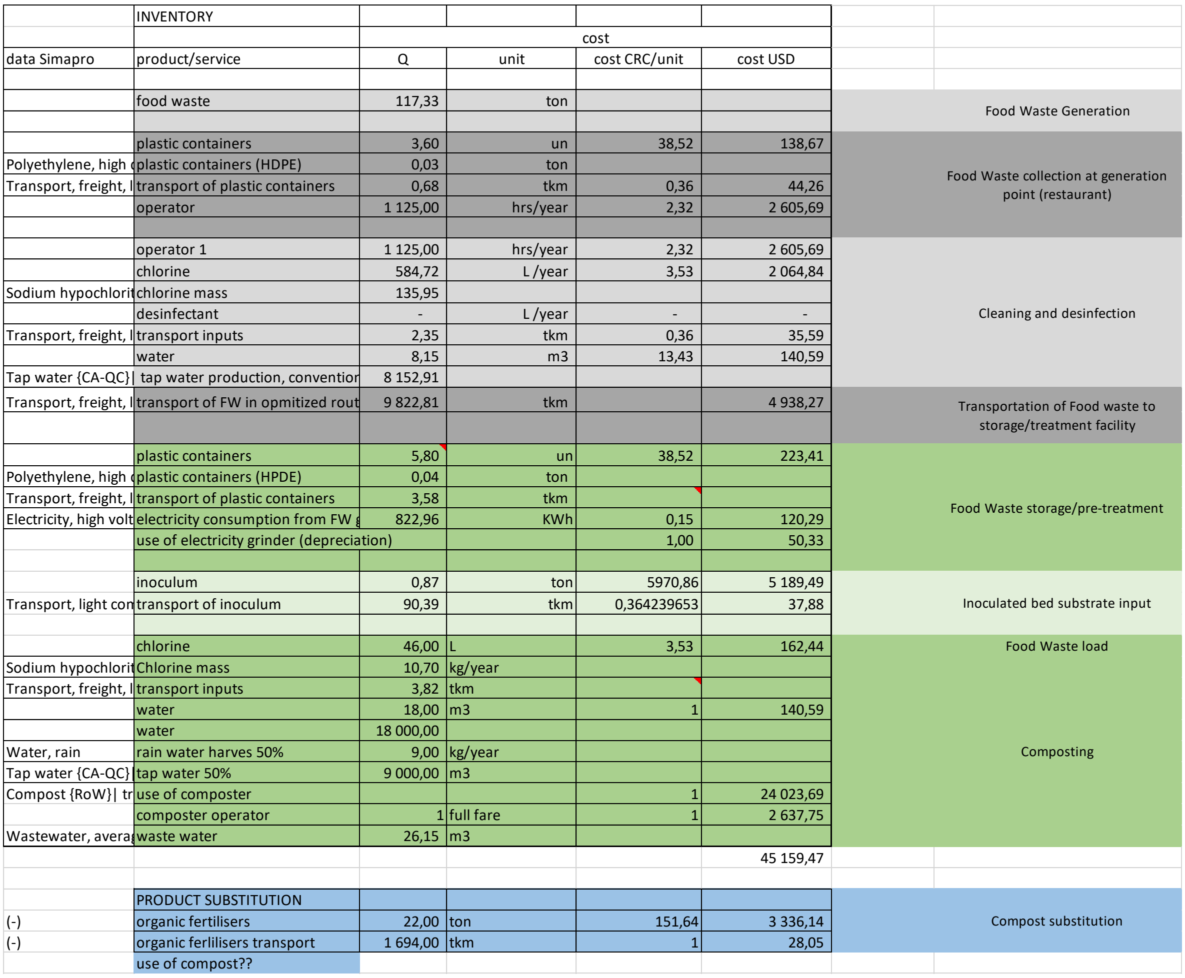
AD1 Inventory

INVENTORY					
	cost				
product/service	Q	unit	cost CRC/unit	cost USD	
food waste	117,33	ton			Food Waste Generation
plastic containers	3,60	un	38,52	138,67	Food Waste collection at generation point (restaurant)
plastic containers (HDPE)	0,03	ton			
transport of plastic containers	0,68	tkm	0,36	44,26	
operator	1 125,00	hrs/year	2,32	2 605,69	
operator 1	1 125,00	hrs/year	2,32	2 605,69	Cleaning and desinfection
chlorine	584,72	L /year	3,53	2 064,84	
chlorine mass	135,95				
desinfectant	-	L /year	-	-	
transport inputs	2,35	tkm	0,36	35,59	
water	8,15	m3	13,43	140,59	
	8 152,91				
transport of FW in opmitized route	9 822,81	tkm		4 938,27	Transportation of Food waste to storage/treatment facility
plastic containers	5,80	un	38,52	223,41	Food Waste storage / pre-treatment
plastic containers (HPDE)	0,04	ton			
transport of plastic containers	3,58	tkm			
electricity consumption from FW grinde	822,96	KWh	0,15	120,29	
use of electricity grinder (depreciation)			1,00	50,33	
					Adding of Food Waste
chlorine	46,00	L	3,53	162,44	Biodigestion (load, operation, cleaning)
Chlorine mass	10,70				
transport inputs	3,82	tkm			
water	18,00	m3	1,00	140,59	
water	18 000,00	kg			
rain water harvesTt 50%	9,00	m3			
tap water 50%	9 000,00	kg			
use of biodigestor (depreciation)			1,00	-	
biodigestor operator	1,00	full fare	1,00	2 637,75	
FW digestion (ton of waste)	117,33	ton			
produced biogas	5 632,00				
waste water	26,15	m3			
				15 908,41	
PRODUCT SUBSTITUTION					Biogas and digestate substitution
methane	3 001 857,07	L	0,23695793	711 313,84	
methane mass	1 609 895,95	kg			
methane transport into system	123 961,99	tkm	0,36423965	28,05	
organic fertilisers	11,00	ton	151,64	1 668,07	
organic fertilizers transport	847,00	tkm	0,36	28,05	
use og biogas					
use of digestate					

AD2 Inventory

INVENTORY					
			cost		
product/service	Q	unit	cost CRC/unit	cost USD	
food waste	117,33	ton			Food Waste Generation
plastic containers	3,60	un	38,52	138,67	Food Waste collection at generation point (restaurant)
plastic containers (HDPE)	0,03	ton			
transport of plastic containers	0,68	tkm	0,36	44,26	
operator	1 125,00	hrs/year	2,32	2 605,69	
operator 1	1 125,00	hrs/year	2,32	2 605,69	Cleaning and desinfection
chlorine	584,72	L /year	3,53	2 064,84	
chlorine mass	135,95				
desinfectant	-	L /year	-	-	
transport inputs	2,35	tkm	0,36	35,59	
water	8,15	m3	13,43	140,59	
	8 152,91				
transport of FW in opmitized route	670,55	tkm		1 709,29	Transportation of Food waste to storage/treatment facility
plastic containers	4,80	un	38,52	184,89	Food Waste storage / pre-treatment
plastic containers (HPDE)	0,02	ton			
transport of plastic containers	0,66	tkm			
electricity consumption from FW grinde	2 468,88	KWh	0,15	360,87	
use of electricity grinder (depreciation)			1,00	150,98	
					Adding of Food Waste
chlorine	138,00	L	3,53	487,32	Biodigestion (load, operation, cleaning)
Chlorine mass	32,09				
transport inputs	1,00	tkm			
water	54,00	m3	1,00	140,59	
water	54 000,00	kg			
rain water harvesTt 50%	27,00	m3			
tap water 50%	27 000,00	kg			
use of biodigestor (depreciation)			1,00	3 647,70	
biodigestor operator	1,00	full fare	1,00	4 616,07	
FW digestion (ton of waste)	117,33	ton			
produced biogas	5 632,00	m3			
waste water	62,15	m3			
				18 933,03	
PRODUCT SUBSTITUTION					Biogas and digestate substitution
methane	3 001 857,07	L	0,23695793	711 313,84	
methane mass	1 609 895,95	kg			
methane transport into system	47 312,49	tkm	0,36423965	42,94	
organic fertilisers	11,00	ton	151,64	1 668,07	
organic fertilizers transport	504,37	tkm	0,36	59,23	
use og biogas					
use of digestate					

CP1 Inventory



	INVENTORY					
		cost				
data Simapro	product/service	Q	unit	cost CRC/unit	cost USD	
	food waste	117,33	ton			Food Waste Generation
	plastic containers	3,60	un	38,52	138,67	Food Waste collection at generation point (restaurant)
Polyethylene, high	plastic containers (HDPE)	0,03	ton			
Transport, freight, l	transport of plastic containers	0,68	tkm	0,36	44,26	
	operator	1 125,00	hrs/year	2,32	2 605,69	
	operator 1	1 125,00	hrs/year	2,32	2 605,69	Cleaning and desinfection
	chlorine	584,72	L /year	3,53	2 064,84	
Sodium hypochlorit	chlorine mass	135,95				
	desinfectant	-	L /year	-	-	
Transport, freight, l	transport inputs	2,35	tkm	0,36	35,59	
	water	8,15	m3	13,43	140,59	
Tap water {CA-QC}|	tap water production, convention	8 152,91				
Transport, freight, l	transport of FW in opmitized rout	9 822,81	tkm		4 938,27	Transportation of Food waste to storage/treatment facility
	plastic containers	5,80	un	38,52	223,41	Food Waste storage/pre-treatment
Polyethylene, high	plastic containers (HPDE)	0,04	ton			
Transport, freight, l	transport of plastic containers	3,58	tkm			
Electricity, high volt	electricity consumption from FW	822,96	KWh	0,15	120,29	
	use of electricity grinder (depreciation)			1,00	50,33	
	inoculum	0,87	ton	5970,86	5 189,49	Inoculated bed substrate input
Transport, light con	transport of inoculum	90,39	tkm	0,364239653	37,88	
	chlorine	46,00	L	3,53	162,44	Food Waste load
Sodium hypochlorit	Chlorine mass	10,70	kg/year			
Transport, freight, l	transport inputs	3,82	tkm			
	water	18,00	m3	1	140,59	
	water	18 000,00				
Water, rain	rain water harves 50%	9,00	kg/year			Composting
Tap water {CA-QC}	tap water 50%	9 000,00	m3			
Compost {RoW}| tr	use of composter			1	24 023,69	
	composter operator	1	full fare	1	2 637,75	
Wastewater, averag	waste water	26,15	m3			
					45 159,47	
	PRODUCT SUBSTITUTION					
(-)	organic fertilisers	22,00	ton	151,64	3 336,14	Compost substitution
(-)	organic ferlilisers transport	1 694,00	tkm	1	28,05	
	use of compost??					

CP2 Inventory

INVENTORY					
	cost				
product/service	Q	unit	cost CRC/unit	cost USD	
food waste	117,33	ton			Food Waste Generation
plastic containers	3,60	un	38,52	138,67	Food Waste collection at generation point (restaurant)
plastic containers (HDPE)	0,03	ton			
transport of plastic containers	0,68	tkm	0,36	44,26	
operator	1 125,00	hrs/year	2,32	2 605,69	
operator 1	1 125,00	hrs/year	2,32	2 605,69	Cleaning and desinfection
chlorine	584,72	L /year	3,53	2 064,84	
chlorine mass	135,95				
desinfectant	-	L /year	-	-	
transport inputs	2,35	tkm	0,36	35,59	
water	8,15	m3	13,43	140,59	
	8 152,91				
transport of FW in opmitized rout	670,55	tkm		1 709,29	Transportation of Food waste to storage/treatment facility
plastic containers	4,80	un	38,52	184,89	Food Waste storage/pre-treatment
plastic containers (HPDE)	0,02	ton			
transport of plastic containers	0,66	tkm			
electricity consumption from FW g	2 468,88	KWh	0,15	360,87	
use of electricity grinder (depreciation)			1,00	150,98	
inoculum	0,66	ton	5970,86	3 916,54	Inoculated bed substrate input
transport of inoculum	32,70	tkm	0,364239653	50,63	
chlorine	138,00	L	3,53	487,32	Food Waste load
Chlorine mass	32,09	kg/year			Composting
transport inputs	1,00	tkm			
water	54,00	m3	1	140,59	
water	54 000,00	L			
rain water harves 50%	27,00	kg/year			
tap water 50%	27 000,00	m3			
use of composter			1	22 112,71	
composter operator	1	full fare	1	4 616,07	
waste water	62,15	m3			
				41 365,21	
PRODUCT SUBSTITUTION					
organic fertilisers	22,00	ton	151,64	3 336,14	Compost substitution
organic ferlilisers transport	1 008,74	tkm	1	59,23	
use of compost??					

Calculations and assumptions

General consortium data

Institution	Code	FW generation (kg/day)	FW generation (ton/day)	FW generation (ton/week)	FW generation (ton/year)	waste disposal costs (USD/ton) in CR	waste disposal cost for daily treated waste
undisclosed	A	185,43	0,19	0,927	41,72	70	2920,52
undisclosed	B	90,29	0,09	0,451	20,32	86	1747,14
undisclosed	C	90,35	0,09	0,452	20,33	95	1931,16
undisclosed	D	37,57	0,04	0,188	8,45	66	557,91
undisclosed	E	117,84	0,12	0,589	26,51	69	1829,52
amount of current sites	5						

(source: REDIES, 2018-2019)

t.c. CRC/USD
586,18

(Source: Banco Central de Costa Rica 8nov2019 https://www.bccr.fi.cr/SitePages/default.aspx)

LANDFILL-CURRENT				
FW transport to landfill				
institution	Landfill	distance	ton	tkm
A	undisclosed	7,2	41,72	300,40
B	undisclosed	12	20,32	243,79
C	undisclosed	3,9	20,33	79,28
D	undisclosed	4,2	8,45	35,50
E	undisclosed	33,3	26,51	882,94
(source: REDIES, 2018-2019)			117,33	1 541,91

FW PRODUCTION		
weeks in the year	52	weeks
Easter week off	1	week
Half period weeks off	2	weeks
Christmas/vacation weeks off	4	weeks
weeks of FW generation	45	weeks (assumed)
working days/week	5	days (assumed)
total days of FW generation	225	days (assumed)
yearly FW generation	117,33	ton

FW DISPOSAL		
cost/year	8 986,26	USD/year

Source: REDIES 2018-2019 + NAMA Residuos CR 2019

FW INTERNAL MANAGEMENT-LABOUR		
hours	1	hrs/day
daily cost	18,53	USD/day
hourly cost	2,32	USD/hour
hours/year	1 125,00	hrs/year
yearly cost	2 605,69	

PLASTIC CONTAINERS			
containers capacity	180	kg/day	
container's weight	0,0075	ton/unit	
weekly FW A	0,93	ton/week	
weekly FW b	0,45	ton/week	
weekly FW C	0,45	ton/week	
weekly FW D	0,19	ton/week	
weekly FW E	0,59	ton/week	
weekly FW A	927,15	kg/week	
weekly FW b	451,46	kg/week	
weekly FW C	451,73	kg/week	
weekly FW D	187,85	kg/week	
weekly FW E	589,22	kg/week	
containers requierement A	5,15	1,2	units
containers requierement B	2,51	0,6	units
containers requierement C	2,51	0,6	units
containers requierement D	1,04	0,4	units
containers requierement E	3,27	0,8	units
total HDPE weigth	0,03	ton/year	
TOTAL containers	3,60	units	
lifespan	5,00	years	
distance from provider to each location			
distance provider-A	6,50	km	
distance provider-B	8,40	km	
distance provider-C	10,40	km	
distance provider-D	14,00	km	
distance provider-E	82,20	km	
tkm-A	0,06	tkm	
tkm-B	0,04	tkm	
tkm-C	0,05	tkm	
tkm-D	0,04	tkm	
tkm-E	0,49	tkm	
total tkm	0,68	tkm/year	
unitary cost	38,52	USD/unit	
total cost	138,67	USD/year	

Sources: Google maps for distances according to suppliers location and data from https://www.logismarket.es/ic/bidones-roma-catalogo-envases-reciclados-704711.pdf y peso en campo for plastic container weight

CLEANING INPUTS	CHLORINE (bleach)		DESINFECTANT		chlorine weight	chlorine weight/year
daily use A	0,95	L/day		L/day	1,46	49,44
daily use B	0,47	L/day		L/day	0,73	24,72
daily use C	0,47	L/day		L/day	0,73	24,72
daily use D	0,24	L/day		L/day	0,37	12,36
daily use E	0,47	L/day		L/day	0,73	24,72
total imput per day	2,60	L/day		L/day	4,03	135,95
total imput per year	584,72	L/year	-	L/year	135,95	kg/year

Source: applied questionnaire to institutional restaurant, 2018 and allocation

distance from provider to each location		
distance provider-A	1,70	km
distance provider-B	3,30	km
distance provider-C	1,10	km
distance provider-D	8,60	km
distance provider-E	83,00	km
tkm-A	0,084	tkm
tkm-B	0,082	tkm
tkm-C	0,027	tkm
tkm-D	0,106	tkm
tkm-E	2,052	tkm
total tkm/year	2,35	tkm
chlorine cost per L	3,53	USD/L
desinfectant cost per L		USD/L
total cost	2 064,84	USD /year

WATER USE-CLEANIING		
daily use A	0,16	m3/day
daily use B	0,08	m3/day
daily use C	0,08	m3/day
daily use D	0,04	m3/day
daily use E	0,08	m3/day
total imput per day	0,44	m3/day
total imput per year	8,15	m3/year
monthly cost	13,43	USD/month
yearly cost	140,59	USD/year

Source: applied questionnaire to institutional restaurant, 2018 and allocation. Google maps for distances according to suppliers location

VALORIZATION COMMON TRANSPORT AND INPUTS

FW VALORISATION TRANSPORT	ROUTE 1			ROUTE 2			
total km/week	230	km		total km/week	33	km	
driver cost/day	19,01	USD/day		driver cost/day	19,01	USD/day	
driver cost/year (no CCSS)	855,27	USD/year		driver cost/year (no CCSS)	855,27	USD/year	
social security	313,12	USD/year		social security	313,12	USD/year	
driver cost/year	1168,39	USD/year		driver cost/year	1168,39	USD/year	
vehicle cost per km	0,36	USD/km		vehicle cost per km	0,36	USD/km	
total vehicle cost in route	3769,88	USD/year		total vehicle cost in route	540,90	USD/year	
total cost of transportation per route	4938,27	USD/year		total cost of transportation per route	1709,29	USD/year	
	km	ton	tkm	DISTANCE	km	ton	tkm
distance A-B	22,00	0,93	20,40	B-A	22	0,45	9,932083333
distance B-D	11,00	1,38	15,16	C-D	11	0,45	4,969066703
distance D-C	11,00	1,57	17,23	E	0	0,59	0
distance C-E	82,00	2,02	165,49				
distance E-A	104,00	0	0,00				
total	126		**218,28**				**14,90**
	230,00		**9822,81**				**670,55**

ROUTE 1			ROUTE 2				
FW VALORISATIO IMPUTS (RECEPTION/STORAGE/PRE-PROCESS)			at A	at D	at E		total route 2
			1,38	0,64	0,59		
weekly drop	2 607,41	kg	1378,61	639,58	589,22	kg	2607,41
containers capacity	180,00	kg/each				kg/each	
amount of containers	28,97	containers	7,66	3,55	3,27	containers	14,49
amount of containers	5,8	final amount per year	1,6	0,8	0,8	final amount	4,80
total weight of containers (HDPE)	0,04	ton of HPDE	0,012	0,006	0,006	ton of HPDE	0,02
distante provider to facility	82,20	km	6,50	14,00	82,20	km	102,70
transport of containers	3,58	tkm	0,078	0,084	0,4932	tkm	0,66
chlorine	1,00	L/week	1,00	1,00	1,00	L/week	3,00
total chlorine use	46,00	L/year	46,00	46,00	46,00	L/year	138,00
total chlorine use	10,70	kg/year	10,70	10,70	10,70	kg/year	32,09
chlorine cost	162,44	USD/year	162,44	162,44	162,44	USD/year	487,32
chlorine transport	3,82	tkm	0,02	0,09	0,89	tkm	1,00
water	0,08	m3/day	0,08	0,08	0,08	m3/day	0,24
total water	18,00	m3/year	18,00	18,00	18,00	m3/year	54,00
water cost	140,59	USD/year	140,59	140,59	140,59	USD/year	421,78

ROUTE 1			ROUTE 2
GRINDER FOR PREPARATION of FW			3
electrical grinder cost	503,2583848	USD/unit	
depreciation	50,32583848	USD/year	150,9775154
electrical consumption	6,096	kwh	
total energy requierements	822,96	kwh/year	2468,88
electricity cost	0,15	USD/kwh	
total electricity cost	120,29	USD/year	360,8680583

Source: applied questionnaire to institutional restaurant, 2018; Google maps for distances according to suppliers location and route optimization calculations

COMPOST							
ROUTE 1			ROUTE 2				
			at A	at D	at E		total route 2
COMPOST PRODUCTION from FW			62,04	28,78	26,51		
TK waste reduction efficiency	81,25	%					
TK compost production pottential	18,75	%					
yearly compost production	22,00	ton	11,63200781	5,396484403	4,971515625	ton	22
required compost inoculum (first load)	1:3:x:WEEK1FW						
required inoculum/year	0,87	ton	0,459536111	0	0,196405556	ton	0,655941667
compost inoculum cost	5970,86	USD/ton					
total compost inocolum cost	5 189,49	USD					
distance from provider to composter	104,00	km	26,7	8,3	104,00	km	139
tota tkm/year	90,39	tkm	12,26961417	0	20,42617778	tkm	32,69579194
daily load in composter	0,08	ton					
required composters	7	units	3,45	0,00	1,47	units	4,9195625
cost/composter	36 854,52	USD	4		2		6
total investment	240 236,93	USD	147 418,06	-	73 709,03	USD	221 127,09
Lifespan of composter	10	years					
yearly depreciation	24 023,69	USD	14 741,81	-	7 370,90	USD	22 112,71

ROUTE 1			ROUTE 2				
SUBSTITUTION-COMMERCIAL COMPOST			at A	at D	at E		total route 2
price per kg of compost	0,15	USD/kg					
savings in commercial compost	3 336,14	USD/year savings in commercial compost					
distance Juan Viña Compost to facility	77,00	km	26,3	59,3	77		
transportation cost	0,36	USD/km					
total transport cost	28,05	USD	9,58	21,60	28,05	USD/year	59,22536763
transport of compost	1 694,00	tkm	305,9218055	320,0115251	382,8067031	tkm	1008,740034

ROUTE 1			ROUTE 2
COMPOSTER ELECTRICITY CONSUMPTION			6 composters not 7
consupmtion	400	v	400
electricidad	11,09	kwatt	11,09
yearly consumption	34918,14	kWh /year	29929,84
electricity cost	5103,8701	USD/kwh	4374,7458

Sources: previous experiments from Chaves, R. et al 2018 DOI: https://doi.org/10.18845/tm.v32i1.4117, local suppliers, national statistics from ; http://www.sepsa.go.cr/productos.html rice husk in this processes represent little of national inventory from national rice production (0,003%), therefore it is not considered in terms of environmental impact attributable to rice production, inoculum transportation impact is considered as well as price; source: https://www.retrade.eu/en/aitem/158418/Jora_1200,_400_volt_kompostkv%C3%A6rn; technical sheed of composter: http://www.joracanada.ca/pdf/JK51002008-EN.pdf; others: https://www.rapidtables.com/calc/electric/Volt_to_Watt_Calculator.html

ANAEROBIC DIGESTION

ROUTE 1			ROUTE 2			
BIOGAS PRODUCTION from FW			at A	at D	at E	
Tsolids in FW	10%	ST				
VS in ST from FW	80%	SV				
expected biogas poduction from FW	600	(m3/ton-1SV)				
expected CH4 production	53,30%	% CH4 in biogas				
FW /year	117,33	ton/year	62,04	28,78	26,51	ton/year
Total solids in FW	11,73	ton TS	6,2037375	2,878125015	2,651475	ton TS
Volatile solids in FW	9,39	ton VS	4,96299	2,302500012	2,12118	ton VS
biogas production per year FW	5632,00	m3 per year	2977,794	1381,500007	1272,708	m3 per year
CH4 production per year	3001,86	m3 CH4	1587,164202	736,3395039	678,353364	m3 CH4

ROUTE 1			ROUTE 2			
DIGESTATE PRODUCTION			at A	at D	at E	
total mass to be digested	117,33	ton/year				
50% of waste (mass) = digestate	58,67	ton/year	31,0186875	14,39062508	13,257375	ton/year
dried digestate	11,00	ton/year	5,816003906	2,698242202	2,485757813	ton/year

ROUTE 1			ROUTE 2				
SUBSTITUTION-COMMERCIAL COMPOST			at A	at D	at E		
price per kg of compost	0,15	USD/kg					
savings in commercial compost	1 668,07	USD/year savings in commercial compost					
distance Juan Viña Compost to facility	77,00	km	26,3	59,3	77	km	
transportation cost	0,36	USD/km					
total transport cost	28,05	USD	9,58	21,60	28,05	USD/YEAR	59,23
transport of compost	847,0003019	tkm	152,9609027	160,0057626	191,4033516	tkm	504,37

ROUTE 1			ROUTE 2			
substitution: BIOGAS			at A	at D	at E	total route 2
methane substituting LPG	3001,86	m3 CH4	1587,164202	736,3395039	678,353364	3001,86
L of gas	3 001 857,07	L	1587164,202	736339,5039	678353,364	3001857,07
price/liter LPG	0,236957931	USD/L				0,00
mass of gass	1 609 895,95	kg	851 196,16	394 898,88	363 800,91	1609895,95
transport into system	123 961,99	tkm	5873,253515	13426,56178	28012,67	47312,49
savings in LPG	711 313,84	USD/year savings in LPG				
km RECOPE to facility	77,00		6,9	34	77	

ROUTE 1			ROUTE 2			
BIOGAS PLANT			at A	at D	at E	proportional capacity**
230kg daily FW plant cost	20 844,00	USD/small unit	20 844,00	15 633,00	0	USD/small unit
double size for this case	52 110,00	USD/big unit				
livespan	10	years				
depreciation costs	5 211,00	USD/year	2 084,40	1 563,30	-	3 647,70
E facility already has biodigestor	0	USD/year				USD/year

ROUTE 1			ROUTE 2			
LABOUR COSTS PROCESSING PLANT			at A	at D	at E	proportional laboour**
daily operator cost	17,16	USD/day				
hours a day	8,58	usd/ laboured hours per day	6,44	4,29	4,29	usd/ laboured hours per day
days a week	5	days				
number of weeks	45	weeks				
total operator cost (no CCSS)	1 930,86	USD/year	1 448,15	965,43	965,43	3 379,01
social security	706,89	CCSS	530,17	353,44	353,44	1 237,06
total operator cost	2 637,75	USD/year	1 978,32	1 318,88	1 318,88	4 616,07

Sources: biogas data from AINIA adapted by de Steffen, R., et al. (1998) http://www.coitavc.org/cms/site_0001/comunicados/AINIA; doi:10.1016/j.biortech.2006.02.039; doi:10.1088/1755-1315/230/1/012075, digestate production and biogas plant estimates from Bergamin, O (2018). Comparisons with other energy sources and yields from: http://revistas.tec.ac.cr/index.php/tec_marcha/article/view/2016/1829; https://www.recope.go.cr/productos/precios-nacionales/tabla-precios/; http://mdgs.un.org/unsd/energy/balance/2013/05.pdf; https://www.recope.go.cr/productos/calidad-y-seguridad-de-productos/gas-licuado-de-petroleo-glp/

General Data and Sources

item	amount	unit	sources and comments
plastic containers (180kg)	22 579,00	CRC/unit	local provider, virgen poliethelene ; https://lacasadeltanque.com/producto/barriles
plastic containers lifespan	5,00	years	expert opinion /current lifespan of existing ones
compost inoculum	3 500,00	CRC/kg	local provider, questionnaire institution A, 2018
Jk5100 Composter	21 603 380,00	CRC/unit	local provider, questionnaire institution A, 2018
chlorine	2 070,00	CRC/L	local provider, questionnaire institution A, 2018
desinfectant	0,74	CRC/L	local provider, questionnaire institution A, 2018
operator (non-qualified)	10 060,75	CRC/day	Ministerio de Trabajo CR, jornada ordinaria TNC
water	7 875,00	CRC/month	per each 1000m3/month Costa Rican official institutions
driver	11 141,00	CRC/day	Ministerio de Trabajo CR, jornada ordinaria chofer; http://www.mtss.go.cr/temas-laborales/salarios/Documentos-Salarios/lista_ocupacion_2018.pdf
transportation cost	213,51	CRC/km	Contraloría general Rep CR vehículo rural diesel 0 años; https://www.cgr.go.cr/02-consultas/consulta-zon-kilo-via.html
social security	0,37	%	CCSS ; https://www.ccss.sa.cr/calculadora
biodigestor	20 844,00	USD/unit of 16m3	Bergamin Oliviero 2018-feasibility study
electrical grinder	295000	CRC/unit	local provider, questionnaire institution A, 2018
electrical grinder electricity consumption	6,10	kWh	local provider, questionnaire institution A, 2018
plastic bins type 2	7,50	kg/bin	local provider, questionnaire institution A, 2018; https://www.logismarket.es/ic/bidones-roma-catalogo-envases-reciclados-704711.pdf y peso en campo
commercial compost	88,89	CRC/kg compost	local cost, publication; http://revistas.tec.ac.cr/index.php/tec_marcha/article/view/2016/1829
commercial LPG Gas	189,30	CRC/L	RECOPE; https://www.recope.go.cr/productos/precios-nacionales/tabla-precios/
electricity cost	85,68	CRC/kwh	CNFL; https://www.cnfl.go.cr/servicios-residenciales-sr/tarifas-vigentes-sr
LPG consumption Costa Rica	2222,00	TJ	RECOPE 2016, POLITICA SECTORIAL PARA LOS PRECIOS DE GAS LICUADO DE PETRÓLEO, BUNKER, ASFALTO Y EMULSIÓN ASFÁLTICA
LGP density	536,30	kg/m3	RECOPE 2019; https://www.recope.go.cr/productos/calidad-y-seguridad-de-productos/gas-licuado-de-petroleo-glp/
families that use LGP	382677,00		RECOPE 2016; https://presidencia.go.cr/wp-content/uploads/2016/01/POLITICA-SECTORIAL-PARA-LOS-PRECIOS-DE-GAS-LICUADO-DE-PETRO%CC%81LEO-BUNKER-ASFALTO-Y-EMULSIO%CC%81N-ASFA%CC%81LTICA-13Ene16.docx
chlorine density	1,55	kg/L	technical sheet; source: https://www.prisa.cl/catalog/ficha_products.php?id=85960 densidad hipoclorito de sodio comercial

Used questionnaire for the AHP Process (*Spanish version*)

Consulta a expertos sobre opciones de valorización de desperdicio de alimentos, estrategias para recuperación energética:

"*Food waste-to-energy*"

Estimado(a) experto(a):

Desde ahora agradecemos su valiosa contribución a nuestro estudio de valorización de residuos, dentro de una visión de Economía Circular. Estaremos atentos a sus consultas en la dirección labrenes@tec.ac.cr

Presentación:

Los residuos no gestionados adecuadamente representan una fuente de degradación ambiental. Los bioresiduos, formados en buena parte por residuos no comestibles de cocina y desperdicio de alimentos, podrían ser vistos más bien como una fuente de energía y materiales, según la Economía Circular. La recuperación de energía y materiales a partir de este tipo de residuos, podría realizarse mediante digestión anaeróbica o compostaje; de ahí que las estrategias de valorización de este tipo de materias tienen el potencial de fomentar sistemas circulares, y por tanto, sistemas alimentarios más sostenibles.

Amparados en la premisa anterior, nuestro grupo de investigación realizó un estudio de caso donde consideró la valorización del residuo y desperdicio alimentario producido por un consorcio de cinco universidades. Se evaluaron cuatro escenarios de valorización, mediante un Análisis de Ciclo de Vida y Costeo de Ciclo de Vida, y se compararon con un escenario tradicional como sería el envío del residuo a relleno sanitario.

Objetivos de esta consulta:

Esta consulta busca contar con su opinión, basada en la experiencia que ha desarrollado en su campo, para determinar cuáles criterios son más relevantes a la hora de evaluar opciones de valorización de bioresiduos, así como cuáles alternativas de valorización podrían ser más apropiadas según el contexto local.

Estructura del cuestionario:

Este cuestionario se divide en tres secciones: 1) información general, 2) criterios para evaluar las opciones de valorización de residuos y 3) alternativas de valorización de residuos. Existe además una sección al final para que agregue comentarios adicionales si lo estima pertinente.

¡Gracias por su tiempo y valiosos aportes!

INFORMACIÓN GENERAL

1.1. Área de experticia. Seleccione el área con la que más se identifica (por favor seleccionar solo 1 opción):

☐Ciencias Ambientales
☐Administración y Economía
☐Ciencias Sociales
☐Ingeniería
☐otro ________ (indique)

1.2. Nivel académico. Seleccione la opción que representa el nivel académico más alto que usted ha completado:

☐Primaria
☐Secundaria
☐Técnico / Diplomado
☐Universidad (bachillerato o licenciatura)
☐Posgrado universitario

1.3. Sector. Seleccione la opción relacionada al sector con el que usted colabora mayormente en la actualidad.

- ☐Gestor(a) ambiental en una organización
- ☐Organización Internacional
- ☐Docente/ Investigador(a) Académico(a)
- ☐Empresario(a) relacionado(a) a la gestión de residuos
- ☐Agente gubernamental /gestor(a) de política pública
- Otro: _________ (indique)

Nos interesa conocer su opinión respecto a la relevancia que podrían tener varios factores por considerar en la evaluación de alternativas de valorización de bioresiduos provenientes de desperdicio alimentario, sean esos factores ambientales, económicos y sociales.

Para responder esto, coloque una “X” en la casilla que coincide con el nivel de importancia que usted desea darle a un factor respecto al otro, en cada uno de los pares de factores presentados. Por favor utilice la siguiente escala: 9 significa importancia extremadamente fuerte y evidente de un factor respecto a otro, 7 significa que importancia muy fuerte y demostrada de un factor respecto a otro, 5 significa importancia mayor de un factor sobre otro, 3 significa importancia moderada de un factor respecto a otro, y 1 representa igual importancia entre los dos factores mostrados.

A continuación, le damos un ejemplo:

Se le pregunta a un grupo de individuos, qué era más importante para ellos cuando se graduaron de la secundaria: ¿estudiar o trabajar?. Estas fueron sus respuestas:

Respuesta del individuo 1

Estudiar		x								Trabajar
	9	7	5	3	1	3	5	7	9	

Respuesta del individuo 2

Estudiar									x	Trabajar
	9	7	5	3	1	3	5	7	9	

Respuesta del individuo 3

Estudiar					x					Trabajar
	9	7	5	3	1	3	5	7	9	

Estas respuestas indican que el Individuo 1 consideró que estudiar tenía una importancia más fuerte para él ante la opción de trabajar. El Individuo 2 señaló que para él lo más importante era trabajar en lugar de estudiar. El Individuo 3 indicó que estudiar y trabajar eran igualmente importantes para él.

Ahora, bien, procedamos con la pregunta. Por favor, marque solo un valor por cada par de opciones.

2.1. En cada par que se muestra, ¿cuál criterio es más importante entre ellos para usted?

Potencial de calentamiento global	9	7	5	3	1	3	5	7	9	Uso de suelo

Potencial de calentamiento global	9	7	5	3	1	3	5	7	9	Facilidad de implementación del tratamiento de residuos

Potencial de calentamiento global	9	7	5	3	1	3	5	7	9	Generación de empleo

Potencial de calentamiento global	9	7	5	3	1	3	5	7	9	Costos de depreciación asociados a la inversión

Potencial de calentamiento global	9	7	5	3	1	3	5	7	9	Efecto económico neto de una alternativa (nuevos costos-costos evitados)

Uso de suelo	9	7	5	3	1	3	5	7	9	Facilidad de implementación del tratamiento de residuos

Uso de suelo	9	7	5	3	1	3	5	7	9	Generación de empleo

Uso de suelo	9	7	5	3	1	3	5	7	9	Costos de depreciación asociados a la inversión

Uso de suelo	9	7	5	3	1	3	5	7	9	Efecto económico neto de una alternativa (nuevos costos-costos evitados)

Facilidad de implementación del tratamiento de residuos	9	7	5	3	1	3	5	7	9	Generación de empleo

	☐	☐	☐	☐	☐	☐	☐	☐	☐	
Facilidad de implementación del tratamiento de residuos	9	7	5	3	1	3	5	7	9	Costos de depreciación asociados a la inversión

	☐	☐	☐	☐	☐	☐	☐	☐	☐	
Facilidad de implementación del tratamiento de residuos	9	7	5	3	1	3	5	7	9	Efecto económico neto de una alternativa (nuevos costos-costos evitados)

	☐	☐	☐	☐	☐	☐	☐	☐	☐	
Generación de empleo	9	7	5	3	1	3	5	7	9	Costos de depreciación asociados a la inversión

	☐	☐	☐	☐	☐	☐	☐	☐	☐	
Generación de empleo	9	7	5	3	1	3	5	7	9	Efecto económico neto de una alternativa (nuevos costos-costos evitados)

	☐	☐	☐	☐	☐	☐	☐	☐	☐	
Costos de depreciación asociados a la inversión	9	7	5	3	1	3	5	7	9	Efecto económico neto de una alternativa (nuevos costos-costos evitados)

2) ALTERNATIVAS DE VALORIZACIÓN DE RESIDUOS

Nos interesa conocer su opinión en cuanto a alternativas de valorización de bioresiduos provenientes de Desperdicio de alimento. Para esto, agradeceremos que nos indique cuál alternativa es más apropiada en cada par dado, en función de distintos criterios de evaluación y la Información técnica resultante del estudio que facilitamos en el documento adjunto complementario.

Por favor utilice la siguiente escala: 9 significa importancia extremadamente fuerte y evidente de una alternativa respecto a otra, 7 significa que importancia muy fuerte y demostrada de una alternativa respecto a otra, 5 significa importancia mayor de un una alternativa respecto a otra, 3 significa importancia moderada de una alternativa respecto a otra, y 1 representa igual importancia entre las dos alternativas mostradas.

Por favor, marque solo un valor por cada par de opciones.

3.1. Para cada criterio mostrado (ya sea ambiental, económico o social), indique cuál alternativa de valorización de bioresiduo será más apropiada según su criterio:

Potencial de calentamiento global										
Digestión anaeróbica 1 (AD1)	☐	☐	☐	☐	☐	☐	☐	☐	☐	Compostaje 1 (CP1)
	9	7	5	3	1	3	5	7	9	
Uso de Suelo										
Digestión anaeróbica 1 (AD1)	☐	☐	☐	☐	☐	☐	☐	☐	☐	Compostaje 1 (CP1)
	9	7	5	3	1	3	5	7	9	
Facilidad de implementación del tratamiento de residuos										
Digestión anaeróbica 1 (AD1)	☐	☐	☐	☐	☐	☐	☐	☐	☐	Compostaje 1 (CP1)
	9	7	5	3	1	3	5	7	9	
Generación de empleo										
Digestión anaeróbica 1 (AD1)	☐	☐	☐	☐	☐	☐	☐	☐	☐	Compostaje 1 (CP1)
	9	7	5	3	1	3	5	7	9	
Costos de depreciación asociados a la inversión										
Digestión anaeróbica 1 (AD1)	☐	☐	☐	☐	☐	☐	☐	☐	☐	Compostaje 1 (CP1)
	9	7	5	3	1	3	5	7	9	
Efecto económico neto de una alternativa (nuevos costos-costos evitados)										
Digestión anaeróbica 1 (AD1)	☐	☐	☐	☐	☐	☐	☐	☐	☐	Compostaje 1 (CP1)
	9	7	5	3	1	3	5	7	9	

Potencial de calentamiento global

Digestión anaeróbica 1 (AD1)										Digestión anaeróbica 2 (AD2)
	9	7	5	3	1	3	5	7	9	

Uso de Suelo

Digestión anaeróbica 1 (AD1)										Digestión anaeróbica 2 (AD2)
	9	7	5	3	1	3	5	7	9	

Facilidad de implementación del tratamiento de residuos

Digestión anaeróbica 1 (AD1)										Digestión anaeróbica 2 (AD2)
	9	7	5	3	1	3	5	7	9	

Generación de empleo

Digestión anaeróbica 1 (AD1)										Digestión anaeróbica 2 (AD2)
	9	7	5	3	1	3	5	7	9	

Costos de depreciación asociados a la inversión

Digestión anaeróbica 1 (AD1)										Digestión anaeróbica 2 (AD2)
	9	7	5	3	1	3	5	7	9	

Efecto económico neto de una alternativa (nuevos costos-costos evitados)

Digestión anaeróbica 1 (AD1)										Digestión anaeróbica 2 (AD2)
	9	7	5	3	1	3	5	7	9	

Potencial de calentamiento global

Digestión anaeróbica 1 (AD1)										Compostaje 2 (CP2)
	9	7	5	3	1	3	5	7	9	

Uso de Suelo

Digestión anaeróbica 1 (AD1)										Compostaje 2 (CP2)
	9	7	5	3	1	3	5	7	9	

Facilidad de implementación del tratamiento de residuos

Digestión anaeróbica 1 (AD1)										Compostaje 2 (CP2)
	9	7	5	3	1	3	5	7	9	

Generación de empleo

Digestión anaeróbica 1 (AD1)										Compostaje 2 (CP2)
	9	7	5	3	1	3	5	7	9	

Costos de depreciación asociados a la inversión

Digestión anaeróbica 1 (AD1)										Compostaje 2 (CP2)
	9	7	5	3	1	3	5	7	9	

Efecto económico neto de una alternativa (nuevos costos-costos evitados)

Digestión anaeróbica 1 (AD1)										Compostaje 2 (CP2)
	9	7	5	3	1	3	5	7	9	

Potencial de calentamiento global

Digestión anaeróbica 2 (AD2)	☐	☐	☐	☐	☐	☐	☐	☐	☐	Compostaje 1 (CP1)
	9	7	5	3	1	3	5	7	9	

Uso de Suelo

Digestión anaeróbica 2 (AD2)	☐	☐	☐	☐	☐	☐	☐	☐	☐	Compostaje 1 (CP1)
	9	7	5	3	1	3	5	7	9	

Facilidad de implementación del tratamiento de residuos

Digestión anaeróbica 2 (AD2)	☐	☐	☐	☐	☐	☐	☐	☐	☐	Compostaje 1 (CP1)
	9	7	5	3	1	3	5	7	9	

Generación de empleo

Digestión anaeróbica 2 (AD2)	☐	☐	☐	☐	☐	☐	☐	☐	☐	Compostaje 1 (CP1)
	9	7	5	3	1	3	5	7	9	

Costos de depreciación asociados a la inversión

Digestión anaeróbica 2 (AD2)	☐	☐	☐	☐	☐	☐	☐	☐	☐	Compostaje 1 (CP1)
	9	7	5	3	1	3	5	7	9	

Efecto económico neto de una alternativa (nuevos costos-costos evitados)

Digestión anaeróbica 2 (AD2)	☐	☐	☐	☐	☐	☐	☐	☐	☐	Compostaje 1 (CP1)
	9	7	5	3	1	3	5	7	9	

Potencial de calentamiento global

Digestión anaeróbica 2 (AD2)										Compostaje 2 (CP2)
	9	7	5	3	1	3	5	7	9	

Uso de Suelo

Digestión anaeróbica 2 (AD2)										Compostaje 2 (CP2)
	9	7	5	3	1	3	5	7	9	

Facilidad de implementación del tratamiento de residuos

Digestión anaeróbica 2 (AD2)										Compostaje 2 (CP2)
	9	7	5	3	1	3	5	7	9	

Generación de empleo

Digestión anaeróbica 2 (AD2)										Compostaje 2 (CP2)
	9	7	5	3	1	3	5	7	9	

Costos de depreciación asociados a la inversión

Digestión anaeróbica 2 (AD2)										Compostaje 2 (CP2)
	9	7	5	3	1	3	5	7	9	

Efecto económico neto de una alternativa (nuevos costos-costos evitados)

Digestión anaeróbica 2 (AD2)										Compostaje 2 (CP2)
	9	7	5	3	1	3	5	7	9	

Potencial de Calentamiento Global

Compostaje 1 (CP1)										Compostaje 2 (CP2)
	9	7	5	3	1	3	5	7	9	

Uso de Suelo

Compostaje 1 (CP1)										Compostaje 2 (CP2)
	9	7	5	3	1	3	5	7	9	

Facilidad de implementación del tratamiento de residuos

Compostaje 1 (CP1)										Compostaje 2 (CP2)
	9	7	5	3	1	3	5	7	9	

Generación de empleo

Compostaje 1 (CP1)										Compostaje 2 (CP2)
	9	7	5	3	1	3	5	7	9	

Costos de depreciación asociados a la inversión

Compostaje 1 (CP1)										Compostaje 2 (CP2)
	9	7	5	3	1	3	5	7	9	

Efecto económico neto de una alternativa (nuevos costos-costos evitados)

Compostaje 1 (CP1)										Compostaje 2 (CP2)
	9	7	5	3	1	3	5	7	9	

3) COMENTARIOS ADICIONALES

Si tuviera comentarios o sugerencias que quisiera hacer, puede anotarlos en este espacio.

Annex 2: supplementary materials from chapter 3

Literature review for selection of relevant factors

number	Authors	Title	year	DOI
1	Tschora, H., Cherubini, F.	Co-benefits and trade-offs of agroforestry for climate change mitigation and other sustainability goals in West Africa	2020	10.1016/j.gecco.2020.e00919
2	Andreotti, F., Speelman, E.N., Van den Meersche, K., Allinne, C.	Combining participatory games and backcasting to support collective scenario evaluation: an action research approach for sustainable agroforestry landscape management	2020	10.1007/s11625-020-00829-3
3	Hindsley, P., McEvoy, D.M., Morgan, O.A.	Consumer Demand for Ethical Products and the Role of Cultural Worldviews: The Case of Direct-Trade Coffee	2020	10.1016/j.ecolecon.2020.106776
4	Pico-Mendoza, J., Pinoargote, M., Carrasco, B., Limongi Andrade, R.	Ecosystem services in certified and non-certified coffee agroforestry systems in Costa Rica	2020	10.1080/21683565.2020.1713962
5	Acosta-Alba, I., Boissy, J., Chia, E., Andrieu, N.	Integrating diversity of smallholder coffee cropping systems in environmental analysis	2020	10.1007/s11367-019-01689-5
6	Bro, A.S., Ortega, D.L., Clay, D.C., Richardson, R.B.	Understanding individuals' incentives for climate change adaptation in Nicaragua's coffee sector	2020	10.1080/17565529.2019.1619506
7	Wagner, S., Rigal, C., Liebig, T., Mremi, R., Hemp, A., Jones, M., Price, E., Preziosi, R.	Ecosystem services and importance of common tree species in coffee-agroforestry systems: Local knowledge of small-scale farmers at Mt. Kilimanjaro Tanzania	2019	10.3390/f10110963
8	Jezeer, R.E., Verweij, P.A., Boot, R.G.A., Junginger, M., Santos, M.J.	Influence of livelihood assets experienced shocks and perceived risks on smallholder coffee farming practices in Peru	2019	10.1016/j.jenvman.2019.04.101
9	Mili, S., Ferro Soto, C., Bouayad, A.	Measuring the overall and integrated performance of socially responsible companies: The case of fair trade	2019	
10	Hernandez-Aguilera, J.N., Conrad, J.M.,	The Economics and Ecology of Shade-grown Coffee: A Model	2019	10.1016/j.ecolecon.2019.01.015

	Gómez, M.I., Rodewald, A.D.	to Incentivize Shade and Bird Conservation		
11	Acosta-Alba, I., Chia, E., Andrieu, N.	The LCA4CSA framework: Using life cycle assessment to strengthen environmental sustainability analysis of climate smart agriculture options at farm and crop system levels	2019	10.1016/j.agsy.2019.02.001
12	Smith Dumont, E., Gassner, A., Agaba, G., Nansamba, R., Sinclair, F.	The utility of farmer ranking of tree attributes for selecting companion trees in coffee production systems	2019	10.1007/s10457-018-0257-z
13	Anh, N.H., Bokelmann, W., Nga, D.T., Van Minh, N.	Toward sustainability or efficiency: The case of smallholder coffee farmers in Vietnam	2019	10.3390/economies7030066
14	Van Der Wolf, J., Jassogne, L., Gram, G.I.L., Vaast, P.	Turning local knowledge on agroforestry into an online decision-support tool for the tree selection in smallholders' farms	2019	10.1017/S001447971600017X
15	Rich, K.M., Chengappa, P.G., Muniyappa, A., Yadava, C.G., Manjyapura, G.S., Pradeepa Babu, B.N., Shubha, Y.C., Rich, M.	Coffee certification in India: Awareness practices and sustainability perception of growers	2018	10.1080/21683565.2017.1361497
16	Chalfoun, S.M., Martins, C.P., Matos, C.S.M., Pereira, A.B., Silva, V.N.	Conductivity to rust in coffee under different wooden and fruit tree intercropping systems [Condutividade à ferrugem em café sob diferentes sistemas de consórcio]	2018	10.25186/cs.v13i2.1429
17	Karungi, J., Cherukut, S., Ijala, A.R., Tumuhairwe, J.B., Bonabana-Wabbi, J., Nuppenau, E.A., Hoeher, M., Domptail, S., Otte, A.	Elevation and cropping system as drivers of microclimate and abundance of soil macrofauna in coffee farmlands in mountainous ecologies	2018	10.1016/j.apsoil.2018.08.003
18	Rahn, E., Vaast, P., Läderach, P., van Asten, P., Jassogne, L., Ghazoul, J.	Exploring adaptation strategies of coffee production to climate change using a process-based model	2018	10.1016/j.ecolmodel.2018.01.009
19	Pyk, F., Hatab, A.A.	Fairtrade and sustainability: Motivations for Fairtrade certification among	2018	10.3390/su10051551

		smallholder coffee growers in Tanzania		
20	Hirons, M., Mehrabi, Z., Gonfa, T.A., Morel, A., Gole, T.W., McDermott, C., Boyd, E., Robinson, E., Sheleme, D., Malhi, Y., Mason, J., Norris, K.	Pursuing climate resilient coffee in Ethiopia – A critical review	2018	10.1016/j.geoforum.2018.02.032
21	Hernandez-Aguilera, J.N., Gómez, M.I., Rodewald, A.D., Rueda, X., Anunu, C., Bennett, R., van Es, H.M.	Quality as a Driver of Sustainable Agricultural Value Chains: The Case of the Relationship Coffee Model	2018	10.1002/bse.2009
22	Ongole, S., Sankaran, M., Karanth, K.K.	Responses of aerial insectivorous bats to local and landscape-level features of coffee agroforestry systems in Western Ghats India	2018	10.1371/journal.pone.0201648
23	Hamdani Harahap, R., Humaizi, Muda, I.	Sustainable management of coffee farms (case in Karo Regency North Sumatera Indonesia)	2018	
24	Birkenberg, A., Birner, R.	The world's first carbon neutral coffee: Lessons on certification and innovation from a pioneer case in Costa Rica	2018	10.1016/j.jclepro.2018.03.226
25	Van Loo, E.J., Nayga, R.M., Jr., Campbell, D., Seo, H.-S., Verbeke, W.	Using eye tracking to account for attribute non-attendance in choice experiments	2018	10.1093/erae/jbx035
26	Rigal, C., Vaast, P., Xu, J.	Using farmers' local knowledge of tree provision of ecosystem services to strengthen the emergence of coffee-agroforestry landscapes in southwest China	2018	10.1371/journal.pone.0204046
27	Haggar, J., Soto, G., Casanoves, F., Virginio, E.D.M.	Environmental-economic benefits and trade-offs on sustainably certified coffee farms	2017	10.1016/j.ecolind.2017.04.023
28	Solér, C., Sandström, C., Skoog, H.	How Can High-Biodiversity Coffee Make It to the Mainstream Market? The Performativity of Voluntary Sustainability Standards and Outcomes for Coffee Diversification	2017	10.1007/s00267-016-0786-z
29	Ssebunya, B.R., Schmid, E., Van Asten,	Stakeholder engagement in prioritizing sustainability	2017	10.1017/S1742170516000363

	P., Schader, C., Altenbuchner, C., Stolze, M.	assessment themes for smallholder coffee production in Uganda		
30	Allinne, C., Savary, S., Avelino, J.	Delicate balance between pest and disease injuries and other ecosystem services in the complex coffee-based systems of Costa Rica	2016	10.1016/j.agee.2016.02.001
31	Von Geibler, J., Cordaro, F., Kennedy, K., Lettenmeier, M., Roche, B.	Integrating resource efficiency in business strategies: A mixed-method approach for environmental life cycle assessment in the single-serve coffee value chain	2016	10.1016/j.jclepro.2015.12.052
32	De Jesús Crespo, R., Newsom, D., King, E.G., Pringle, C.	Shade tree cover criteria for non-point source pollution control in the Rainforest Alliance coffee certification program: A snapshot assessment of Costa Rica's Tarrazú coffee region	2016	10.1016/j.ecolind.2016.01.025
33	Evizal, R., Sugiatno, Prasmatiwi, F.E., Nurmayasari, I.	Shade tree species diversity and coffee productivity in Sumberjaya West Lampung Indonesia	2016	10.13057/biodiv/d170134
34	Mariño, Y.A., Pérez, M.-E., Gallardo, F., Trifilio, M., Cruz, M., Bayman, P.	Sun vs. shade affects infestation total population and sex ratio of the coffee berry borer (Hypothenemus hampei) in Puerto Rico	2016	10.1016/j.agee.2015.12.031

Farm Characterisation: Soil sampling analysis[5]

	F1	F2	F3	F4	F5	F6	Critical range	
							Inferior	**Superior**
pH	4,81	4,80	4,80	4,77	4,77	4,82	5,60	6,50
K (Cmol(+)/L)	0,53	0,53	0,52	0,54	0,51	0,53	0,20	0,60
Ca (Cmol(+)/L)	1,20	1,12	1,22	1,19	1,02	1,22	4,00	20,00
Mg (Cmol(+)/L)	0,53	0,51	0,55	0,59	0,48	0,52	1,00	5,00
Acidity (Cmol(+)/L)	2,03	2,09	2,13	2,41	2,07	1,97	0,50	1,50
P (mg/L)	7,86	7,89	6,68	7,02	6,31	6,39	10,00	20,00
Fe (mg/L)	179,10	187,82	161,50	155,10	150,13	153,94	10,00	100,00
Cu (mg/L)	5,35	5,20	4,69	4,63	6,06	5,27	2,00	20,00
Zn (mg/L)	2,99	2,88	2,86	3,10	2,61	2,84	2,00	10,00
Mn (mg/L)	27,91	28,55	24,73	27,02	23,30	23,98	5,00	50,00
M.O (%)	6,74	6,54	6,09	6,05	6,20	6,24	3,00	8,00
% Sat. Acidez	44,70	46,78	44,98	47,20	48,28	43,47	10,00	50,00

Farm Characterisation: Foliage sampling analysis [1]

	F1	F2	F3	F4	F5	F6	Critical range		
							Low	**Sufficient**	**High**
N (%)	3,16	3,18	3,16	2,89	3,01	3,07	< 2,3	2,3 - 2,8	> 2,8
P (%)	0,15	0,14	0,12	0,16	0,16	0,13	< 0,12	0,12 - 0,20	> 0,20
Ca (%)	1,12	1,1	1,09	0,68	1,02	1,13	< 1,1	1,1 - 1,7	> 1,7
Mg (%)	0,24	0,23	0,22	0,22	0,21	0,23	< 0,20	0,20 - 0,35	> 0,35
K (%)	2,21	2,07	2,04	1,2	2,25	2,02	< 1,7	1,7 - 2,7	> 2,7
Fe (mg/kg)	159	184	144	402	228	192	< 75	75 - 275	> 275
Cu (mg/kg)	16	14	12	13	15	13	< 6	6 - 12	> 12
Zn (mg/kg)	13	12	17	9	12	10	< 15	15 - 30	> 30
Mn (mg/kg)	140	145	142	117	161	122	< 50	50 - 150	> 150

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[5] *Critical range based on the Soil and Foliage Laboratory recommendations of the University of Costa Rica–CIA/UCR* (Molina & Meléndez, 2002).

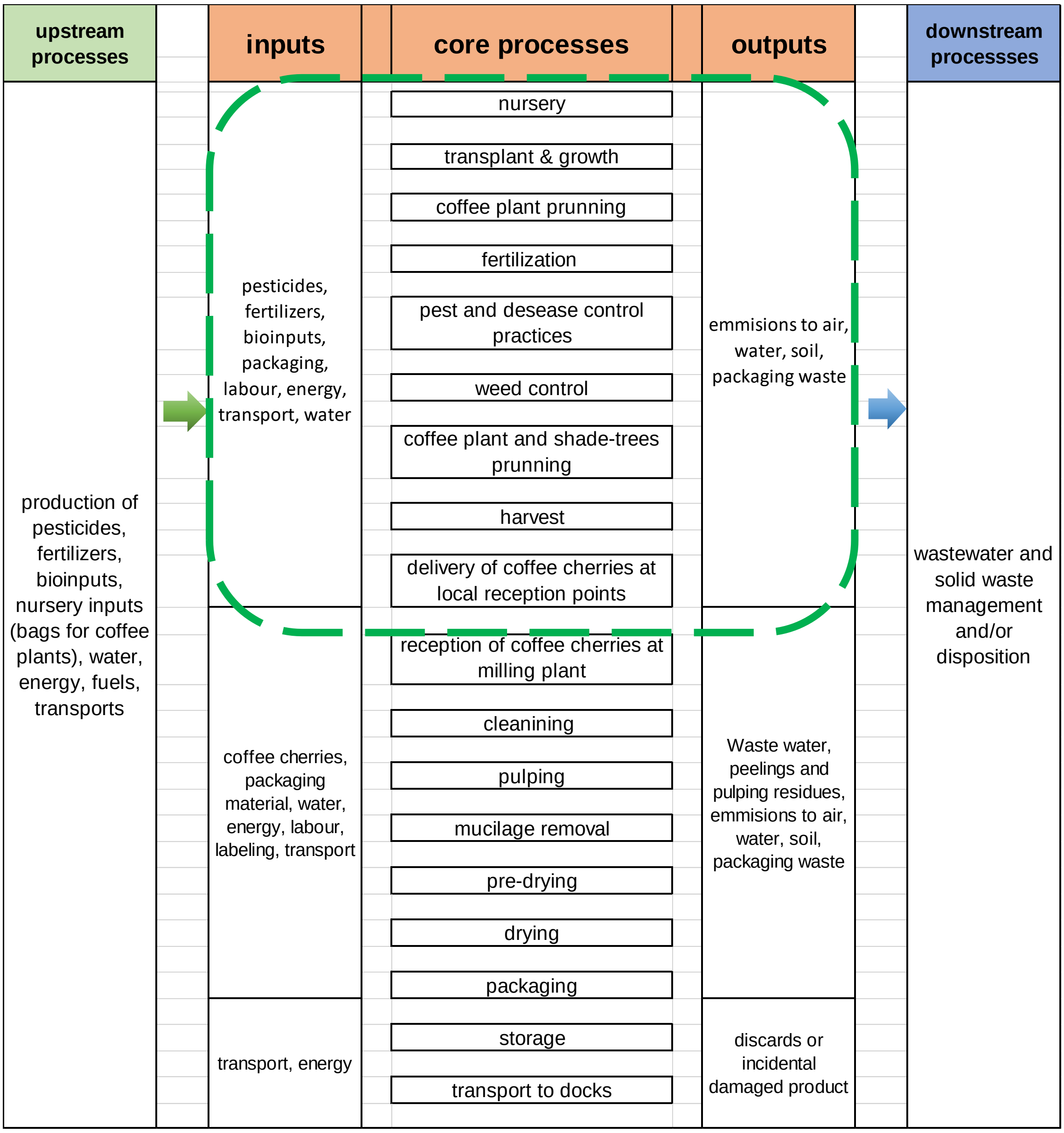
Farm Characterisation: Life Cycle Assessment Inventory

Goal and Scope

Based on ISO14044 and Hunkeler et al., the study aims to characterize the farms in regards to the environmental and cost impacts of producing 1 kg of green coffee beans at 11,5% of humidity content from six small coffee farms under shaded-systems from the 2019-2020 harvest. The farms are afilliated to Coopetarrazú R.L., a Cooperative in the South-Central Moundain system of Costa Rica, Central America; considered the biggest productive unit in the coutry, with over 3000 small and medium afiliated farms. The study is conducted under an attributional approach, with system boundares from cradle to farm gate.

Functional Unit: 1kg of beans of green coffee de café at 11,5% RH

System Boundaries: from cradle to gate



COFFEE SEEDLING FOR FOR ESTABLISHMENT OF PLANTATION

Production of: 1 kg of seed

IMPUTS

SEED CONDITIONING

	active ingredient		
Soil	soil	0,5	m2
Water	water	1	kg
Rizolex	P	40	g
Furadán	Carbofurano (thio carbamate)	0,44	g
Daconil	Chlorothalonil	0,54	g
Transport of inputs (port to CICAFE)	Transport of inputs	4	kgkm
Transport of inputs (port to port)	Transport of inputs (port to port)	350,76	kgkm
Transport of inputs (origin to port)	Transport of inputs (origin to port)	4,4	kgkm

PROCESSING OF SEED

Water	Water	9,092	L
Electricity for milling process	Electricity for milling process	0,04205	kWh
Transport of wastes	Transport of wastes	0,01909	tkm
Woodchips for seed drying	Woodchips for seed drying	3,273	MJ
Trasport of woodchips	Trasport of woodchips	0,00268	tkm
Electricity for drying process	Electricity for drying process	0,09626	kWh

OUTPUTS

emissions — considered in dataset for transport

waste

Wastewater treatment	9,092	L
Solid waste	2,387	kg

source: consultation to experts

COFFEE PRODUCTION

WATER CONSUMPTION

total water consumption	**farm (L/FU)**					
	1	**2**	**3**	**4**	**5**	**6**
	0,002595	0,003042	0,003085	0,002926	0,003652	0,002557

COFFEE-PLANT NURSERY FOR ESTABLISHMENT OF PLANTATION

IMPUTS							unit
	farm 1	farm 2	farm 3	farm 4	farm 5	farm 6	
coffee seeds	0,000082	0,000096	0,000097	0,000092	0,000115	0,000080	kg
soil	1,895602	2,221955	2,253470	2,137000	2,667587	1,868088	kg
rice husk	0,019351	0,022682	0,023004	0,021815	0,027232	0,019070	kg
bags	0,000463	0,000543	0,000551	0,000522	0,000652	0,000457	kg
CAN	0,000379	0,000444	0,000450	0,000427	0,000533	0,000373	kg
P	0,000492	0,000577	0,000585	0,000555	0,000693	0,000485	kg
K	0,000589	0,000691	0,000701	0,000664	0,000829	0,000581	kg
Chlorpyrifos	0,000002	0,000003	0,000003	0,000003	0,000003	0,000002	kg
CICOPRONAZOL	0,000001	0,000001	0,000001	0,000001	0,000001	0,000001	kg
Azoxistrobina	0,000001	0,000001	0,000001	0,000001	0,000001	0,000001	kg

OUTPUTS							
emissions							
air	farm 1	farm 2	farm 3	farm 4	farm 5	farm 6	
ammonia NH3	0,000008	0,000010	0,000010	0,000009	0,000012	0,000008	kg
NOx	0,000004	0,000005	0,000005	0,000005	0,000006	0,000004	kg
N2O (no NO3)	0,000008	0,000010	0,000010	0,000009	0,000012	0,000008	kg
groundwater							
NO3 multiplicado	0,386316	0,386318	0,386319	0,386318	0,386322	0,386316	kg
phosphate leaching	0,000030	0,000035	0,000035	0,000033	0,000042	0,000029	kg
surface water							
Phosphate run-off	0,000123	0,000144	0,000146	0,000139	0,000173	0,000121	kg
P emissions through erosion	0,000000	0,000000	0,000000	0,000000	0,000000	0,000000	kg
waste							
bags	0,000463	0,000543	0,000551	0,000522	0,000652	0,000457	kg
inputs packaking ** PET bottles and mixed plastics	0,000134	0,000080	0,000050	0,000058	0,000126	0,000057	kg
	0,000597	0,000623	0,000601	0,000580	0,000778	0,000513	

*assumption wastewater not consider after supposing uptake by plants

**assumption 10kg of packaging waste/year/farm during this establishment period of 2years, from plants that last 25year

TRANSPORT FOR ESTABLISHMENT OF PLANTATION

1 kg Seed transport
(Los Santos) (ICAFE) 19,71 kgkm

	farm 1	farm 2	farm 3	farm 4	farm 5	farm 6	unit
coffee seeds/ farm (kg)	0,487590833	0,961423365	1,550295176	1,271813926	0,729148453	1,13630296	
kgkm coffee seeds	9,61041531	18,94965453	30,55631793	25,06745248	14,37151601	22,39653134	kgkm
	0,009610415	0,018949655	0,030556318	0,025067452	0,014371516	0,022396531	tkm

	land distances			
inputs	Port-distributor	distributor-seller	seller-farm	total km
rice husk	70	4,2		74,2
bags	40	4,2		44,2
Tierra Fecunda	0	4,2		4,2
10-30-10	12,9	139	4,2	156,1
pyrinex	102	49,9	4,2	156,1
Atemi	12,4	57,1	4,2	73,7
Mistral	87,3	65,6	4,2	157,1
root enhancer	75,8	63,3	4,2	143,3
				101,1125

farm 1	farm 2	farm 3	farm 4	farm 5	farm 6	unit
kgkm	kgkm	kgkm	kgkm	kgkm	kgkm	
1,435839564	1,683038239	1,706909819	1,618688677	2,02058613	1,414998766	
0,020475109	0,024000168	0,024340577	0,023082541	0,028813609	0,020177918	
0,051749936	0,060659368	0,061519738	0,058340108	0,07282513	0,0509988	
0,242887439	0,284703708	0,288741838	0,273818299	0,341803501	0,239361998	
0,000721881	0,000846163	0,000858164	0,00081381	0,001015868	0,000711403	
0,00054096	0,000634093	0,000643087	0,000609849	0,000761266	0,000533108	
0,000576864	0,000676179	0,00068577	0,000650326	0,000811793	0,000568491	
0,001325376	0,001553557	0,001575592	0,001494158	0,001865136	0,001306138	
1,75412	2,05611	2,08527	1,97750	2,46848	1,72866	kgkm
0,001754	0,002056	0,002085	0,001977	0,002468	0,001729	tkm

TRANSPORT FOR ESTABLISHMENT OF PLANTATION						
-	farm 1	farm 2	farm 3	farm 4	farm 5	farm 6
seeds	0,009610	0,018950	0,030556	0,025067	0,014372	0,022397
rest of inputs	0,001754	0,002056	0,002085	0,001977	0,002468	0,001729
total	0,011365	0,021006	0,032642	0,027045	0,016840	0,024125

TOTAL WATER CONSUMPTION

	farm (L/FU)					
	1	**2**	**3**	**4**	**5**	**6**
	1,34	1,93	1,64	1,43	1,64	1,19
water consumption per source	river	river			river	river
	1,34	1,93			1,64	1,19
			ASADA	ASADA		
			1,31	1,43		
			rainwater harvest			
			0,33			

INPUTS (FERTILIZERS AND PESTICIDES)

IMPUTS		
	farm 1	**unit**
total N supply	**0,23**	
AN	0,077034	kg
CAN	0,043865	kg
COMPOST	0,064801	kg
POULTRY	0,041865	kg
P	0,13	kg
K	0,234156	kg
Mg	0,029712	kg
S	0,000110	kg
Ca	0,055175	kg
Zn	0,000233	kg
B	0,000758	kg
Cu	0,000088	kg
Fe	0,133182	kg
Mo	0,000087	kg
Ciproconazol	0,000060	kg
pyraclostrobin	0,000026	kg
epoxiconazole	0,000069	kg
Carbendazina	0,000109	kg
Diquat	0,000282	kg
Chlorpyrifos	0,001467	kg
citratos	0,000007	kg
Edatos queletantes	0,000008	kg
Polyoxiethylene Alkyl ether	0,000262	kg
Alcohol etoxilado	0,000051	kg
indicador de alcalinidad	0,000000	kg
Trichoderma	0,012015	kg

OUTPUTS		
air		
ammonia NH3	0,007651	kg
NOx	0,002655	kg
N2O emission (kg N2O ha-1)	0,001371	kg
CO2 after limestome		
groundwater		
NO3 (Kg N /(ha*year))	0,151471	kg
phosphate leaching (kg /(ha*a))	0,002909	kg
surface water		
Phosphate run-off	0,031626	kg
P emissions through erosion	-	kg
waste		
packaking waste (PET and mixed plastics) *	0,001673	kg

	farm 2	**unit**
total N supply	**0,16**	
CAN	0,160440	kg
P	0,04	kg
K	0,169818	kg
Mg	0,017842	kg
S	0,007983	kg
Ca	0,008150	kg
Zn	0,000365	kg
B	0,000438	kg
Si	0,273100	kg
Cu	0,000207	kg
Mn	0,000622	kg
Ciproconazol	0,000104	kg
epoxiconazole	0,000030	kg
Chlorpyrifos	0,001050	kg
citratos	0,000100	kg
Edatos queletantes	0,000125	kg
Polyoxiethylene Alkyl ether	0,000443	kg
Alcohol etoxilado	0,000055	kg
indicador de alcalinidad	0,000000	kg

air		
ammonia NH3	0,003507	kg
NOx	0,001891	kg
N2O emission (kg N2O ha-1)	0,000715	kg
CO2 after limestome		
groundwater		
NO3 (Kg N /(ha*year))	0,111369	kg

phosphate leaching (kg /(ha*a))	0,000645	kg
surface water		
Phosphate run-off	0,002687	kg
P emissions through erosion	0,000000	kg
waste		
packaking waste (PET and mixed plastics) *	0,000995	kg

	farm 3	**unit**
total N supply	**0,13**	
AN	0,044311	kg
CAN	0,078001	kg
COMPOST	0,009086	kg
MAP	0,000338	kg
OTHER	0,000307	kg
UAN	0,000219	kg
P	0,02	kg
K	0,116976	kg
Mg	0,003049	kg
S	0,000982	kg
Ca	0,007884	kg
Zn	0,000270	kg
B	0,003055	kg
Cu	0,000038	kg
Fe	0,018673	kg
Mo	0,000001	kg
pyraclostrobin	0,000054	kg
epoxiconazole	0,000168	kg
(Tebuconazole, Triadimenol) Familia TRIAZOL	0,000164	kg
Carbendazina	0,000344	kg
Diquat	0,000325	kg
Permetrina	0,000109	kg
citratos	0,000244	kg
Edatos queletantes	0,000304	kg
	0,000000	

air		
ammonia NH3	0,003727	kg
NOx	0,001550	kg
N2O emission (kg N2O ha-1)	0,000274	kg
CO2 after limestome	0,000454	kg
groundwater		
NO3 (Kg N /(ha*year))	0,051651	kg
phosphate leaching (kg /(ha*a))	0,000151	kg
surface water		
Phosphate run-off	0,000628	kg
P emissions through erosion	0,000000	kg
waste		
packaking waste (PET and mixed plastics) *	0,000626	kg

	farm 4	**unit**
total N supply	**0,15**	
CAN	0,087045	kg
COMPOST	0,017505	kg
OTHER	0,047896	kg
P	0,02	kg
K	0,105653	kg
Mg	0,041211	kg
S	0,020367	kg
Ca	0,024697	kg
Zn	0,001554	kg
B	0,022342	kg
Cu	0,000001	kg
Fe	0,036018	kg
Ciproconazol	0,000093	kg
pyraclostrobin	0,000017	kg
epoxiconazole	0,000044	kg
Diquat	0,000325	kg
Polyoxiethylene Alkyl ether	0,000020	kg
Alcohol etoxilado	0,000031	kg
indicador de alcalinidad	0,000000	kg
Glufosinato de Amonio	0,000105	kg
S-metacloro	0,000174	kg
Biofecunda- plus	0,004338	L

air		
ammonia NH3	0,004285	kg
NOx	0,001787	kg
N2O emission (kg N2O ha-1)	0,000378	kg
CO2 after limestome		
groundwater		
NO3 (Kg N /(ha*year))	0,061818	kg
phosphate leaching (kg /(ha*a))	0,000199	kg
surface water		
Phosphate run-off	0,000827	kg
P emissions through erosion	0,000000	kg
waste		
packaking waste (PET and mixed plastics) *	0,000723	kg

	farm 5	**unit**
total N supply	**0,20**	
AN	0,000572	kg
CAN	0,161641	kg
COMPOST	0,033539	kg
P	0,05	kg
K	0,216782	kg
Mg	0,028269	kg
S	0,009470	kg
Ca	0,018903	kg
Zn	0,004158	kg
B	0,000208	kg
Cu	0,002079	kg
Fe	0,071531	kg
Mn	0,002079	kg
Mo	0,000260	kg
Co	0,000010	kg
Ciproconazol	0,000184	kg
pyraclostrobin	0,000047	kg
epoxiconazole	0,000126	kg
esteres metílicos	0,000207	kg
Biofecunda	0,001102	L
Trichofecunda	0,001102	kg

air		

ammonia NH3	0,004776	kg
NOx	0,002302	kg
N2O emission (kg N2O ha-1)	0,000970	kg
CO2 after limestome		
groundwater		
NO3 (Kg N /(ha*year))	0,124174	kg
phosphate leaching (kg /(ha*a))	0,000872	kg
surface water		
Phosphate run-off	0,003633	kg
P emissions through erosion	0,000000	kg
waste		
packaking waste (PET and mixed plastics) *	0,001574	kg

	farm 6	**unit**

total N supply	**0,10**	
AN	0,016597	kg
CAN	0,056123	kg
OTHER	0,027336	kg
P	0,02	kg
K	0,061832	kg
Mg	0,018224	kg
S	0,003254	kg
Ca	0,042199	kg
B	0,029289	kg
Azoxistrobina	0,000045	kg
Ciproconazol	0,000028	kg
Azoxistrobina	0,000080	kg
Diazinon	0,000446	kg
citratos	0,000123	kg
Edatos queletantes	0,000154	kg
Polyoxiethylene Alkyl ether	0,000031	kg
Alcohol etoxilado	0,000047	kg
indicador de alcalinidad	0,000000	kg
Glufosinato de Amonio	0,000009	kg
Oxifluorfen.	0,000004	kg
Biofecunda	0,005616	L
Trichofecunda	0,005616	kg

air		
ammonia NH3	0,002827	kg
NOx	0,001173	kg
N2O emission (kg N2O ha-1)	0,000372	kg

CO2 after limestome	0,001961	kg
groundwater		
NO3 (Kg N /(ha*year))	0,092244	kg
phosphate leaching (kg /(ha*a))	0,000249	kg
surface water		
Phosphate run-off	0,001039	kg
P emissions through erosion	0,000000	kg
waste		
packaking waste (PET and mixed plastics) *	0,000707	kg

FUELS

fuels	farm (kg/FU)						
IMPUTS	farm 1	farm 2	farm 3	farm 4	farm 5	farm 6	unit
diesel	0,01	0,01	-	0,00	0,22	0,00	kg
gasoline	0,001673	0,002273	0,007662	0,001869	0,026385	0,003573	|
lubricating oils	0,001765	0,002453	0,001434	0,001658	0,002748	0,001607	kg

OUTPUTS							
emissions	farm 1	farm 2	farm 3	farm 4	farm 5	farm 6	unit
CO2	0,031252	0,046661	0,023259	0,011952	0,754758	0,022084	kg
CH4	0,004614	0,006883	0,003607	0,001798	0,111052	0,003325	g
N2O	0,000295	0,000440	0,000231	0,000115	0,007099	0,000213	g

TRANSPORT OF INPUTS							
imported inputs	farm 1	farm 2	farm 3	farm 4	farm 5	farm 6	
mass	0,650935565	1,246435442	0,637126819	0,699185578	0,876748381	0,54774252	kgkm
average terrestrial distance provider*	146	146	146	146	146	146	km
average terrestrial distance to farm	1,2	2,2	4,26	6,3	3	2,5	km
total distance	147,2	148,2	150,26	152,3	149	148,5	km
transport	95,8177152	184,7217325	95,73467579	106,4859636	130,6355087	81,33976427	kgkm
	0,095818	0,184722	0,095735	0,106486	0,130636	0,081340	tkm
local inputs	farm 1	farm 2	farm 3	farm 4	farm 5	farm 6	
mass	4,900451368	0	0,501973238	0,971441754	1,855211745	0,011231619	kg
average terrestrial distance to farm	1,2	2,2	4,26	6,3	3	2,5	km
transport	5,880541642	0	2,138405996	6,120083048	5,565635235	0,028079047	kgkm
	0,005881	-	0,002138	0,006120	0,005566	0,000028	tkm
fuels	farm 1	farm 2	farm 3	farm 4	farm 5	farm 6	

mass	0,01007	0,01503	0,00766	0,00388	0,24283	0,00718	kg
average terrestrial distance RECOPE-GasStation	106,00000	106,00000	106,00000	106,00000	106,00000	106,00000	km
average terrestrial distance to farm*	1,22000	2,22000	4,26000	6,30000	3,00000	2,25000	km
total distance	107,22000	108,22000	110,26000	112,30000	109,00000	108,25000	km
	1,07969	1,62642	0,84477	0,43607	26,46829	0,77702	kgkm
	0,001080	0,001626	0,000845	0,000436	0,026468	0,000777	tkm

TRANSPORT OF HARVESTED COFFEE	farm 1	farm 2	farm 3	farm 4	farm 5	farm 6	
mass	5 977,37	10 054,98	15 986,91	13 829,96	6 351,84	14 135,10	kg
average terrestrial distance*	1,2	2,2	4,26	6,3	3	2,25	km
transport	7 172,85	22 120,96	68 104,23	87 128,74	19 055,51	31 803,96	kgkm
	7,17	22,12	68,10	87,13	19,06	31,80	tkm
	0,001200	0,002200	0,004260	0,006300	0,003000	0,002250	tkm/FU

transport	farm 1	farm 2	farm 3	farm 4	farm 5	farm 6	
inputs	0,102778	0,186348	0,098718	0,113042	0,162669	0,082145	tkm
harvested coffee	0,001200	0,002200	0,004260	0,006300	0,003000	0,002250	tkm

*average distance according to supplier information provided by Cooperative and google maps calculations

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GENERAL INFORMATION MILLING PROCESS

annual production (fanegas)	annual production kg
322 900,10	14 482 069,49

MILLING WATER

IMPUTS

	annual amount		amount/FU	
water	54 570,12	m3	0,003768	m3

OUTPUTS

	54570,1169	L	0,003768	m3
DBO	20000	mg/l	0,001381	kg
DQO	30000	mg/l	0,002072	kg

wastewater comes from water brought into the process + mucilage remved from the coffee cherries (aguasmiel)

mucilage	20988,51	Bio	0,001449	L

26 563,29

0,001834219 kg

INPUTS

IMPUTS

	units	mass (kg)
jute bags	215 527,33	199 578,31

OUTPUTS

waste

1% discard of jute bags	0,000138	kg
coffee brush treatment	2,341137	kg
total treated waste (organic)	0,002341	ton

MILLING FUELS

IMPUTS

	annual amount		amount/FU	
wood	12 593,10	m3	0,00087	m3
coffee husk	3 390 450,00	kg	0,23411	kg
gasoline*	245,92	L	0,00002	L

	annual amount /FU		density	annual amount (kg/FU)
wood	0,00087	m3	0,75	0,00065
coffee husk	0,23411	kg		0,23411
gasoline	0,00002	L	734,9	0,00001

OUTPUTS	
air	
	kg/UF
CO2 fossil	0,000038
CH4 fossil	0,000006
N2O	0,000000

TRANSPORT OF INPUTS		
imported inputs		
mass	0,013781063	kg
average terrestrial distance provider*	146	km
average terrestrial distance to farm	45,2	km
total distance	191,2	km
	2,634939188	kgkm
	0,002635	tkm
fuels		
wood	0,00065	kg
distance	10,00000	km
coffee husk	0,23411	kg
distance	0,00000	km
gasoline	0,00002	kg
distance	106,00000	km
	0,00832	kgkm
	0,000008	tkm

TRANSPORT OF HARVESTED COFFEE		
mass	66 336,15	kg
average terrestrial distance*	14	km
transport	928 706,14	kgkm
	928,71	tkm
	0,000064	tkm/FU

*average distance according to supplier information provided by Cooperative and google maps calculations, from local reception sites to main reception site at milling facility

MILLING ENERGY (ELECTRICITY)

IMPUTS		
	kWh	kWh/FU
Electricity	3 077 237,95	0,212486065

OUTPUTS		
	kg CO2e/kWh	kg CO2e
electriciy CR	0,0395	0,0083932

TRANSPORT OF GREEN COFFEE TO EXPORT DOCKS		
mass	12 599 400,45	kg
distance to conditioning and packaging plant	41,60	km
	524 135 058,80	
mass to Moín	8 189 610,29	kg
distance to Moin	179,00	km
	1 465 940 242,58	
mass to Caldera	4 409 790,16	kg
distance to Caldera	109	km
	480 667 127,24	
	2 470 742 428,63	kgkm
	170,61	tkm
transport	0,170607	tkm

establishment costs		**1**	**2**	**3**	**4**	**5**	**6**
item	category	USD/unit	USD/unit	USD/unit	USD/unit	USD/unit	USD/unit
water	water	0,0007	0,0008	0,0008	0,0008	0,0009	0,0007
plants (seeds, fertilizers, pesticides, substrate)	inputs	0,0072	0,0084	0,0085	0,0081	0,0101	0,0071
transport	transport	0,0000	0,0001	0,0001	0,0001	0,0002	0,0001
driver plants& inputs	transport	0,0007	0,0004	0,0003	0,0003	0,0006	0,0003
workers farm	labour	0,0091	0,0054	0,0034	0,0039	0,0086	0,0039
TOTAL		0,0177	0,0151	0,0131	0,0132	0,0205	0,0120

Production costs	**1**	**2**	**3**	**4**	**5**	**6**
category	USD/unit	USD/unit	USD/unit	USD/unit	USD/unit	USD/unit
water	0,34	2,58	2,19	1,92	2,19	1,59
fuels	0,03	0,02	0,01	0,00	0,28	0,01
labour	1,86	1,54	2,03	1,11	1,52	1,03
transport	0,05	0,03	0,02	0,02	0,04	0,01
inputs	0,85	0,73	0,40	0,45	0,59	0,27
total	**3,13**	**4,90**	**4,65**	**3,51**	**4,63**	**2,91**

Shade system evaluation

a) **Shade coverage**: with the information of the composition and dimension data from individuals, the indicator was expressed as a percentage of shade coverage, calculated using equation 1.

$$\% \, Shade = \frac{A_{tree\ top}\ x\ O}{A_t}\ x\ 100 \qquad \text{(Equation 1)}$$

The % Shade is the porcentage of the land area covered by shade; $A_{\text{tree top}}$ is the dimension of the area that offer shade presented as an elliptical area = π x r_1 x r_2; $r_1 = \frac{d_{tree\ top\ 1}}{2}$; $r_2 = \frac{d_{tree\ top2}}{2}$; O: Occlusion (used a 0,4 factor) and A_t is the area of the plot. The total area covered by the shade of the individuals was calculated through the aggregation of all the % Shade in the plot (Somarriba, 2002).

b) **Biodiversity**: the biodiversity of each plot was analysed through the Importance Value Index (IVI) and the Shannon diversity index (H') (Somarriba, 1999). Equation 2 was first used to determine the basal area (G) of the individuals, and then calculate the IVI. The diameter (d) of the Musaceae species within the plots was calculated through a random sample of 20 pseudostems and then fixed at 11cm; the diameter (d) for the rest of species was measured through DBH, following Sanchez-Monge (2013) recommendations.

$$G = \frac{\pi}{4}\ x\ \left(\left(\frac{d}{100}\right)^2\right) \qquad \text{(Equation 2)}$$

Intermediate calculations were required to determine the absolute abundance-Ab (amount of individuals * sampled area^{-1}), the absolute frequency-Fr (amount of lots where species are present * total amount of sampling lots^{-1}) and the absolute dominance- D (total basal area per each species * sampled area^{-1}). Then they were transformed into relative variables: relative abundance-Ab% (absolute abundance for each species * absolute abundance of all species^{-1} *100), relative frequency-Fr% (100* frequence per each species*frequence of all species^{-1} *100), and relative dominance-D% (absolute dominance per species *absolute dominance of all speches^{-1} *100), used in equation 3 to obtain the IVI.

$$IVI = Ab\% + Fr\% + D\% \qquad \text{(Equation 3)}$$

Then the H' index used equation 4, considering the proportion (of Ab%) of each species.

$$H' = -\sum p_i ln p_i \qquad \text{(Equation 4)}$$

Where p_i is the relative abundance of each species.

c) **Carbon storage**: this variable represented the amount of stored carbon in the existing biomass above ground belonging to the shade species. The calculation was based on the IPCC guidelines (IPCC, 2006), considering first the volume (V) of the wood within the tree species present in the plots, according to equation 5.

$$V = \frac{\pi}{4}\ x\ (d)^2\ x\ h\ x\ ff \qquad \text{(Equation 5)}$$

The d is the diameter or DBH, h is the total height of the individual, and ff is the shape factor, fixed at a value of 0,50. To calculate the biomass (B) of trees and shrub individuals, equation 6 used the volume (V), the density of the wood (DM) and a biomass expansion factor (FEB) of 1,5 according to the IPCC.

$$B = V\ x\ DM\ x\ FEB \qquad \text{(Equation 6)}$$

In the case of the biomass of *Musaceae* species (Bm), the allometric equation 7 was used, considering the height of the individual (H_t).

$$B_m = 1,5\ x\ H_t \qquad \text{(Equation 7)}$$

Once the biomass was obtained, stored Carbon was estimated using a fraction of carbon (FC) of 0,44 according to IPCC (2006), as described in equation 8. Then a ratio of 44/12 was used to obtain the conversion factor to CO_2 (Carbon Dioxide, equation 9) regarding the atomic weight of its components.

$$CarbonB\ x\ 0{,}44 \qquad \text{(Ecuación 8)}$$

$$CO_2 = Carbon\ x\ \frac{44}{12} \qquad \text{(Ecuación 9)}$$

(ISM) Expert consultation regarding related factors of sustainable production decision making in coffee farms

Dear expert:

We thank you for your valuable contribution to our study regarding coffee sustainability, throught a case study in Tarrazú Canton, Costa Rica. We can be reached for any questions at the e-mail address labrenes@tec.ac.cr .

Introduction:

Coffee is one of the most traded commodities worldwide, millions of jobs and families depend on it and there is a lot of attention on its challenges, and impacts. Therefore, there have been important efforts to improve its productive, social, economic and environmental performance. Most common and recent studies evaluate services provided by the shade, and evaluate the environmental footprint of coffee production through Life Cycle Assessment, as well as the definition of sustainability in the sector. However, aspects within those studies are not always regarded in integrated manners. Therefore, we want to dedicate our research to the relations among productive, environmental, and socioeconomic factors, and to farmers' decision making processes when aiming at more sustainable systems. A section of the study was performed in six farms in Tarrazú, showing that the use of fertilizers is relevant in the contribution of environmental impacts and costs, but also some impacts and input use seem to be related also to productive and shade-system practices in the farms.

Aim of the consultation

A) Validate our selection of relevant factors
B) Detect the relations among factors

Structure of the questionnaire:

This questionnaire is divided in four sections: 1) general information, 2) validation and priorisation of factors, 3) determination of relations among factors, 4) section of additional comments.

¡Thank you for your time and valuable inputs!

1) General information

1.4. Area of expertise, select only one alternative in which you feel the most identified.

☐environmental sciences
☐management and economics
☐Social Sciences
☐Agriculture/related disciplnes
☐other ________ (mention)

1.5. Academic level, select the highest finished degree

☐High-school
☐Technical degree
☐University
☐Postgraduate

1.6. Sector, select the sector you identify yourself the most with.

☐coffee production
☐Academia
☐technical advisory
☐Public institution
☐other ________ (mention)

4) Validation of factors (questionnaire 1)

You are presented with a list of factors we found in literature reviews and field observations and interviews, which are related to the decisions made by farmers in sustainable coffee production. The factors are grouped in three main areas. Please mark with a ✓if the factor should remain in the selection or and X if it should not be considered. If it remains in the list, please indicate its importance using the 4 value scale we provide, where 1 is least important and 4 most important.

Group	Factor	Maintain or not ✓or X	Importance			
			1	2	3	4
Life cycle impacts	1. Amount of GHG emissions 2. Possible water pollution 3. Water consumption 4. Environmental costs					
Shade in the coffee production aspects	5. Conservation and/or enhancement of biodiversity 6. Climate change adaptation and resilience, including the provision of adequate microclimate conditions (water availability, temperature, pollinators and biocontrollers enabling environment) 7. Improvement of pre-existing soil conditions (fertility organic matter deficiencies, erosion propensity) 8. Adoption of certification schemes and their requirements as well as benefits (price premium, market access and distinctions) 9. Operative and investment costs of shade-system management 10. Possibility of income diversification 11. Possibility of food supply diversification for the family 12. Incentives per adopted practices (such as payments for ecosystem services or conservation) 13. Previous knowledge, tradition, cultural perspectives and sustainability commitment					
Productive, management and comercial aspects	14. Results related to productivity, yield, price and final cup quality 15. Preference and access to coffee varieties 16. Use and cost of inputs, such as fertilizers, pesticides, herbicides and alternative ones (compost, bioinputs, biochar) 17. Conditions of coffee plant nutrition 18. Training and capacity building needs and availability 19. Existing Policies (enabling or disenabling the adoption of practices) 20. Support, requirements and/or motivation from Cooperative schemes they belong to 21. Easiness of sustainable cropping practices (fertilization, pest, disease and weed management, input application, pruning, harvesting)					
	Others: -					

5) Relation among factors (questionnaire 2)

This section contains pairs of factors, please indicate with arrows the relation of influence of one towards the other. Please use these symbols

→	factor on the left (A) influences factor on the right (B), in other words A→B
←	factor on the left (A) is influenced by factor on the right (B), in other words A←B
←→	Factors influence each other, A influences B and B also influences A, or A←→B
-	factors are not related and none influences the other

A	**relation**	**B**
Amount of GHG emissions		Possible water pollution
		Water consumption
		Environmental costs
		Conservation and/or enhancement of biodiversity
		Climate change adaptation and resilience, including the provision of adequate microclimate conditions (water availability, temperature, pollinators and biocontrollers enabling environment)
		Improvement of pre-existing soil conditions (fertility organic matter deficiencies, erosion propensity)
		Adoption of certification schemes and their requirements as well as benefits (price premium, market access and distinctions)
		Operative and investment costs of shade-system management
		Possibility of income diversification
		Possibility of food supply diversification for the family
		Incentives per adopted practices (such as payments for ecosystem services or conservation)
		Previous knowledge, tradition, cultural perspectives and sustainability commitment
		Results related to productivity, yield, price and final cup quality
		Preference and access to coffee varieties
		Use and cost of inputs, such as fertilizers, pesticides, herbicides and alternative ones (compost, bioinputs, biochar)
		Conditions of coffee plant nutrition
		Training and capacity building needs and availability
		Existing Policies (enabling or disenabling the adoption of practices)
		Support, requirements and/or motivation from Cooperative schemes they belong to
		Easiness of sustainable cropping practices (fertilization, pest, disease and weed management, input application, pruning, harvesting)

A	relation	B
Possible water pollution		Water consumption
		Environmental costs
		Conservation and/or enhancement of biodiversity
		Climate change adaptation and resilience, including the provision of adequate microclimate conditions (water availability, temperature, pollinators and biocontrollers enabling environment)
		Improvement of pre-existing soil conditions (fertility organic matter deficiencies, erosion propensity)
		Adoption of certification schemes and their requirements as well as benefits (price premium, market access and distinctions)
		Operative and investment costs of shade-system management
		Possibility of income diversification
		Possibility of food supply diversification for the family
		Incentives per adopted practices (such as payments for ecosystem services or conservation)
		Previous knowledge, tradition, cultural perspectives and sustainability commitment
		Results related to productivity, yield, price and final cup quality
		Preference and access to coffee varieties
		Use and cost of inputs, such as fertilizers, pesticides, herbicides and alternative ones (compost, bioinputs, biochar)
		Conditions of coffee plant nutrition
		Training and capacity building needs and availability
		Existing Policies (enabling or disenabling the adoption of practices)
		Support, requirements and/or motivation from Cooperative schemes they belong to
		Easiness of sustainable cropping practices (fertilization, pest, disease and weed management, input application, pruning, harvesting)

A	relation	B
Water consumption		Environmental costs
		Conservation and/or enhancement of biodiversity
		Climate change adaptation and resilience, including the provision of adequate microclimate conditions (water availability, temperature, pollinators and biocontrollers enabling environment)
		Improvement of pre-existing soil conditions (fertility organic matter deficiencies, erosion propensity)
		Adoption of certification schemes and their requirements as well as benefits (price premium, market access and distinctions)
		Operative and investment costs of shade-system management
		Possibility of income diversification
		Possibility of food supply diversification for the family
		Incentives per adopted practices (such as payments for ecosystem services or conservation)
		Previous knowledge, tradition, cultural perspectives and sustainability commitment
		Results related to productivity, yield, price and final cup quality
		Preference and access to coffee varieties
		Use and cost of inputs, such as fertilizers, pesticides, herbicides and alternative ones (compost, bioinputs, biochar)
		Conditions of coffee plant nutrition
		Training and capacity building needs and availability
		Existing Policies (enabling or disenabling the adoption of practices)
		Support, requirements and/or motivation from Cooperative schemes they belong to
		Easiness of sustainable cropping practices (fertilization, pest, disease and weed management, input application, pruning, harvesting)

A	relation	B
Environmental costs		Conservation and/or enhancement of biodiversity
		Climate change adaptation and resilience, including the provision of adequate microclimate conditions (water availability, temperature, pollinators and biocontrollers enabling environment)
		Improvement of pre-existing soil conditions (fertility organic matter deficiencies, erosion propensity)
		Adoption of certification schemes and their requirements as well as benefits (price premium, market access and distinctions)
		Operative and investment costs of shade-system management
		Possibility of income diversification
		Possibility of food supply diversification for the family
		Incentives per adopted practices (such as payments for ecosystem services or conservation)
		Previous knowledge, tradition, cultural perspectives and sustainability commitment
		Results related to productivity, yield, price and final cup quality
		Preference and access to coffee varieties
		Use and cost of inputs, such as fertilizers, pesticides, herbicides and alternative ones (compost, bioinputs, biochar)
		Conditions of coffee plant nutrition
		Training and capacity building needs and availability
		Existing Policies (enabling or disenabling the adoption of practices)
		Support, requirements and/or motivation from Cooperative schemes they belong to
		Easiness of sustainable cropping practices (fertilization, pest, disease and weed management, input application, pruning, harvesting)

A	relation	B
Conservation and/or enhancement of biodiversity		Climate change adaptation and resilience, including the provision of adequate microclimate conditions (water availability, temperature, pollinators and biocontrollers enabling environment)
		Improvement of pre-existing soil conditions (fertility organic matter deficiencies, erosion propensity)
		Adoption of certification schemes and their requirements as well as benefits (price premium, market access and distinctions)
		Operative and investment costs of shade-system management
		Possibility of income diversification
		Possibility of food supply diversification for the family
		Incentives per adopted practices (such as payments for ecosystem services or conservation)
		Previous knowledge, tradition, cultural perspectives and sustainability commitment
		Results related to productivity, yield, price and final cup quality
		Preference and access to coffee varieties
		Use and cost of inputs, such as fertilizers, pesticides, herbicides and alternative ones (compost, bioinputs, biochar)
		Conditions of coffee plant nutrition
		Training and capacity building needs and availability
		Existing Policies (enabling or disenabling the adoption of practices)
		Support, requirements and/or motivation from Cooperative schemes they belong to
		Easiness of sustainable cropping practices (fertilization, pest, disease and weed management, input application, pruning, harvesting)

A	relation	B
Climate change adaptation and resilience…..		Improvement of pre-existing soil conditions (fertility organic matter deficiencies, erosion propensity)
		Adoption of certification schemes and their requirements as well as benefits (price premium, market access and distinctions)
		Operative and investment costs of shade-system management
		Possibility of income diversification
		Possibility of food supply diversification for the family
		Incentives per adopted practices (such as payments for ecosystem services or conservation)
		Previous knowledge, tradition, cultural perspectives and sustainability commitment
		Results related to productivity, yield, price and final cup quality
		Preference and access to coffee varieties
		Use and cost of inputs, such as fertilizers, pesticides, herbicides and alternative ones (compost, bioinputs, biochar)
		Conditions of coffee plant nutrition
		Training and capacity building needs and availability
		Existing Policies (enabling or disenabling the adoption of practices)
		Support, requirements and/or motivation from Cooperative schemes they belong to
		Easiness of sustainable cropping practices (fertilization, pest, disease and weed management, input application, pruning, harvesting)

A	relation	B
Improvement of pre-existing soil conditions (fertility organic matter deficiencies, erosion propensity)		Adoption of certification schemes and their requirements as well as benefits (price premium, market access and distinctions)
		Operative and investment costs of shade-system management
		Possibility of income diversification
		Possibility of food supply diversification for the family
		Incentives per adopted practices (such as payments for ecosystem services or conservation)
		Previous knowledge, tradition, cultural perspectives and sustainability commitment
		Results related to productivity, yield, price and final cup quality
		Preference and access to coffee varieties
		Use and cost of inputs, such as fertilizers, pesticides, herbicides and alternative ones (compost, bioinputs, biochar)
		Conditions of coffee plant nutrition
		Training and capacity building needs and availability
		Existing Policies (enabling or disenabling the adoption of practices)
		Support, requirements and/or motivation from Cooperative schemes they belong to
		Easiness of sustainable cropping practices (fertilization, pest, disease and weed management, input application, pruning, harvesting)

A	relation	B
Adoption of certification schemes and their requirements as well as benefits (price premium, market access and distinctions)		Operative and investment costs of shade-system management
		Possibility of income diversification
		Possibility of food supply diversification for the family
		Incentives per adopted practices (such as payments for ecosystem services or conservation)
		Previous knowledge, tradition, cultural perspectives and sustainability commitment
		Results related to productivity, yield, price and final cup quality
		Preference and access to coffee varieties
		Use and cost of inputs, such as fertilizers, pesticides, herbicides and alternative ones (compost, bioinputs, biochar)
		Conditions of coffee plant nutrition
		Training and capacity building needs and availability
		Existing Policies (enabling or disenabling the adoption of practices)
		Support, requirements and/or motivation from Cooperative schemes they belong to
		Easiness of sustainable cropping practices (fertilization, pest, disease and weed management, input application, pruning, harvesting)

A	relation	B
Operative and investment costs of shade-system management		Possibility of income diversification
		Possibility of food supply diversification for the family
		Incentives per adopted practices (such as payments for ecosystem services or conservation)
		Previous knowledge, tradition, cultural perspectives and sustainability commitment
		Results related to productivity, yield, price and final cup quality
		Preference and access to coffee varieties
		Use and cost of inputs, such as fertilizers, pesticides, herbicides and alternative ones (compost, bioinputs, biochar)
		Conditions of coffee plant nutrition
		Training and capacity building needs and availability
		Existing Policies (enabling or disenabling the adoption of practices)
		Support, requirements and/or motivation from Cooperative schemes they belong to
		Easiness of sustainable cropping practices (fertilization, pest, disease and weed management, input application, pruning, harvesting)

A	**relation**	**B**
Possibility of income diversification		Possibility of food supply diversification for the family
		Incentives per adopted practices (such as payments for ecosystem services or conservation)
		Previous knowledge, tradition, cultural perspectives and sustainability commitment
		Results related to productivity, yield, price and final cup quality
		Preference and access to coffee varieties
		Use and cost of inputs, such as fertilizers, pesticides, herbicides and alternative ones (compost, bioinputs, biochar)
		Conditions of coffee plant nutrition
		Training and capacity building needs and availability
		Existing Policies (enabling or disenabling the adoption of practices)
		Support, requirements and/or motivation from Cooperative schemes they belong to
		Easiness of sustainable cropping practices (fertilization, pest, disease and weed management, input application, pruning, harvesting)

A	**relation**	**B**
Possibility of food supply diversification for the family		Incentives per adopted practices (such as payments for ecosystem services or conservation)
		Previous knowledge, tradition, cultural perspectives and sustainability commitment
		Results related to productivity, yield, price and final cup quality
		Preference and access to coffee varieties
		Use and cost of inputs, such as fertilizers, pesticides, herbicides and alternative ones (compost, bioinputs, biochar)
		Conditions of coffee plant nutrition
		Training and capacity building needs and availability
		Existing Policies (enabling or disenabling the adoption of practices)
		Support, requirements and/or motivation from Cooperative schemes they belong to
		Easiness of sustainable cropping practices (fertilization, pest, disease and weed management, input application, pruning, harvesting)

A	**relation**	**B**
Incentives per adopted practices (such as payments for ecosystem services or conservation)		Previous knowledge, tradition, cultural perspectives and sustainability commitment
		Results related to productivity, yield, price and final cup quality
		Preference and access to coffee varieties
		Use and cost of inputs, such as fertilizers, pesticides, herbicides and alternative ones (compost, bioinputs, biochar)
		Conditions of coffee plant nutrition
		Training and capacity building needs and availability
		Existing Policies (enabling or disenabling the adoption of practices)
		Support, requirements and/or motivation from Cooperative schemes they belong to
		Easiness of sustainable cropping practices (fertilization, pest, disease and weed management, input application, pruning, harvesting)

A	relation	B
Previous knowledge, tradition, cultural perspectives and sustainability commitment		Results related to productivity, yield, price and final cup quality
		Preference and access to coffee varieties
		Use and cost of inputs, such as fertilizers, pesticides, herbicides and alternative ones (compost, bioinputs, biochar)
		Conditions of coffee plant nutrition
		Training and capacity building needs and availability
		Existing Policies (enabling or disenabling the adoption of practices)
		Support, requirements and/or motivation from Cooperative schemes they belong to
		Easiness of sustainable cropping practices (fertilization, pest, disease and weed management, input application, pruning, harvesting)

A	relation	B
Results related to productivity, yield, price and final cup quality		Preference and access to coffee varieties
		Use and cost of inputs, such as fertilizers, pesticides, herbicides and alternative ones (compost, bioinputs, biochar)
		Conditions of coffee plant nutrition
		Training and capacity building needs and availability
		Existing Policies (enabling or disenabling the adoption of practices)
		Support, requirements and/or motivation from Cooperative schemes they belong to
		Easiness of sustainable cropping practices (fertilization, pest, disease and weed management, input application, pruning, harvesting)

A	relation	B
Preference and access to coffee varieties		Use and cost of inputs, such as fertilizers, pesticides, herbicides and alternative ones (compost, bioinputs, biochar)
		Conditions of coffee plant nutrition
		Training and capacity building needs and availability
		Existing Policies (enabling or disenabling the adoption of practices)
		Support, requirements and/or motivation from Cooperative schemes they belong to
		Easiness of sustainable cropping practices (fertilization, pest, disease and weed management, input application, pruning, harvesting)

A	relation	B
Use and cost of inputs, such as fertilizers, pesticides, herbicides and alternative ones (compost, bioinputs, biochar)		Conditions of coffee plant nutrition
		Training and capacity building needs and availability
		Existing Policies (enabling or disenabling the adoption of practices)
		Support, requirements and/or motivation from Cooperative schemes they belong to
		Easiness of sustainable cropping practices (fertilization, pest, disease and weed management, input application, pruning, harvesting)

A	relation	B
Conditions of coffee plant nutrition		Training and capacity building needs and availability
		Existing Policies (enabling or disenabling the adoption of practices)
		Support, requirements and/or motivation from Cooperative schemes they belong to
		Easiness of sustainable cropping practices (fertilization, pest, disease and weed management, input application, pruning, harvesting)

A	relation	B
Training and capacity building needs and availability		Existing Policies (enabling or disenabling the adoption of practices)
		Support, requirements and/or motivation from Cooperative schemes they belong to
		Easiness of sustainable cropping practices (fertilization, pest, disease and weed management, input application, pruning, harvesting)

A	relation	B
Existing Policies (enabling or disenabling the adoption of practices)		Support, requirements and/or motivation from Cooperative schemes they belong to
		Easiness of sustainable cropping practices (fertilization, pest, disease and weed management, input application, pruning, harvesting)

A	relation	B
Support, requirements and/or motivation from Cooperative schemes they belong to		Easiness of sustainable cropping practices (fertilization, pest, disease and weed management, input application, pruning, harvesting)

6) ADDITIONAL COMMENTS

Please use this bos for any additional comments or suggestions.

Annex 3: supplementary materials from chapter 4

Social-Life cycle assessment of food supply chains in Costa Rica: opportunities and vulnerabilities

Laura Brenes-Peralta[1], María Fernanda Jiménez-Morales[2], Rooel Campos-Rodríguez[3], Matteo Vittuari[4]

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S-LCA indicators

Scale based on Subcategory assessment method (SAM)[6]

A	B	C	D
4	3	2	1
proactive, surpasses BRs	complies with BRs	non-compliant with BRS, similar to its context	non-compliant with BRs, even when context does

Note: BR (basic requirements, build upon international and national standards, regulations and conditions)

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[6]

M. D'Eusanio, M. Serreli, A. Zamagni and L. Petti, “Assessment of social dimension of a jar of honey: A methodological outline,” *Journal of Cleaner Production Volume 199,* pp. 503-517 https://doi.org/10.1016/j.jclepro.2018.07.157, 2018.

L. Petti, P. K. Sanchez Ramirez, M. Traverso and C. M. Lie Ugaya, “An Italian tomato BCuore di Bue^ case study: challenges and benefits using subcategory assessment method for social life cycle assessment,” *International Journal of Life Cycle Assessment Volume 23* , pp. 569–580 DOI 10.1007/s11367-016-1175-9, 2018.

P. K. Sanchez Ramirez, L. Petti, N. T. Haberland and C. M. Lie Ugaya, “Subcategory assessment method for social life cycle assessment. Part 1: methodological framework,” *International Journal of Life Cycle Assessment Volume 19* , pp. 1515–1523 DOI 10.1007/s11367-014-0761-y, 2014.

Stakeholder: Farmer

	name of subcategory	Aim of assessment [7]	indicators
1	Meeting basic needs	To assess the extent to which the basics needs of farmers are met and the extent to which a contribution is made towards improving the status quo.	F1.1. Access to potable water F1.2. Access to wastewater disposal and treatment Service F1.3. Access to electricity service F1.4. Access to enough food (food security)
2	Access to services and inputs	To evaluate the extent to which farmers have access to inputs such as credit, banking or a secure method for storing and saving money, good-quality seeds, and services such as ICT, electricity and infrastructure (e.g. roads, bridges, schools). This social topic aims to assess both local conditions and the contributions made by value-chain actors.	F2.1. Access to telephone Service F2.2. Internet coverage F2.3. Physical access to the farm (accessible roads through the year) F2.4. Presence of nearby public transportation F2.5. Access to production inputs F2.6. Access to supplementary services (extension and training, credit, insurance)
3	Women´s empowerment, inclusion and non-discrimination practices	To assess the extent to which a role of female farmers is recognised within the value chain and the extent to which contributions are made to empower female small-scale farmers (i.e. equal access to jobs, training, advancement and benefits, and other rights for women, as well as opportunities to maintain cultural identity).	F3.1. Gender balance F3.2. Integration of diverse populations F3.3. Presence of women in leading or decision-making roles F3.4. Equal pay for men and women F3.5. Evidence of Empowerment, equity and diversity policies (actual or factual)
4	Child Labour	To identify if child labour takes place, since it is defined as work that deprives children of their childhood, their potential	F4.1. Absence of underage workers (<15 years old, according to national legislation in allowed tasks)

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[7] Descriptions of the aim of the subcategory assessment for the tables of farmers, workers and local community based or extracted from:

UNEP/SETAC, The Methodological Sheets for Subcategories in Social Life Cycle Ass essm ent (S-LCA), Paris https://www.lifecycleinitiative.org/wp-content/uploads/2013/11/S-LCA_methodological_sheets_11.11.13.pdf, 2013.

M. Goedkoop, D. Indrane and . I. de Beer, Product Social Impact Assessment Methodology Report 2018, Amersfoort: PRé Consultants BV and the Roundtable for Product Social Metrics, 2018.

		and their dignity, and is harmful to physical and mental development. Minor children can work at their own parents' farm, or workshop in activities not considered hazardous, as long as this does not affect their school attendance and their moral, social and physical development. Work must be appropriate to the subject's age and physical condition.	F4.2. Absence of underage workers (<15<18 years old) in extended working days F4.3. Related or family minors are in formal educational system F4.4. Evidence of Child Labour prevention policies or mechanisms
5	Health and safety	Defined as the extent to which farmers maintains safe working conditions for themselves, their families and workers. This social topic aims to measure the risks associated with farmers working conditions and the extent to which the activity/farm is making contributions to good safety procedures by engaging related actors in training programmes, awareness raising events, etc.	F5.1. Low accendibility /year related to work F5.2. No fatalities related to work F5.3. Evidence of job security and accident prevention policies or mechanisms F5.4. Low rate of incapacities and illnesses/year F5.5. Safety material is provided to workers F5.6. Safety material is used by workers F5.7. Training and capacity to prevent accidents and job security F5.8. Use of signals for delimitation of areas (storage, process, transit, high voltage, etc) F5.9. Access to basic hygiene conditions (water, soap, toilet or restroom)
6	Land rights	To assess the farmers' legal rights to land and tenure security.	F6.1. Production is done in own land F6.2. If rented, basic conditions are supported by contracts, fair rental price, among others. F6.3. No evidence of threads to land rights
7	Corporate responsibility	To assesses to what extent an organization is engaged in reducing its negative impacts that affect sustainability.	OS1.1. Contribution of the activity to national food safety and security OS1.2. Contribution of the activity to national economic development OS1.3. Promotion of compliance with social and labour security OS1.4. Promotion of compliance with health and environment regulations OS1.5. Evidence of Good practices (GAP, GMP, animal welfare)

8	Fair trading relationships	To evidence the quality of the trading relationship of the farmers within the value-chain	OS2.1. Presence of organizations that represent the sector (farmers’ association, chamber, etc.) OS2.2. Evidence of inter and intra-sector alliances OS2.3. Local suppliers’ preference OS2.4. Presence of regulations and practices promoting fair-trade conditions OS2.5. Sustainable purchases principles are in place

Stakeholder: Worker

	name of subcategory	Aim of assessment	indicators
1	Freedom of association and Collective Bargaining	To verify the compliance of the organization with freedom of association and collective bargaining standards.	W1.1. No evidence that collective bargaining of association is forbidden W1.2. Presence of organized workers' groups W1.3. % of workers that are affiliated to a group, association W1.4. Evidence/testimony of agreements between employees and employers in reference to working conditions
2	Child labour	To verify if the organization might or is employing children (as defined in the ILO conventions) and to identify the nature of any child labour.	W2.1. No presence of underage workers (<15 years old, according to national legislation in allowed tasks) W2.2. No presence of underage workers (<15<18 years old) in extended working days W2.3. Related or family minors are in formal educational system W2.4. Evidence of Child Labour prevention policies or mechanisms
3	Fair salary	To assess whether practices concerning wages are in compliance with established standards and if the wage that is payed meets legal requirements, whether it is above, meeting or below sector average and whether it can be considered as a living wage	W3.1. Salary is equal or above minimum in the country by law. W3.2. The salary allows the worker to fulfil basic needs (food, health, housing) W3.3. Evidence of payments (receipts, payroll records, digital information system) W3.4. Deductions are not applied in arbitrary manners
4	Hours of work	To verify if the number of hours really worked is in accordance with the ILO standards and when overtime occurs, compensation in terms of money or free time is planned and provided to workers.	W 4.1. Weekly worked hours fit national regulation (48 hours/week) W4.2. Weekly extra-worked hours do not surpass national regulation (ordinary and extraordinary won´t surpass 12hrs/day when summed) W4.3. Workers can enjoy a 1 day of rest/week and holidays W4.4. Respect to agreed working Schedule W4.5. Evidence/testimony of communication and consensus mechanisms when extraordinary working schedules are needed

5	Forced Labour	To verify that there is no use of forced or compulsory labour in the organization	W5.1. Workers come to work freely W5.2. Contract conditions are clear for the worker W5.3. Evidence or register of working contract (written or oral when applicable) W5.4. Personal documents from workers are never retained W5.5. Workers can quit freely, with corresponding notice when applicable
6	Equal opportunities/ no-Discrimination	To assess equal opportunity management practices and the presence of discrimination in the opportunities offer to the workers by the organizations and in the working conditions.	W6.1. Gender balance within delegated decision-makers or working structure W6.2. Gender balance in the general working structure (peers) W6.3. Integration of diverse populations W6.4. No reported incidents related to discrimination W6.5. The worker states not having felt discriminated W6.6. Evidence of non-discrimination policies (actual or factual) and practices W6.7. Absence of illegal workers W6.8. Evidence of opportunities for training, capacity biulding and education inside or outside the organization.
7	Health and security	To assess both the rate of incidents and the status of prevention measure and management practices. An incident is defined as a work-related event(s) in which a injury or ill health (regardless of severity) or fatality occurred or could have occurred.	W7.1. Low accendibility /year related to work W7.2. No fatalities related to work W7.3. Evidence of job security and accident prevention policies or mechanisms W7.4. Low rate of incapacities and illnesses/year W7.5. Safety material is provided to workers W7.6. Safety material is used by workers W7.7. Training and capacity to prevent accidents and job security W7.8. Use of signals for delimitation of areas (storage, process, transit, high voltage, etc) W7.9. Access to basic hygiene conditions (water, soap, toilet or restroom)
8	Social Benefits/Social Security	To assess whether an organization provides for social benefits and social security of workers and to what extent.	W8.1. Worker is covered by minimum social security payed by employer W8.2. Worker is covered by job- risks security

	W8.3. absence of incidents related to employers’ social security breach W8.4. Access to resting areas W8.5. Promotion of healthy habits and lifestyle W8.6. Flexibility in working hours and conditions (extraordinary permits, etc.)

Stakeholder: Local Community

number	name of subcategory	Aim and approach of indicator assessment	indicators
1	Delocalization and migration	The assessment aims to assess whether organizations contribute to delocalization, migration or "involuntary resettlement" within communities and whether populations are treated adequately.	LC1.1. Absence of emigration due to the farm activity LC1.2. Immigration attracted due to decent job opportunities created by the farm LC1.3. Immigrants integrate to the community they arrived at LC1.4. Evidence or policies or mechanisms supporting better and decent conditions for immigrants
2	Community involvement	This subcategory assesses whether an organization includes community stakeholders in relevant decision-making processes. It also considers the extent to which the organization engages with the community, in general.	LC2.1. Involvement of the farm (farmer, family, employees) in local activities to promote development, awareness, volunteering, in environmental, health, emergency aspects). LC2.2. Involvement in Local Development Associations (municipality) or boards LC2.3. Existence of Alternate conflict resolution mechanisms
3	Cultural heritage	This subcategory assesses whether an organization respects local cultural heritage and recognizes that all community members have a right to pursue their cultural development	LC3.1. Evidence of inclusion and respect for cultural heritage within productive practices LC3.2. Involvement in activities related to the rescue of cultural heritage LC3.3. Translation of related productive/farm information into local native language
4	Respect of Indigenous Rights	This subcategory assesses organizational respect for the rights of indigenous peoples, as a group or as individuals.	LC4.1. Existence of policies protecting Indigenous Rights LC4.2. Indigenous peoples' integration to local community and activities LC4.3. Existence of sessions or specific groups supporting indigenous rights or consensus in decision -making processes. LC4.4. Absence of incidents with Indigenous peoples' (discrimination, disrespect, etc)
5	Local Employment	This subcategory assesses the role of an organization in directly or indirectly affecting local employment	LC5.1. Evident local employment LC5.2. Evidence of policies (actual or factual) or mechanisms for preference of local employees LC5.3. Preference for local provisioning

6	Access to Immaterial Resources	This subcategory assesses the extent to which organizations respect, work to protect, to provide or to improve community access to immaterial resources.	LC6.1. Involvement in educational activities in the community LC6.2. Low incidence of conflicts with the community
7	Access to material resources	This subcategory assesses the extent to which organizations respect, work to protect, to provide or to improve community access to local material resources (i.e. water, land, mineral and biological resources) and infrastructure (i.e. roads, sanitation facilities, schools, etc.).	LC7.1. Support to the community in tangible resources improvement (roads, electrification, buildings, related services) LC7.2. The farm activity represent low risk to tangible resources of the community, such as water, soil, other resources LC7.3. Evidence of environmental management systems or responsible practices
8	Safe and Healthy Living Conditions	This subcategory assesses how organizations impact community safety and health. This includes the general safety conditions of operations and their public health impacts.	LC8.1. Absence of environmental or physical incidents related to the farm (pollution Events, damage of infrastructure) LC8.2. Absence of health-related incidents due to the farm LC8.3. Support for improved security and health local conditions
9	Secure Living Conditions	This subcategory assesses how organizations impact the security of local communities with respect to the conduct of private security personnel and how the organization interacts with state-led forces.	LC9.1. Evidence of policies related to responsible security personnel practices (weapon possession and permits, training). LC9.2. Absence of incidents related to security personnel of the farm (shootings, abuse of authority, violence) LC9.3. Absence of fatalities related to security personnel of the farm