Application of the TEEB for Agriculture and Food (TEEBAgriFood) Framework;

Case of cocoa and coffee agroforestry value chains in Ghana and Ethiopia

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Acronyms and Abbreviations

AF	Agroforestry
BOD	Biological oxygen demand
COD	Chemical oxygen demand
CO2e [1]	Carbon dioxide equivalent
CMC	Cocoa marketing company
CPI	Consumer price index
COCOBOD	Ghana cocoa board
CSSVD	Cocoa swollen shoot virus disease
ECTA	Ethiopian Coffee and Tea Authority
ES	Ecosystem services
ECX	Ethiopian Commodity Exchange
ETB	Ethiopian Birr
FOB	Freight on Board
GH Cedis	Ghana Cedis
GHG	Greenhouse gases
GoG	Government of Ghana
HTP	Human Toxicity Potential
ILO	International Labour Organization
LBCs	Licensed buying companies
LCA	Life-cycle Assessment
PPP	Purchasing Power Parity
REDD+	Reducing Emissions from deforestation and forest degradation
TEEB	The Economics of Ecosystems and Biodiversity
TEEBAgriFood	The Economics of Ecosystems and Biodiversity for Agriculture & Food
TDS	Total Dissolved solids
TSS	Total suspended solids
USD	US dollar

[1] To convert one tonne C to one tonne CO2e a conversion factor of 3.67 is used.

1. Introduction

Agricultural ecosystems are actively managed by humans to optimize the provision of food, fiber and fuel (Zhang *et al.* 2007). Nonetheless, they generate large and unacceptable impacts on the environment and on vulnerable populations. According to Sukhdev *et al.* (2016), food systems are the source of 60% of terrestrial biodiversity loss, 24% of greenhouse-gas emissions, 33% of soil degradation and 61% of the depletion of commercial fish stocks. Generally, agricultural ecosystems provide both services and dis-services and the flows of these services and dis-services directly depend on how agricultural ecosystems are managed and upon the diversity, composition, and functioning of remaining natural ecosystems in the landscape (Zhang *et al.* 2007).

Quantification and valuation of ecosystem services is beneficial for policy making since the economic and social contribution of these services would be well articulated. Various policy instruments can be designed to create demand for ecosystem services, such as cap and trade on carbon emissions, wetland and biodiversity banking, payments for ecosystem services and environmental certification (Sandhu *et al.* 2012). Another reason for valuing ecosystems services is to highlight the invisibility of nature in decision making (TEEB 2015). Most of the ecosystem services may be "invisible" since they may not affect stakeholders directly or because there are no functional markets for these services. However, by valuing them we are able to account for them.

There is also a gap in the identification and valuation of ecosystem services within the entire agricultural value chain. Most studies on economic valuation of ecosystem services within agricultural and food systems focus exclusively on the production stage even though other value chain processes also contribute positively or negatively to the ecosystem. There are externalities in the way food is produced, processed, distributed, and consumed. These externalities - both positive and negative - are rarely captured in conventional economic analyses, which usually focus on the production and consumption of goods and services that are traded in markets (TEEB 2018). Thus, for this study we identify and value ecosystem services within the entire agroforestry cocoa and coffee value chain in Ghana and Ethiopia, respectively from production, processing and distribution to consumption.

To fully conceptualize and identify the ecosystem services from the value chain, we apply "The Economics for Ecosystems and Biodiversity for Agriculture and Food (TEEBAgriFood)" Framework due to Obst and Sharma (2018). The Framework highlights all relevant dimensions of the eco-agrifood value chain and pushes policymakers, researchers, and businesses to include these in decision-making. These dimensions include social, economic, and environmental elements as well as inputs/outputs across the value chain. The Framework therefore establishes all of "what should be evaluated" (TEEB 2018).

The remaining part of this section presents a brief description of cocoa and coffee in Ghana and Ethiopia, respectively, and outlines the objectives of the study. Section 2 presents the scope of the study for both coffee in Ethiopia and cocoa in Ghana while section 3 provides a description of the methods and data used. Section 4 and 5 presents and discusses the results for agroforestry cocoa in Ghana and agroforestry coffee in Ethiopia, respectively. Section 6 discusses the limitations of the study and the research gaps and finally section 7 concludes and outlines the policy recommendations arising from the study.

1.1. Cocoa in Ghana

Cocoa serves as the major source of revenue for the provision of socioeconomic infrastructure in Ghana. The cocoa industry employs about 3.2 million people along its commodity chain and accounts for 25% of foreign exchange earnings (Essegbey and Ofori-Gyamfi 2012). In terms of employment, the industry employs about 60% of the national agricultural labour force and contributes about 70–100% of their annual household incomes (Ntiamoah and Afrane 2008). Similarly, cocoa contributes substantially to the country's GDP as shown in Figure 1.

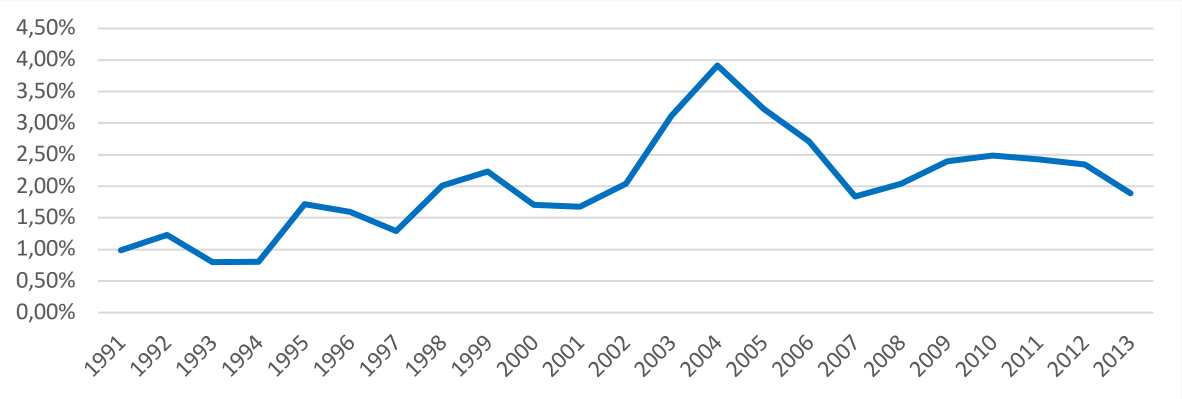

Figure 1: Cocoa contribution to GDP in Ghana
Data source; FAOSTAT Database

Cocoa occupies 1.7 million hectares in Ghana, second only to Côte d'Ivoire in the world (FAOSTAT 2017). Even though cocoa farming is one of the country's dominant land-use activities, it is characterized by relatively small landholdings that range from 0.4 to 4 hectares. Over the last three decades, cocoa produced in Ghana has increased significantly, total cocoa produced in 2017 is almost six times the amount produced in 1987. As shown in Figure 2, the trend for area harvested mirrors the total production trend implying that the increase in cocoa produced is majorly from an increase in area under production as opposed to an increase in yield. The area under cocoa in Ghana has more than doubled over the last 30 years. The average cocoa yields in these West African countries including Ghana however remain relatively low due to low input use, inadequate maintenance and pest & disease control, little or no fertilizer use and the old age of cocoa farms (Wessel and Quist-Wessel 2015).

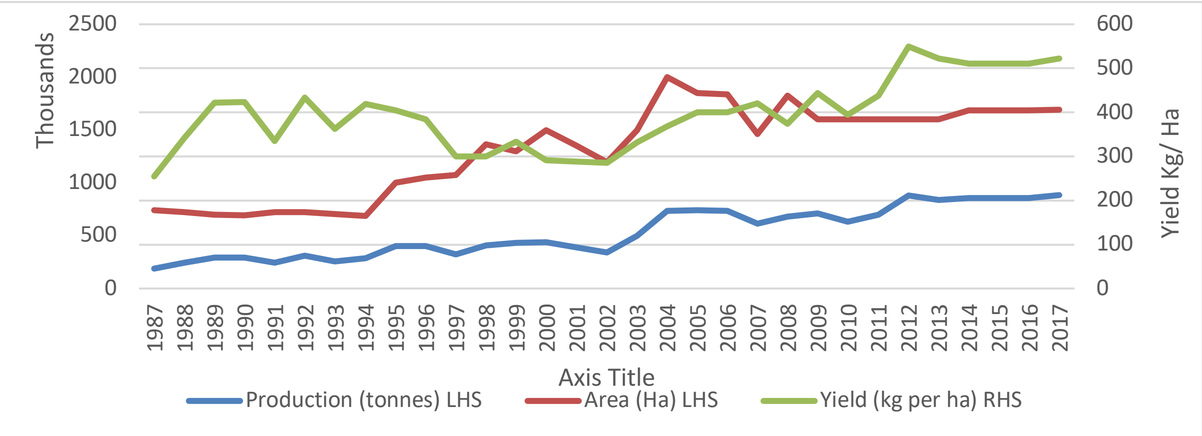

Figure 2: Production and area harvested trends for cocoa in Ghana
Data source; FAOSTAT Database

Cocoa has played a key role in the conservation of forests and their biodiversity in Ghana, both negatively and positively. On one hand, cocoa has been an important factor in forest conversion for agriculture (Asare 2006). The rapid expansion of extensive cocoa production systems in the last two decades has been found to be a major cause for deforestation and forest degradation in West Africa (Obiri *et al.* 2007; Gockowski and Sonwa 2011). On the other hand, shaded cocoa provides valuable secondary habitat for forest fauna and flora in agricultural landscapes (Schroth and Ruf 2004). It is estimated that 50% of the cocoa farming area is under mild shade in Ghana, while about 10% is managed under no shade. Overall, the last decades have seen a decrease in the use of shade in cocoa in West Africa (Ruf 2011; Läderach *et al.* 2013). Shaded cocoa is mostly defined as having more than 50% of its tree canopy above the cocoa canopy and full sun cocoa defined as any farm with fewer than 13 shade trees per ha (Gockowski and Sonwa 2011). Most often, cocoa is inter-cropped with food crops such as plantain within full-sun production systems. A High-Tech (plantation) cocoa production system on the other hand is an intensive cocoa production system and it involves high input use and is in most cases without any shade (Gockowski *et al.* 2013).

Ghana's cocoa beans are primarily exported for processing into cocoa butter, liquor, and powder for chocolate confectionery, and used in cosmetics and beauty products (Deans *et al.* 2018). Representing a global value chain, cocoa has become the country's most important agricultural export commodity and a vital contributor to Ghana's development (Kolavalli and Vigneri 2011). The livelihoods of 30% of the population depend upon the cocoa sector (Gockowski *et al.* 2011). As shown in Figure 3, Ghana's contribution to total world cocoa has been rising over the last three decades from approximately 9% in 1987 to about 17% in 2017. Ghana's contribution to global cocoa production is second only to Cote d'Ivoire which contributes about 39% of the world's total cocoa as of 2017 (FAOSTAT data). This highlights the role of Ghana's cocoa production within the global cocoa value chain - changes in world cocoa prices directly affect cocoa prices in Ghana.

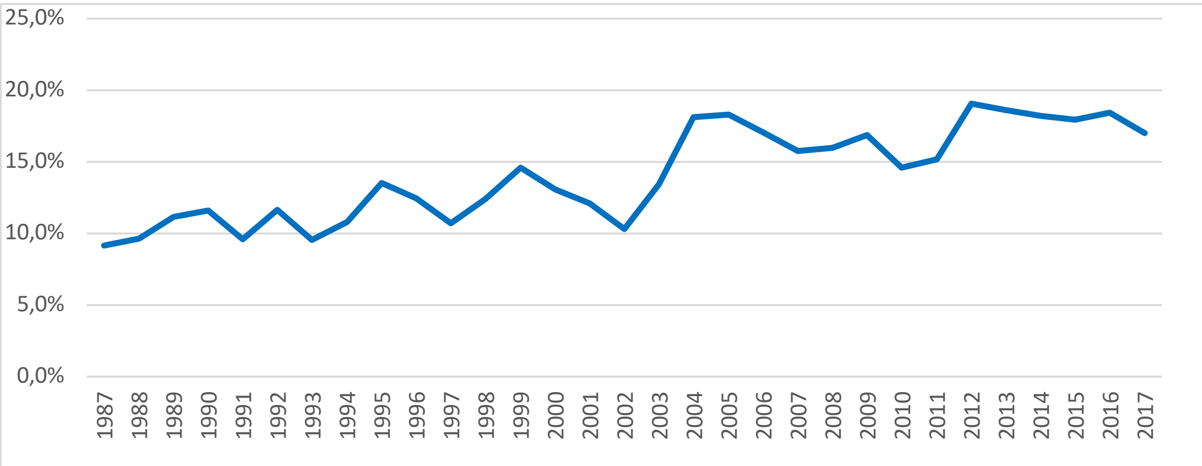

Figure 3: Ghana's contribution to total world cocoa over the years
Data source; FAOSTAT Database

In contrast to other cocoa-producing countries, Ghana only partially liberalized its cocoa market (Kolavalli and Vigneri 2018). Ghana's parastatal Cocoa Board (COCOBOD), continues to be a major actor with control throughout the Ghanaian part of the cocoa value chain, setting prices and minimum standards, and licensing buying companies (Deans *et al.* 2018). Farmers sell cocoa beans to Licensed

Buying Companies (LBCs), who transport the beans from villages to the marketing subsidiary of COCOBOD - Cocoa Marketing Company (CMC). CMC exports cocoa and sells it to domestic processors. Most of the cocoa produced in Ghana is exported, for example, during the 2013/14 season, Ghana exported 80.5% of its cocoa in the form of raw beans and sold the rest to the domestic processors (COCOBOD 2014). The cocoa beans sold to the domestic processors are processed into semi-finished products such as liquor, butter and powder, of which 95% is exported. The remaining 5% is used for cocoa beverages, toffees and chocolate destined for the local markets (Camargo and Nhantumbo 2016). There are also a limited number of domestic efforts to process cocoa by-products (husks, shells, cocoa pulp) as well as inferior quality beans into various finished products not traditionally associated with cocoa such as shampoos, soaps, alcohol, etc.

1.2. Coffee in Ethiopia

Coffee accounts for 60% of Ethiopia's exports and the government estimates that about 15 million households depend either directly or indirectly on coffee for their livelihood. More importantly, about 25% of the Ethiopian population is engaged in coffee production, processing and marketing services, and derive their livelihood from these systems (Ethiopian coffee and Tea Authority (ECTA) 2018). These coffee production systems play a critical role in supporting socioeconomic aspects of millions of people in Ethiopia. In the main coffee growing areas, such as the Yayu Coffee Forest Biosphere Reserve, about 87% cash revenue is earned from non-timber forest products such as coffee, honey and spices of which coffee accounts for over 70% (Seyoum 2010). If there is a market for the diverse coffee genetic resources globally, Ethiopia can earn up USD 1.5 billion per year, by providing useful genes to the major producers worldwide (Hein and Gatzweiler 2006).

Globally, Ethiopia contributes a substantial proportion of the world's coffee. As shown in Figure 4, Ethiopia's contribution to total world coffee has been on the increase over the last two decades, contributing to about 5% of the total world's coffee as of 2017. Ethiopia mainly exports green coffee beans; roasted beans account for less than 0.05% of exports (ECTA 2018). As of 2018, Ethiopia was the largest coffee producing and exporting country in Africa[2].

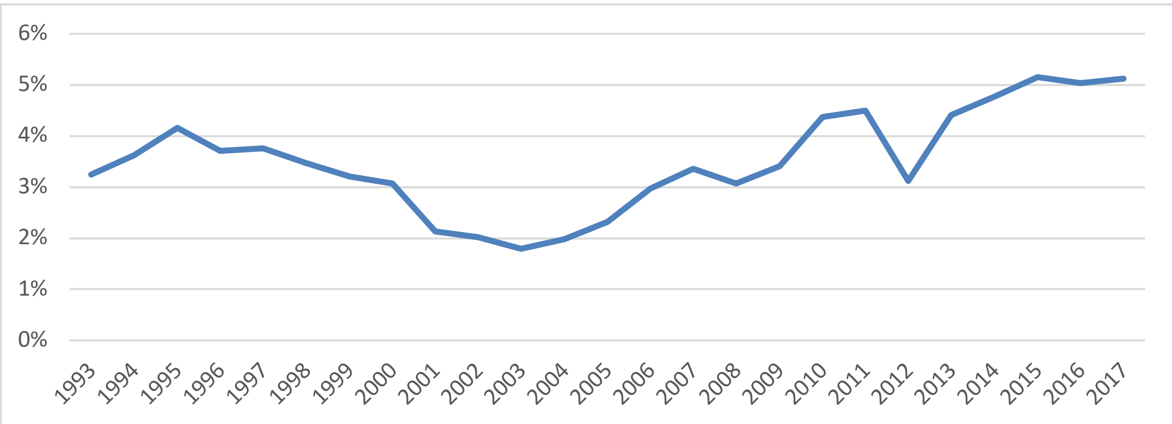

Figure 4: Ethiopia's contribution to total world coffee

Data source; FAOSTAT Database

[2] https://www.worldatlas.com/articles/top-coffee-producing-countries.html

The coffee sector in Ethiopia is largely a smallholder sector with 95% of production occurring on small family farms with an average farm size of less than 2 ha, and the remainder on large plantations (Mitiku *et al.* 2017; Hirons *et al.* 2018). As shown in Figure 5, total coffee production in Ethiopia has been rising continuously over the years from approximately 180 million tonnes in 1993 to about 471 million tonnes in 2017. Similarly, the area under coffee in Ethiopia has been rising over the years, in 2017 it had more than doubled compared to 1993. The coffee yield in Ethiopia has however not changed substantially over the years. Thus, the increase in coffee production in Ethiopia has mostly been due to land expansion as opposed to intensification. The country has an additional 5.47 million hectares of land potentially suitable for growing coffee (Ethiopian coffee and Tea Authority (ECTA) 2018).

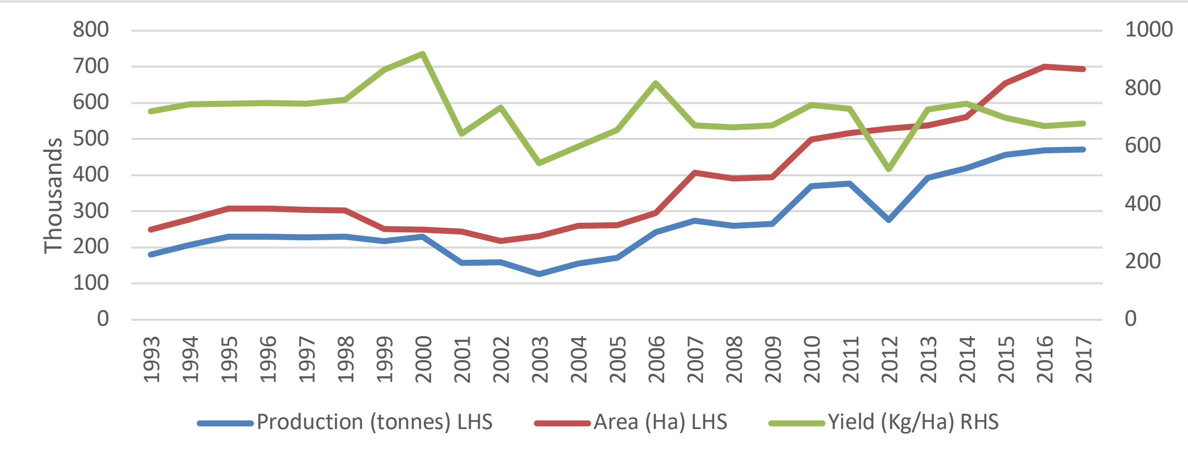

Figure 5: Coffee production, area harvested and yields in Ethiopia over the years
Data source; FAOSTAT Database

Coffee production in Ethiopia constitutes; forest coffee 10%, semi-forest coffee 30%, garden coffee 50% and plantation coffee accounts for 10% (Amamo 2014). Forest coffee is a wild coffee growing under the shade of natural forest trees with no defined owner. Semi-forest coffee is also grown under forest shade, but with clear ownership established by deliberate thinning and pruning of trees and weeding the forest area. Semi-forest coffee is organically produced and grown in the forest under the canopy of shade trees. The forest is thinned out to give the coffee plants more space. As the agronomic conditions are near optimal, only some minimum husbandry practices are needed to produce very fine Arabica coffee (Reichhuber and Requate 2012). Garden coffee on the other hand is normally grown in the vicinity of a farmer's residence and is inter-cropped with other staple crops or trees, with some organic fertilizer input. Garden coffee is also called coffee home garden and it involves numerous prototypes with varying shares of coffee shrubs, trees, other foods and cash crops (e.g. khat and sugar cane) and wild foods (e.g. bush meat) (Abebe *et al.* 2013). Coffee home gardens provide both food and cash benefits throughout the year. Plantation coffee is grown on large commercial farms, private as well as state farms and uses highly intensified agronomy practices; pruning, mulching and organic fertilizing, stumping, integrated weed and pest management, well-regulated shade and plant density, and farmers also use high-yielding and disease resistance varieties. Plantation coffee has been on a rising trend in Ethiopia since 2009 (Duguma et al. 2019).

1.3. Objectives and purpose of the study

This study aims to identify and estimate the monetary value of the impacts of agroforestry cocoa and coffee value chains to natural capital, human capital, financial capital and social capital based on case studies from Ghana and Ethiopia respectively. This is done by comparing the impacts and flows between different cocoa and coffee production systems at the production stage. We also extend this to valuing the impacts along the cocoa and coffee value chains in Ghana and Ethiopia, respectively. To fully conceptualize these impacts and dependencies, we applied the TEEB for Agriculture and Food (TEEBAgriFood) Framework.

Specific objectives include:

a. Comparison of impacts/benefits between different cocoa and coffee production systems (agroforestry system versus other production systems).
b. Quantifying and/or qualifying the impacts and dependencies on natural, social, produced and human capital along the cocoa and coffee value chains in Ghana and Ethiopia, respectively.
c. Valuing the negative and positive impacts to health, ecosystems and the economy of the processes associated with the value chains of the two commodity crops.
d. Identifying opportunities for evidence-based policy support in enhancing positive impacts and discouraging negative impacts.

2. Scope of the study

2.1. Value chain scope for cocoa in Ghana

Figure 6 presents a summarised cocoa value chain for Ghana sourced from Sutton and Kpentey (2012). The cocoa value chain in Ghana can be sub-divided into four phases, starting at the cultivation of the cocoa beans and ending at the consumption of the final chocolate product. The first phase is the production of the cocoa beans which takes place in Ghana at the location where the cocoa trees grow. The second phase is the processing of cocoa beans and manufacturing which generally takes place in other countries mostly in Europe. The manufacturing phase is where the cocoa is prepared for confectionary consumption. The third phase is the marketing and distribution of the cocoa products and transport is a key process in this phase. Finally, the fourth phase involves consumption which mostly occurs outside Ghana. The worldwide sales of chocolate were estimated to be worth more than USD101 billion in 2015 with Europe accounting for 45% of the global consumption (Konstantas *et al.* 2018).

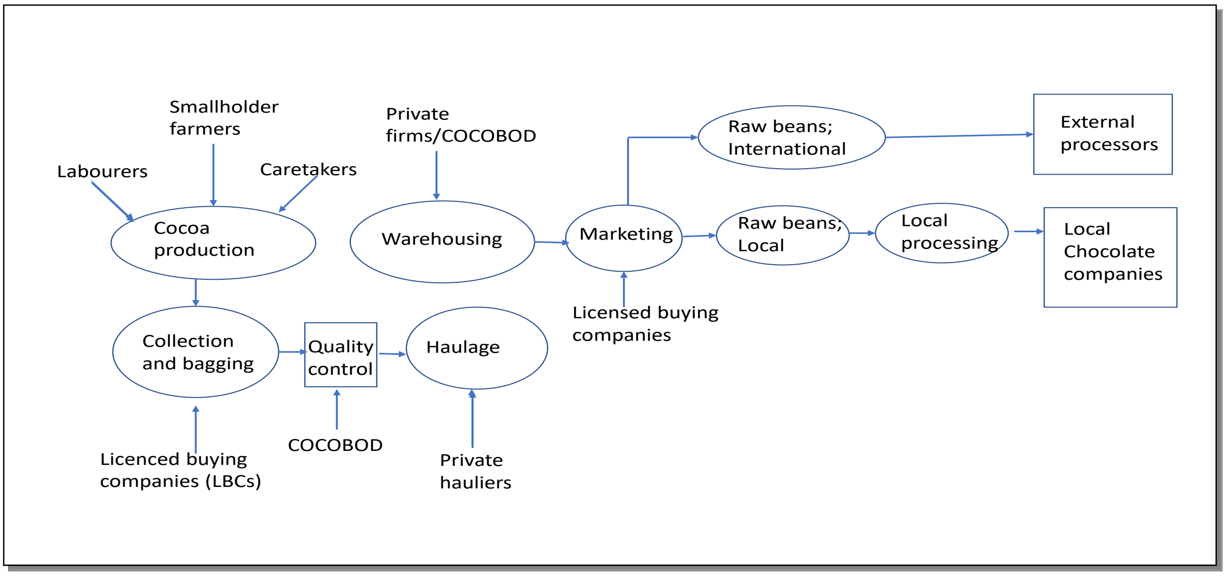

Figure 6: Ghana cocoa supply chain
Source; Sutton and Kpentey (2012)

The cocoa sector in Ghana is partially liberalised, but Ghana's cocoa board (COCOBOD) still has a monopoly on cocoa marketing and export through its subsidiary, the Cocoa Marketing Company (CMC) (Camargo and Nhantumbo 2016). The upstream collection of cocoa (from farmers to COCOBOD warehouses) was privatised, but all processes in the supply chain are still coordinated by this body (Camargo and Nhantumbo 2016). COCOBOD has the sole responsibility for the sale and export of Ghanaian cocoa beans, and it fixes the farm-gate price of cocoa every year before the commencement of the cocoa season in consultation with key stakeholders, including farmers' representatives. It takes into account the world price before coming up with the price it can offer to farmers for the entire crop year. The Government of Ghana (GoG) has as its policy to offer farmers at least 70% of Freight on Board (FOB) price. Farm-gate prices in Ghana are fixed by a Producer Price Review Committee (PPRC) made up of COCOBOD officials, a farmers' representative, government representatives and representatives of the LBCs. Producer prices follow the world market price and include the premium

that Ghanaian cocoa receives for its quality, as well as deductions for services provided by COCOBOD (Foundjem-tita *et al.* 2016).

COCOBOD also provides phyto-sanitary support to farmers and regulates the marketing of bulk Ghanaian cocoa on international markets. This has helped to maintain the quality of Ghanaian bulk cocoa, which earns an international price premium of between 7% and 10% above the price paid for other West African origin bulk cocoa (Owusu-Amankwah 2015). Table 1 presents the activities and actors involved within the cocoa value chain in Ghana.

Table 1: Actors within the cocoa value chain in Ghana

Activity	**Actor**	**Output**
Input supply	Private input dealers	Seeds, fertilizers, pesticides, fungicides
	COCOBOD	
Production	Farmers	Cocoa beans
Internal marketing	Licensed Buying Companies (LBCs)	Purchases of cocoa beans from farmers and delivers it to COCOBOD
Transportation	LBCs	Transportation of cocoa beans
	Hauliers	
Exports	COCOBOD	Exporting of cocoa beans
Processing	Processors	Cocoa powder, chocolate, cocoa butter, liquor, cakes, beverages
Cocoa waste marketing	Cocoa waste companies	Exporting of inferior cocoa and cocoa waste
Retail	Big supermarkets	Delivering of products to consumers
	Small retailers	
	Table-tops	

Reproduced from Monastyrnaya et al. (2016)

2.2. Value chain scope for coffee in Ethiopia

Figure 7 presents the detailed value chain for coffee in Ethiopia adapted from Hirons et al. (2018). Below is a brief discussion of the various stages that Ethiopian coffee goes through from tree to cup/export market.

Production

Coffee production in Ethiopia constitutes; forest coffee 10%, semi-forest coffee 30%, garden coffee 50 % and plantation coffees 10% (Amamo 2014). The coffee sector in Ethiopia is largely a smallholder sector with 95% of production realized on small family farms with an average farm size of less than 2 ha, and the remainder on large plantations (Mitiku *et al.* 2017; Hirons *et al.* 2018).

Manufacturing and processing

There are two ways through which coffee in Ethiopia is processed; wet (fermented and washed) and dry (natural) processing. In Ethiopia, dry processing involves drying the coffee cherries naturally under the sun, which can take several weeks (Musebe *et al.* 2007; FAO 2014). Producers undertake the drying themselves, unless they sell the cherries as “fresh cherries.” Once the cherries are dried, producers then sell them to collectors, wholesalers or cooperatives. These actors then hull the cherries, to

remove the outer pulp, and obtain green beans that can be sold on the outer market (FAO 2014). The wet coffee processing procedure on the other hand requires mechanical removal of pulp with the help of water, as a result of it uses a lot of water and also produces a considerable volume of wastewater (Olani 2018). Wet processing produces higher quality coffee and it is increasingly becoming popular in Ethiopia (Woldesenbet *et al.* 2015). Wet processing can either be done using the hand pulpers or coffee washing machines (Musebe *et al*. 2007). In wet industrial processes, a large amount of coffee-pulp (about 29% dry weight of the whole coffee berry) is produced as the first by-product. However, for dry processing 0.18 tonnes of coffee husks are generated for every tonne of fresh coffee berries. Thus, wet processing yields more environmental costs compared to dry processing (Olani 2018).

Marketing and Distribution

There are two streams of coffee marketing in Ethiopia, the Ethiopian Commodity Exchange (ECX) and the co-operative structure; which are co-ordinated and regulated by the state through the Ministry of Trade and Co-operative Promotion Agency respectively (Hirons et al. 2018). The Ethiopian Commodity Exchange (ECX) is a private-public enterprise established in 2008 in response to concerns regarding markets for products such as coffee, low market penetration into rural areas, high transaction costs, and risks associated with a lack of quality assurance particularly prevalent (Gelaw et al. 2017; Hirons et al. 2018). Coffee is sold into local markets in small towns, where the price is fixed relative to prices in national and international markets (i.e. the price cannot be negotiated between farmers and traders), and then transported to regional ECX centres where it is graded for quality and then stored in the Addis Ababa warehouse before export (Gelaw et al. 2017). Farmers can also join co-operatives and sell their coffee there. Co-operatives are licensed and regulated by the Co-operative Promotion Agency and organised into collectives, known as Co-operative Unions. These unions can sell coffee through the ECX or export directly. Co-operatives are highly promoted by the government in Ethiopia because the co-ordination of farmers can deliver benefits in terms of navigating market fluctuations (Hirons et al. 2018). Exporters purchase their coffee from the wholesalers in the ECX markets or through the co-operatives. The selling prices of the exporters are largely determined by the international market price (New York Price) (Shumeta et al. 2012).

Consumption

Approximately 40-50% of the coffee produced in Ethiopia is consumed domestically while the rest is exported (Mitiku *et al.* 2017; Hirons *et al.* 2018). There is however a difference in quality between coffee for the local market and export coffee. In an attempt to increase coffee exports and earnings, the government prohibits the sale of export quality coffee on the local market (Mitiku *et al.* 2017). Ethiopian coffee exports in 2016/17 reached 58 countries. European countries took the lion’s share accounting for 43% of total coffee export. Export to Middle Eastern, Asian and African countries accounted for 21%, 15%, and 3% respectively. Export to the USA was 13%, while exports to Australia and New Zealand combined were 3% (ECTA 2018).

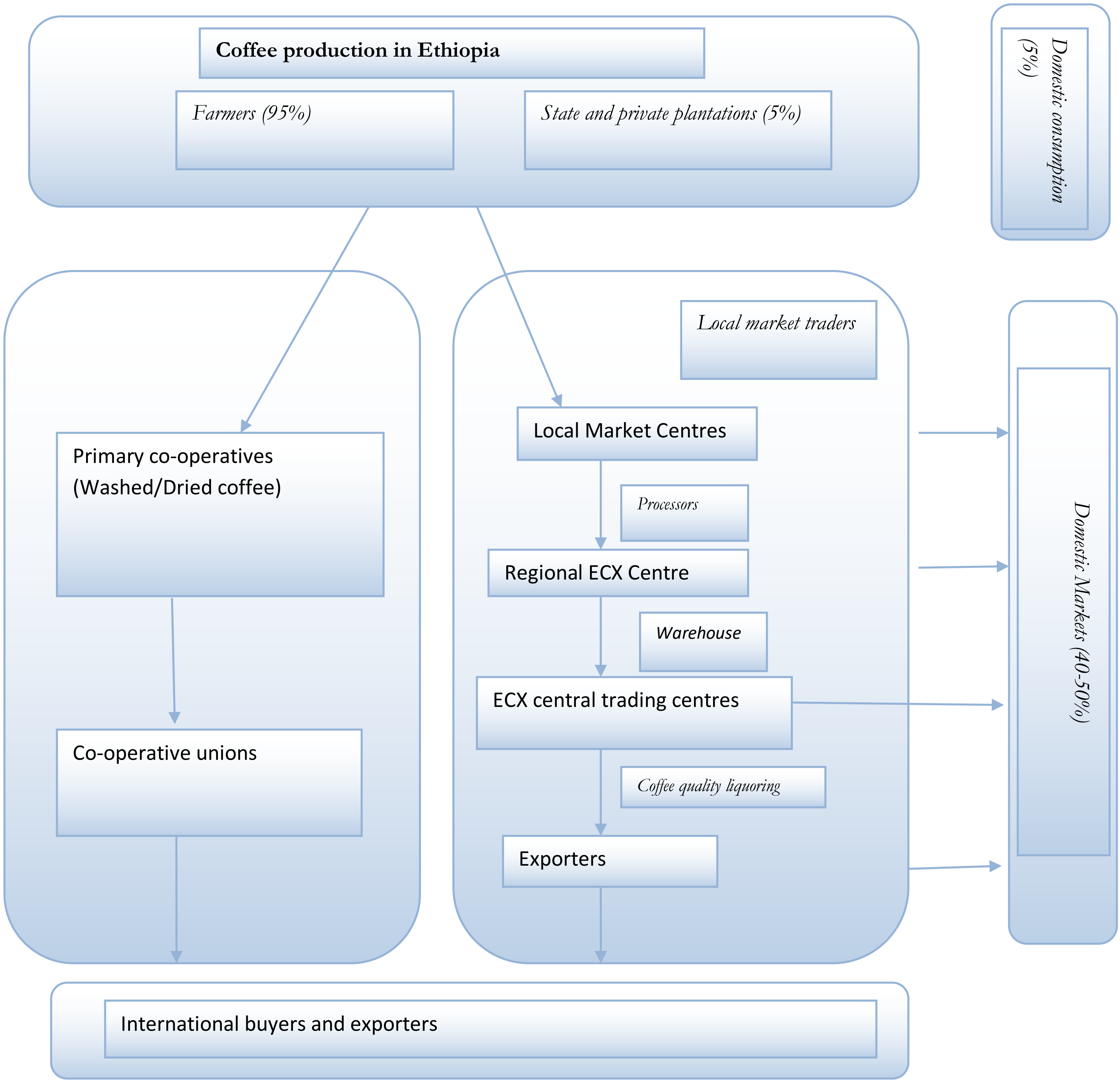

Figure 7: Coffee value chain in Ethiopia
Source; Hirons *et al.* (2018)

2.3 Cocoa growing areas in Ghana

Cocoa cultivation has spread across six regions of Ghana: Eastern, Ashanti, Brong-Ahafo, Central, Volta and the Western region as shown in Figure 8. Due to fluctuating rainfall and decreasing fertility of soils, production has moved westward to the point where the Western region is now Ghana's main producer of cocoa[3].

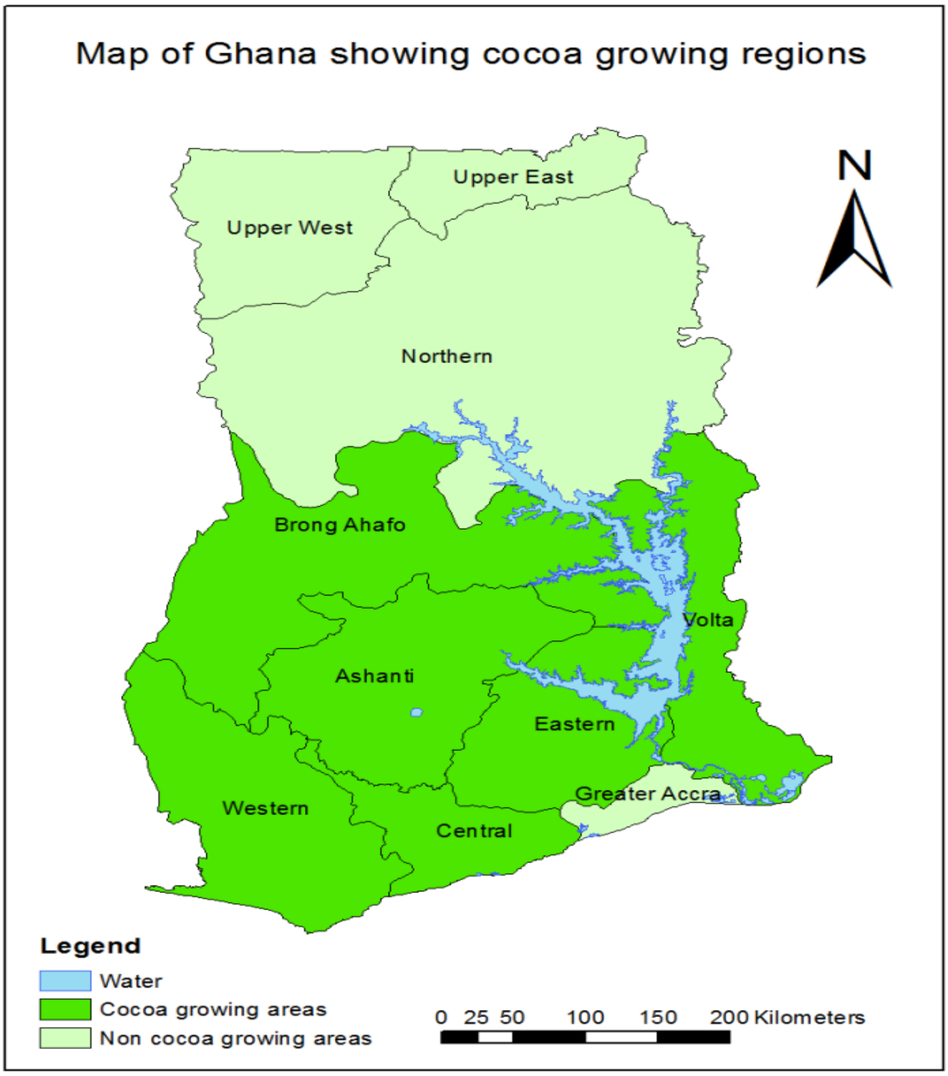

Figure 8: Map of Ghana showing the cocoa producing regions
Source; Lartey (2013)

2.4. Coffee growing areas in Ethiopia

For this study, we do not focus on one specific coffee growing zone, instead we generalize for all coffee growing areas. Figure 9 shows the location of the main coffee growing areas in Ethiopia sourced from Moat *et al.* (2017).

[3] https://onthecocoatrail.com/2014/06/12/cocoa-is-ghana-ghana-is-cocoa/

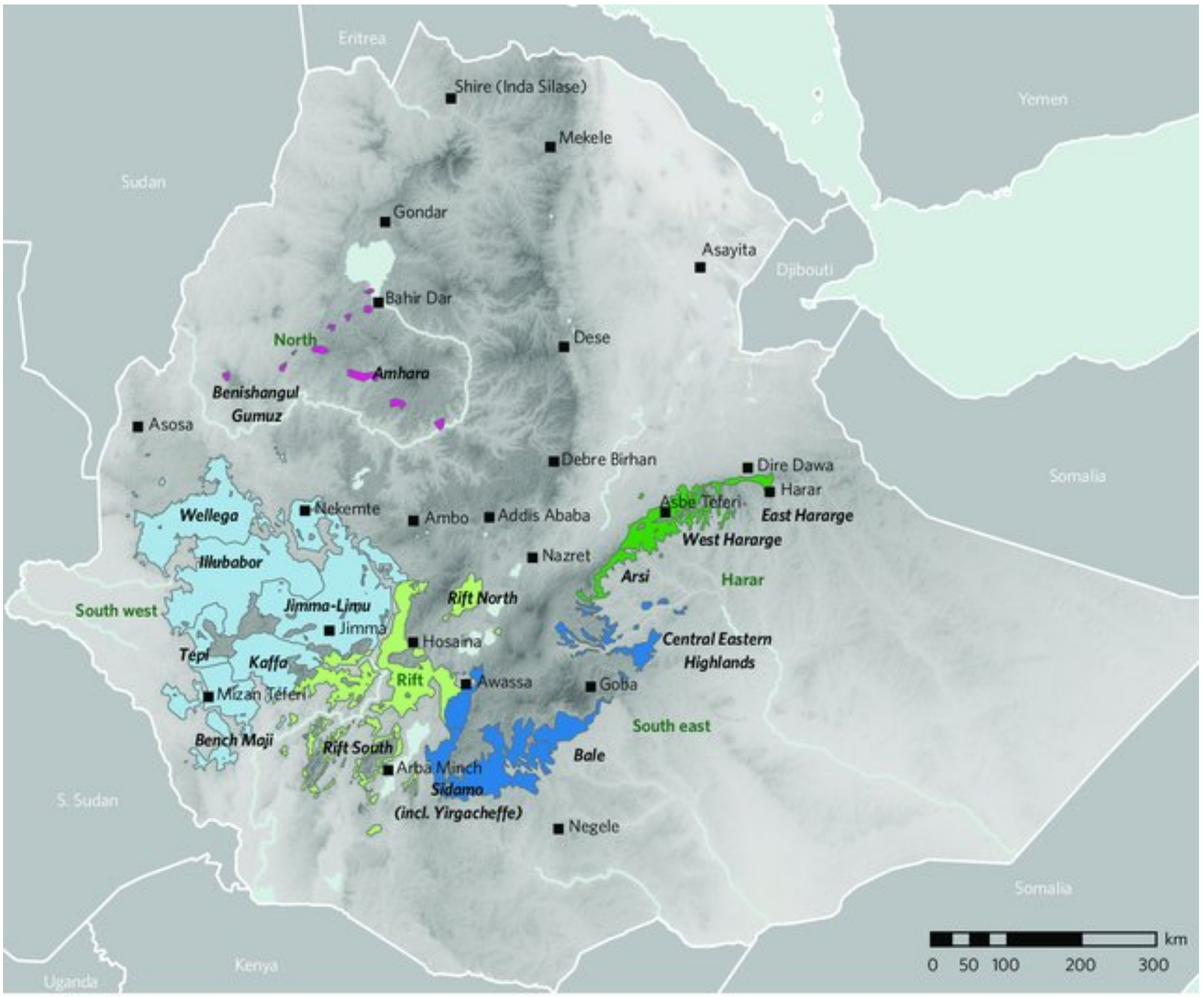

Figure 9: Coffee growing areas in Ethiopia

The coffee zones represented by coloured polygons: red/pink, North Zone (coffee areas: Amhara and Benishangul Gumuz); light blue, South West Zone (coffee areas: Wellega, Illubabor, Jimma-Limu, Kaffa, Tepi and Bench Maji); light green, Rift Zone (coffee areas: Rift North and Rift South); dark blue, South East Zone (coffee areas: Sidamo, Yirgacheffe, Bale and Central Eastern Highlands); dark green, Harar Zone (coffee areas: Arsi, West Hararge and East Hararge) (Moat *et al.* 2017).

3. Methodology

3.1. TEEBAgriFood Evaluation framework

To effectively capture the negative and positive impacts to health, ecosystems and the economy of the processes associated with the cocoa and coffee value chains, we apply the TEEB for Agriculture and Food (TEEBAgriFood) Framework explained in TEEB (2018). The Framework highlights all relevant dimensions of the eco-agrifood value chain and pushes policymakers, researchers, and businesses to include these in decision-making. These dimensions include social, economic, and environmental elements as well inputs/outputs across the value chain. The Framework therefore establishes all of "what should be evaluated" (TEEB 2018). The TEEBAgriFood Evaluation Framework[4] defines the four elements - stocks, flows, outcomes and impacts - that support a standardised evaluation of eco-agri-food systems. In providing these definitions and associated measurement concepts and boundaries, the Framework establishes *what* aspects of eco-agri-food systems should be included within a comprehensive evaluation or assessment. The elements of the framework include:

i. Stocks

The stocks provide the capital base for production. The TEEBAgriFood Framework classifies stock to align with four types of capital - produced capital, natural capital, human capital and social capital. According to Obst and Sharma (2018):

- **Produced/financial capital** incorporates all manufactured capital such as buildings, machines and equipment, physical infrastructure (roads, water systems), the knowledge and intellectual capital embedded in, for example, software, patents, brands, etc., and financial capital.
- **Natural capital** refers to the limited stocks of physical and biological resources found on earth, and of the limited capacity of ecosystems to provide ecosystem services. It includes all mineral and energy resources, timber, fish and other biological resources, land and soil resources and all ecosystem types (forests, wetlands, agricultural areas, coastal and marine, etc.). The connection between natural capital and eco-agri-food systems can be seen from two perspectives: the role that natural capital plays in supporting agricultural production, and the effects that agricultural production has on the condition of natural capital.
- **Human capital** refers to the knowledge, skills, competencies and attributes embodied in individuals that facilitate the creation of personal, social and economic well-being.
- **Social capital** encompasses "networks together with shared norms, values and understandings that facilitate cooperation within or among groups. It is seen as a form of capital that enables the production and allocation of other forms of capital.

ii. Flows

Flows include capital inputs (including inputs from produced capital, labour from human capital, ecosystem services from natural capital and inputs from social capital); flows of goods and services through the agri-food system (including agricultural and food products and manufactured input such as fertilizers, pesticides, fuel and electricity); and residual flows arising from production and consumption activity such as GHG emissions, excess nitrogen, harvest losses and food waste (Obst and Sharma 2018). Obst and Sharma (2018) classifies the flows along the value chain into:

[4] Examples of detailed TEEBAgriFood frameworks (for cocoa and coffee) are presented in the annex (Table A1 and Table A2.

- **Agricultural and food outputs** which include all the agricultural and food products produced, value added incomes throughout the value chain, subsidies, taxes and interests earned/incurred throughout the value chain.
- **Purchased inputs** which include labour used throughout the value chain as well as other inputs used e.g. land, water, energy, fuel costs, packaging materials and so on.
- **Ecosystem services** which are categorized into provisioning services (e.g. biomass growth, fresh water), regulating services, supporting services and cultural services.
- **Residuals** which include greenhouse gas emissions, other emissions to air, soil and water, waste water and solid waste and other residuals.

iii. Outcomes and impacts

Outcomes are fully reflected as changes in the extent or condition of the stocks of capital due to value chain activities and hence can be described in terms of the changes in the four types of capital – produced, natural, human and social. These changes may be positive, i.e. through increases in the stock of capital, or they can be negative (Obst and Sharma 2018).

By applying this framework, we identified several "visible" and "invisible" benefits and costs within these value chains. The "invisible" costs and benefits may affect or benefit either the person producing the externality only, the local community or the global community in some instances. Some of the invisible costs identified within the value chains include greenhouse gas emissions, waste water from coffee processing, pesticide residues on soils and water, and child labour among others. Identified invisible benefits include biological pest and disease control, pollination, carbon sequestration, water regulation and treatment, water footprint among others. Tables A3 and A4 in the annex presents a summary of these benefits and costs. We quantified most of these benefits and costs in monetary values except for some invisible benefits such as biodiversity, vegetative diversity and aquatic life diversity which were measured using diversity indices such as Shannon-H index, Simpsons index, species richness index, Alpha index and so on.

3.2. Valuation of Ecosystem services

There are a variety of methods used to estimate both the market and non-market component of ecosystem services (ES). For most of the ecosystem services we used data collected in the respective countries and valued them. However, for some where no data exists in the respective countries, we sourced data from other similar places and applied the benefit transfer method. Benefit transfer translates the monetary value determined from one place and time to make inferences about the economic value of ES at another place and time. In the absence of site-specific valuation information, benefit transfer is an alternative to estimating non-existing values. It adapts existing valuation information to new policy contexts, and it is principally useful when budgets and time constrain primary data collection. However, there are limitations to the use of benefit transfer, including the availability, reliability, and distribution of data on services and values across ecosystems, and variation in socioeconomic and geographic settings (Temesgen *et al.* 2018).

For the provisioning services and the direct costs, we applied the market price to value them. For the "invisible" costs and benefits, we use different approaches to value them as explained in the sub-sections. We used GDP deflators, consumer price index (CPI) and producers' price index (PPI) to adjust

the prices for inflation to reflect the value as of 2017 USD[5]. These parameters were sourced from the World Bank database[6]. However, for some ecosystem services and costs such as biodiversity and species diversity, the monetary values were not available, hence, we used other non-monetary measures to quantify them. We discuss the approaches used to quantify and/or value some of these ecosystems services which were cross-cutting for both agroforestry systems below[7].

3.2.1. Measuring biodiversity and aquatic species diversity

To quantify biodiversity within the agroforestry systems, we used diversity measures such as Shannon-index, Simpson's index and species richness index (Beyene *et al.* 2012; Vanderhaegen *et al.* 2015). Similarly to ascertain the levels of loss of aquatic life arising from waste water from production and processing we used the Shannon-H, Alpha and Simpson-D macroinvertebrate diversity index (Beyene *et al.* 2012).

3.2.2. Measuring and valuing water pollution

To assess the level of pollution in rivers from discharge arising from processing wastes and/or from pesticides and fertilizer use, we agreed upon physiochemical measures of toxicity and turbidity in water. We then compared them to the permissible levels by the World Health Organization (WHO) as well as country specific permissible levels. If the observed levels were higher than those recommended by WHO or the country, then the water bodies were considered polluted. These physiochemical parameters include:

i. *Biological oxygen demand (BoD)*: This shows the amount of oxygen needed to biologically break down organic wastes in water (Woldesenbet and Woldeyes 2015). It is measured in mg/l and the WHO permissible level is 100mg/l.
ii. *Chemical oxygen demand (CoD)*: This shows the amount of dissolved oxygen required to combine with chemicals in the waste water (Woldesenbet and Woldeyes 2015). It is also measured in mg/l and the WHO permissible level is 300mg/l.
iii. *Total suspended solids (TSS)*: This measures water turbidity i.e. the concentration of suspended solids in water bodies. The level of TSS in water is also measured in (mg/l) and the recommended level by WHO is 200mg/l. In turbid waters, light penetration is reduced, leading to a decrease in photosynthesis. The resultant decrease in primary production reduces food availability for aquatic organisms higher up the food chain (Olani 2018).
iv. *PH*: The PH indicates the acidity levels of the water bodies. The WHO recommended PH levels are 6.5-7.5 which is about neutral.
v. *Nitrates and phosphates*: The levels of nitrates and phosphates in the water bodies are also measured in mg/l and the recommended WHO levels are 5mg/l for both.

Once we ascertained that rivers/water bodies were polluted we proceeded to value the cost of pollution. We applied the cost of treating the waste water as a proxy for the cost of water pollution.

3.2.3. Valuing health effects from water pollution or exposure to pesticides

The best approach to calculate health costs due to ailments is through estimating the quality adjusted life years (QALYs) and disease adjusted life years (DALYs) (Sassi 2006). However, for this study due to

[5] Conversion rate 1USD=4.722 Ghanaian Cedis, 1 USD=27.600 Ethiopian Birr.
[6] https://data.worldbank.org/indicator/FP.CPI.TOTL?locations=GH
[7] Further details on the ecosystem services are discussed in section 4 and 5 for cocoa and coffee, respectively.

data limitations, we could not compute the QALYs and DALYs. Instead, to estimate the value of negative health effects due to water pollution in Ethiopia and exposure to pesticides in Ghana, we used the treatment cost as a proxy. Several studies have previously applied treatment costs as proxies for health costs. Kouser *et al.* (2019) for instance, estimated the health cost of pesticide use in cotton among Pakistani farmers, and used the cost of treating the illnesses associated with pesticides use. Similarly, in estimating the health cost from pesticide use in eggplants among farmers in India, Krishna and Qaim (2008) used the cost of treating the illness (cost-of -illness) approach.

3.2.4. Valuing carbon estimates

The value of carbon is of great interest since carbon stock is one of the major natural capitals of interest. Greenhouse gas emissions are also vital residues within the cocoa and coffee value chains from production, processing, distribution and even consumption. To value carbon we use both the global market cost of carbon (estimated at USD 6.5 per tonne of CO2e) and the social cost of carbon (estimated at USD 41 per tonne of CO2e sourced from the Institute for Policy Integrity (2017)).

3.2.5. Measuring and valuing the water footprint

Water footprint is a relatively new environmental economic index, which shows processes related to water consumption, use, and virtual water flows both at the national and the international levels (Fogarassy *et al.* 2014). The concept and methodology of estimating the water footprint for different products is attributed to Chapagain and Hoekstra (2007) and Mekonnen and Hoekstra (2011). The water footprint has three components; green water, blue water and grey water.

1. Green water footprint refers to the consumption of the total rainwater evapotranspiration, from fields and plantations, and the water incorporated into the harvested crop or wood.
2. Blue water footprint shows the consumption of surface and groundwater.
3. Grey water footprint refers to pollution that is the quantity of water required to dilute pollutants.

During the water footprint calculation these are combined and completed with the basic processing water needs of each step of the production process. The index shows the actual, direct and indirect water usage measured on the whole value chain – only valid for the given area and period (Fogarassy *et al.* 2014). The water footprint is usually measured in volumes of water used (M^3). To value the reported water footprint level, we use the shadow prices of natural water in the respective countries. In Ethiopia, the shadow price was adopted from Gezahegn and Zhu (2014) estimated at 0.30 ETB (USD 0.0109) per M^3. However, for Ghana due to missing data on water shadow prices specific to Ghana, we applied the shadow price reported for Ethiopia.

3.3 Data sources

For this study we did not collect primary data, instead we used secondary data sourced from different publications within the study areas and outside of the study areas for some economic/ ecosystem services. Data was sourced from grey and peer-reviewed literature including Google Scholar, Web of Science, ResearchGate by searching for different key words. The review process is described below;

- We conducted a rigorous search process for all the economic and ecosystem services outlined in Table 2 and Table 3 for Ghana and Ethiopia, respectively. The review process included journal articles, working papers, technical reports, theses and book chapters.
- We narrowed down the search to specific agro-ecologies within Africa then we further narrowed down to Ghana and Ethiopia.
- We further filtered down the search to the specific research item as shown in Table 2 and Table 3.
- For the ecosystem services, for which we could not find studies conducted within Ethiopia and Ghana, we searched for research conducted in other countries with similar agro-ecologies and applied benefit transfer in valuing them.
- As explained earlier in section 2, most of the post-production processes within the cocoa and coffee value chain take place outside the study countries mostly in Europe. The search for the variables related to these processes were filtered to those countries.
- For data on valuation of health costs using treatment cost (cost- of- illness) approach, the search for treatment drugs and their respective costs was not restricted to any specific region.

Table 2 and Table 3 present the number of articles reviewed for different ecosystem services within the agroforestry cocoa value chain in Ghana and the agroforestry coffee value chain in Ethiopia, respectively. In this study, data sourced from the respective study countries accounted for approximately 86% and 80% for the case of cocoa in Ghana and coffee in Ethiopia, respectively, while the remaining was sourced outside the study countries. For the case of cocoa, the economic or ecosystem services for which substantially more articles were reviewed include: agricultural and food outputs (11), carbon stocks within the cocoa production systems (8), and input use in Ghana's cocoa production (7). On the other hand, few relevant publications were found on some ecosystem services and only one or two publications were reviewed. These include greenhouse gas emissions along the various stages of the cocoa value chain, pollination services, biological pest control and so on. In fact, for some of these we did not find any publication specific for Ghana's case and some of the data was sourced outside Ghana. Table A3 and A4 in the annex presents a summary of the source of data for the various ecosystem/economic services for both the cocoa and coffee case studies. Similarly, for the agroforestry coffee value chain in Ethiopia, we reviewed more articles for some services such as carbon stocks, agricultural and food outputs, as well as biodiversity in coffee production systems.

Table 2: Articles reviewed for various ecosystem services within the agroforestry cocoa value chain in Ghana

Economic/Ecosystem Services	Total number of references	Journal articles	Thesis	Working/ conference papers	Reports	Book chapters
Carbon stocks in Ghana’s cocoa systems	8	6			1	1
Soil nutrient stocks in Ghana’s cocoa systems	4	3				1
Biodiversity in Ghana's cocoa systems	5	3			1	1
Profitability of Ghana's cocoa production systems	2	1			1	
Benefit share to other actors within the cocoa value chain	2				2	
Health effects from pesticides exposure in Ghana	3	2	1			
Child labour in Ghana's cocoa production	4	1		2	1	
Health effects on children from child labour	1				1	
Gender issues in cocoa production	2				2	
Agricultural and food outputs in cocoa production systems in Ghana	11	8			2	1
Input use in Ghana's cocoa production	7	4	1	1	1	
Energy costs in cocoa processing in Ghana	1	1				
Water footprint in chocolate and other cocoa products (outside Ghana)	2	2				
Distribution of cocoa FOB costs within the value chain in Ghana	1				1	
Transport cost in the cocoa value chain (within Ghana and outside Ghana)	1	1				
Biological pest control in shaded cocoa (outside Ghana)	1	1				
Pollination (outside Ghana)	1					
GHGs emission during cocoa processing in Ghana	1	1				
GHGs emission during cocoa transportation (outside Ghana)	2	2				
GHGs emission during chocolate packaging (outside Ghana)	1	1				
GHGs emission during chocolate manufacturing (outside Ghana)	2	2				
GHGs for the entire chocolate value chain (outside Ghana)	2	1			1	
Pesticides emissions to water and soil during cocoa production in Ghana	1	1				
Waste residue in water from processing cocoa beans	1	1				

Table 3: Articles reviewed for various ecosystem services within the Agroforestry coffee value chain in Ethiopia

Economic/Ecosystem Services	Total number of references	Journal articles	Thesis	Working/ conference papers	Reports
Carbon stocks within coffee production systems in Ethiopia	7	7			
Water pollution levels from coffee processing waste in Ethiopia	6	5	1		
Cost of water pollution from processing waste (outside Ethiopia)	1	1			
Soil nutrients and soil fertility stock within coffee production systems in Ethiopia	3	3			
Vegetative diversity in coffee systems in Ethiopia	3	3			
Loss of aquatic life due to water pollution from processing waste in Ethiopia	2	2			
Profitability of different coffee production systems in Ethiopia	2	1			1
Certification premium from growing shaded coffee in Ethiopia	2	2			
Benefit share of profit margins in the Ethiopian coffee value chain	1	1			
Ailments due to processing waste discharged at water bodies	1	1			
Agricultural and food outputs in coffee production systems in Ethiopia	11	9			2
Inputs in coffee production systems in Ethiopia	4	4			
Water use during coffee processing in Ethiopia	4	3	1		
Water footprint within the coffee value chain (outside Ethiopia)	2	2			
Other direct costs incurred in coffee value chain from farm gate to export market	1				1
Soil erosion control and nutrient cycling in coffee AF in Ethiopia	1	1			
Pollination in coffee systems (1 in Uganda and 1 in Ethiopia)	2	2			
Water regulation and water treatment benefit from coffee AF in Ethiopia	1	1			
Biological pest and disease control in coffee AF (5 are outside Ethiopia)	6	6			
GHGs emissions from coffee processing (from Kenya)	1	1			
GHGs emissions from coffee transport (domestic and international)	1	1			
GHGs emissions of Ethiopian coffee post-export	1	1			

4. Cocoa agroforestry in Ghana

We apply the TEEBAgriFood Framework to value both monetary and non-monetary benefits in the cocoa agroforestry systems. For benefits and costs incurred at the production stage of the value chain, we compare shaded cocoa systems, full sun/un shaded and high-tech cocoa systems. Shade trees were defined as any tree with more than 50% of its canopy above the cocoa canopy and full sun cocoa was defined as any farm with fewer than 13 shade trees per ha (Gockowski and Sonwa 2011). High-Tech cocoa on the other hand is the intensive cocoa production system which involves high input use and is in most cases without any shade (Gockowski *et al.* 2013). For the subsequent stages of the value chain (i.e. manufacturing, processing, transport, consumption) we do not differentiate the systems.

4.1. Outcomes, stocks and impact on capital

This section will present the stocks and impact on the stocks (natural, social and human capital) arising from the different activities along the cocoa agroforestry value chain in Ghana.

4.1.1. Natural capital

These refer to the stocks of natural capital within the system. Most of the natural stocks discussed are in the production stage of the value chain. For cocoa systems, we discuss the following stocks; carbon stocks, soil nutrient stocks and biodiversity.

4.1.1.1. Carbon stocks (Above ground, below ground, soil carbon stocks)

Agroforestry systems have received increased attention as potentially cost-effective options for climate change mitigation due to their importance in carbon storage and sequestration, while also maintaining livelihoods. Table 4 presents above ground biomass carbon stock and the soil carbon stock in tonnes per hectare. The carbon stock levels were sourced from different studies conducted in cocoa production systems in Ghana and valued at the current market and social price of carbon. For shaded cocoa, the above ground carbon stock reported by various studies ranges from 15.8 tonnes C ha^{-1} to 25.8 tonnes C ha^{-1}. For unshaded cocoa the range is between 17.8 to 39.2 tonnes C ha^{-1}. The reported soil carbon stock levels are however higher within the shaded cocoa systems; ranging between 34.8 to 83.7 tonnes C ha^{-1} for shaded cocoa systems and from 33.3 to 99.8 tonnes C ha^{-1} for unshaded cocoa.

On average, the level of above carbon stocks is slightly higher for the unshaded cocoa system (25 tonnes C ha^{-1}) valued at approximately USD 519-3,276 per ha compared to the shaded systems (22 tonnes C ha^{-1}) valued at USD 601-3,791 per ha. Similarly, the average level of below ground carbon stock is higher for the unshaded cocoa systems, approximately 58 tonnes C ha^{-1} valued at USD 1,402-8,843 per ha compared to the shaded (53 tonnes C ha^{-1}) valued at USD 1,256-7,922 per ha. However, although the averages are higher for unshaded cocoa systems, a comparison within the same area using the same methods of measuring carbon stocks shows that above carbon stocks are higher within the shaded systems compared to the unshaded systems (Acheampong *et al.* 2014; Mohammed *et al.* 2016). Similarly, for below carbon stocks, a comparison within the same study area for example in Asase *et al.* (2008) shows higher soil carbon stocks within the shaded systems (51.4 tonnes C per ha) compared to the full sun systems (33.3 tonnes C per ha).

Table 4: Carbon stocks for cocoa agroforestry and full-sun systems (above ground and soil carbon stocks)

Service	System	Quantity tonnes C ha^{-1}	Value USD ha^{-1}	References
Biomass C stock	Moderate shade	23.74		Acheampong *et al.* (2014)
		15.77		Dawoe *et al.* (2016)
		25.8		Mohammed *et al.* (2016)
	Average	***21.77***	***519-3,276***	
	Full-sun	17.8		Mohammed *et al.* (2016)
		28.16		Gockowski and Sonwa (2011)
		39.2		Wade *et al.* (2010)
		16.9		Acheampong *et al.* (2014)
		23.9		Asase *et al.* (2008)
	Average	***25.19***	***601-3,791***	
Soil Carbon stock	Moderate shade	83.7		Mohammed *et al.* (2016)
		34.8		Dawoe *et al.* (2014)
		40.7		Dawoe *et al.* (2010)
		51.4		Asase et al. (2008)
	Average	***52.65***	***1,256-7,922***	
	Full-sun	99.8		Mohammed *et al.* (2016)
		43.2		Gockowski and Sonwa (2011)
		33.3		Asase *et al.* (2008)
	Average	***58.77***	***1,402-8,843***	

For valuation we use the market price of carbon (6.5 USD per tonne of CO2e) and the social cost of carbon (41 USD per tonne of CO2e). Conversion rate from tonnes C to tonnes CO2e is 3.67.

4.1.1.2. Soil nutrient stocks and soil fertility

Table 5 presents soil macro nutrient levels mainly nitrogen (N), potassium (K), and phosphorous (P) for shaded cocoa and un-shaded cocoa systems. Different sources report soil nutrients using different parameters, some as kg of the nutrient per ha, some as percentages and some as ug/g. Generally, the soil nutrient levels are higher within the shaded cocoa systems compared to the unshaded systems. For example, Blaser *et al.* (2017) compared soil nutrient levels (C, P, K and N) between shaded cocoa and unshaded cocoa in top soils in Ghana. The soils from shaded cocoa areas had on average significantly more C (by 20%) and more N (by 16%) compared to unshaded cocoa soils. However, there were no significant differences in total P and extractable K between soils in shaded cocoa systems and unshaded systems. A similar comparison by Asase *et al.* (2008) shows higher percentage soil N in moderately shaded cocoa systems (0.24%) compared to high tech cocoa systems (0.19%). Further still Asase *et al.* (2008) report substantially more available soil P stock in shaded cocoa systems (15.5 ug/g) compared to high tech systems (9.9 ug/g). This outlines the benefit of agroforestry systems in enhancing soil fertility.

Table 5: Soil nutrient stock for shaded and un-shaded cocoa production systems

System	Service	Quantity (per ha)	References
Shaded cocoa/moderate shade	Soil C	21.3 g kg^{-1}	Blaser *et al.* (2017)
	Soil N	2.3 g kg^{-1}	
	Available P	0.24 g kg^{-1}	
	Extractable K	31 mg kg^{-1}	
	Soil N stock	3360 kg	Dawoe *et al.* (2010)
		3190 kg	Dawoe *et al.* (2014)
	Average soil N stock	3275 kg	
	% soil N	0.24%	Asase *et al.* (2008)
	Available P stock	3.69 kg	Dawoe *et al.* (2014)
		15.5 ug/g	Asase *et al.* (2008)
	Exchangeable K stock	335.3 kg	Dawoe *et al.* (2014)
	Litter yield		
High tech/no shade cocoa	Soil C	18 g kg^{-1}	Blaser *et al.* (2017)
	Soil N	1.9 g kg^{-1}	
	Available P	0.23 g kg^{-1}	
	Extractable K	30.5 mg kg^{-1}	
	% soil N	0.19%	Asase *et al.* (2008)
	Available P stock	9.9 ug/g	
	Exchangeable K stock	0.1cmol/ (+)	

4.1.1.3 Biodiversity in cocoa agroforestry systems and full sun cocoa

Agroforestry has been shown to improve biodiversity conservation within the habitat. According to Jose (2012), agroforestry plays five major roles in conserving biodiversity: (1) agroforestry provides habitat for species that can tolerate a certain level of disturbance; (2) agroforestry helps preserve germplasm of sensitive species; (3) agroforestry helps reduce the rates of conversion of natural habitat by providing a more productive, sustainable alternative to traditional agricultural systems that may involve clearing natural habitats; (4) agroforestry provides connectivity by creating corridors between habitat remnants which may support the integrity of these remnants and the conservation of area-sensitive floral and faunal species; and (5) agroforestry helps conserve biological diversity by providing other ecosystem services such as erosion control and water recharge, thereby preventing the degradation and loss of surrounding habitat.

Table 6 presents a comparison of biodiversity between agroforestry cocoa systems and full-sun cocoa systems. For example, a comparison by Asase *et al.* (2008) show that shaded cocoa systems have a higher number of vegetation species (60% of those in forest systems) compared to the full-sun systems (8%). The bird species were also higher (77%) in the shaded systems compared to those found in full-sun systems (32%). More fruit-feeding butterflies (61%) were found in the shaded systems compared to the full-sun system (41%). Similarly, Wade *et al.* (2010) found that the shaded cocoa systems had a

higher number of tree species (15% of those found in forests) while the full sun cocoa systems had only 8%. Acheampong *et al.* (2014) also reported higher vegetation diversity index in shaded cocoa systems as indicated by the Shannon-H index of 1.34 compared to an index of 1.3 in full-sun systems. This clearly highlights the positive effect of agroforestry systems in maintaining biodiversity.

Table 6: Biodiversity in cocoa agroforestry systems and full sun cocoa systems

System	% compared to natural forest	Biodiversity index	References and comments
Forest			Wade *et al.* (2010) 170 tree species were identified in forest systems.
		2.67 (Shannon-Weiner-birds)	Holbech (2009)
Moderate shade	15% of number of tree species		Wade *et al.* (2010)
	60% of vegetation species		Asase *et al.* (2008)
		1.34 (Shannon H-vegetation)	Acheampong *et al.* (2014) 40 tree species were identified in moderate shade systems.
	77% bird species		Asase *et al.* (2008)
Mature cocoa agroforests	50% species richness		Anglaaere *et al.* (2011)
	50% bird species richness		Holbech (2009)
		1.47 (Shannon-Weiner-birds)	Holbech (2009)
	61% fruit-feeding butterflies		Asase *et al.* (2008)
Full sun cocoa systems		1.3 (Shannon H)	(Acheampong *et al.*, 2014)
	8% number of tree species		Wade *et al.* (2010) 14 tree species were identified in the full sun systems.
	8% vegetation species		Asase *et al.* (2008)
	32% bird species		Asase *et al.,* 2008)
	41% fruit-feeding butterflies		Asase *et al.* (2008)

Reproduced from Namirembe et al. (2015)

4.1.2. Impact on human capital

4.1.2.1. Impact of use of pesticides and exposure to cocoa processing waste on human health

The pathways through which pesticides applied to cocoa farms may affect human health include 1) through pesticide residues contaminating drinking water sources, 2) through traces of pesticides left in cocoa beans, and 3) through physical contact with the pesticides during the process of pesticide application. The cocoa bean has a high content of butter or fat which can absorb the active ingredients found in insecticides (Afrane and Ntiamoah 2011). Thus Okoffo *et al.* (2016) assessed the levels of pesticide residues in fermented dried cocoa beans to find out whether the pesticides residue levels in

Ghana's cocoa beans are a public health concern. They found that the levels of organochlorine pesticide residues in the fermented dried cocoa beans analysed compared favourably to the European Union (EU) commission regulations on pesticide residues, showing no health risks to consumers of cocoa beans from Ghana and no threat to cocoa export to Europe.

Similarly, several studies have assessed the levels of pesticide residues in soils and drinking water sources from cocoa farms in Ghana (e.g. Fosu-Mensah *et al.* 2016a; Fosu-Mensah *et al.* 2016b; Okoffo, 2015; Okoffo *et al.* 2016) to determine whether they are a health hazard. For these studies, although most of the pesticide residues recorded in water were below the World Health Organization Maximum Residue levels (WHO MRLs) for drinking water, some pesticides exceeded the WHO MRLs at some sampled sites. This therefore suggests that pesticide residue concentrations in some of the wells from which samples were obtained for this study, may pose health hazards to farmer households and their entire community who utilize water from these same sources.

However, most of the direct health effects of pesticides were linked to the process of pesticide application by the cocoa farmers without wearing protective gear. For example, a study by Okoffo (2015) assessed the health effects among cocoa farmers in Ghana. They reported that almost all the farmers interviewed experienced health related issues during and after pesticide application. The reported health effects are presented in Table 7 where it can be seen that the majority of the farmers reported cases of watery eyes (83%), headaches (74%), dizziness (55%), chest pains (42%), coughing (32%) and skin irritation (30%) during and after applying pesticides to the cocoa farms. Other less common health conditions that were reported include nausea, body weakness, burning eyes, itchy eyes and excessive sweating.

Table 7: Health related issues experienced by farmers during and after pesticides application

Health related issue	% of farmers with condition
Watery eyes	83
Headaches	74
Dizziness	55
Chest pains	42
Cough	31.7
Skin irritation	30
Itchy eyes	25
Nausea	22
Burning eyes	21.7
Excessive sweating	17.1
Weakness	15.4
Fever	5.4

Source: Okoffo (2015).

To estimate the health costs related to pesticide use by the cocoa farmers in Ghana, we used the treatment cost as a proxy. Table 8 presents estimates of the cost of treating different ailments reported by farmers who applied pesticides on cocoa farms without protective gear. The majority of the farmers treat these illnesses with over the counter prescription, hence we apply the approximate costs of these prescriptions. The total treatment cost per person was estimated as follows:

$$Ttc = \sum Ac * prob\ affected$$

Where: Ttc= Total treatment cost per person per dosage

AC=Average cost of treatment per person per dosage

Prob affected=Probability that a random person in the area will be infected with a specific illness.

However, this is a minimum estimate of the cost of impacts as it still does not capture all the costs related to pesticide application including hospital visits if any, labour days lost due to the sickness or potential shortened lifespan. There is therefore need for more detailed study to capture all the health costs related to pesticide application possibly by estimating the disability-adjusted life years (DALYs) and quality-adjusted life years (QALYs).

Table 8: Health cost related to pesticides application by the cocoa farmers

Health related issues	**Probability a person will be infected**	**Treatment (drug class)**	**Average cost of one dosage (USD)**	**Treatment cost per person (USD)**
Watery eyes	0.83	Antibiotics	10	8.3
Headaches	0.74	Pain killers (aspirin)	2	1.48
Dizziness	0.55	Antiemetics	11	6.05
Chest pains	0.42	Corticosteroids for asthma and allergies	18	7.56
Cough	0.317	Opiods	10	3.17
Skin irritation	0.3	Corticosteroids	18	5.4
Itchy eyes	0.25	Antihistamines	32	8
Nausea	0.22	Antihistamines	8	1.76
Burning eyes	0.217	Antihistamines	32	6.944
Excessive sweating	0.171	Antiperspirants	10	1.71
Weakness	0.154			0
Fever	0.054	Ibuprofen	13	0.702
Total treatment cost per person per dosage (USD)				51.076

Source of these drugs and cost was global and not specific to Ghana https://www.goodrx.com/

Further still, Ntiamoah and Afrane (2008) and Afrane and Ntiamoah (2011) applied the life cycle assessment (LCA) approach in an effort to capture environmental and health effects associated with production and processing of cocoa in Ghana as well as the pesticides effects in the cocoa food chain in Ghana. These studies reported the health impact in terms of levels of human toxicity potential (HTP) for the production and processing of 1kg cocoa beans in Ghana as shown in Table 9. The HTP is a measure of human toxicity and for both studies, human toxicity was the most significant in terms of magnitude compared to the other measures of environmental impacts, eutrophication, freshwater aquatic and terrestrial toxicity. The reported levels of HTP were almost exclusive to the cocoa production stage (>96%) while the processing stage contributed only a small proportion (Ntiamoah and Afrane 2008; Afrane and Ntiamoah 2011). The high human toxicity levels can therefore be attributed to fertilizer and pesticide use during cocoa production.

Table 9: Human Toxicity Potential in the production and processing of cocoa beans in Ghana (per tonne of cocoa beans)

Human Toxicity Potential (HTP) kg DCB-equiv	Reference
5,144*	Ntiamoah and Afrane (2008)
4,443**	Afrane and Ntiamoah (2011)

*Comprises effects from both production and processing. More than 96% of these are attributable to the cocoa production stage and the processing effect is minimal.

**Only the production stage was considered.

4.1.3. Social capital

Social capital encompasses aspects such as land access/tenure, social networks, laws and regulations, food security and empowerment among the minority groups among others. For cocoa in Ghana, we will discuss the child labour laws around cocoa production in Ghana as well as gender issues around cocoa production in Ghana.

4.1.3.1. Child labour and forced labour within cocoa production in Ghana

In Ghana, about one in every six children aged 7-14 were working in 2005/06 (Krauss 2013). Children aged 5-12 years mainly engage in weeding, gathering and carrying pods to pod-breaking points, carrying water for on-farm spraying, and carting fermented cocoa beans to drying points. Older children (15-17 years) are involved in additional tasks of harvesting pods, pod breaking and mistletoe cutting (Thorsen 2012). The common assumption in the literature is that child labour in developing countries is driven by income poverty. According to Krauss (2013) household decisions for or against child labour are rarely the consequence of one single factor (for example, monetary poverty) or event (for example, an income shock). Rather, in the case of Ghana they are often related to a set of events and factors which include:

- The structure of the economy (which is largely led by family farming),
- Cultural influences (social norms viewing child labour as part of socialization),
- Occupational choices (with no higher reported economic returns to basic education in rural areas),
- Low government priority and capacity (to enforce anti-child labour laws),
- The seasonal demand for agricultural work and,
- Demographic variables (such as low parental education and children's 'economic value' increasing with age).

Children face several physical risks when working in cash crops. Work overload, children's use of machetes, their role in transporting cocoa pods and other crops, and their participation in spraying pesticides and other agro-chemicals are the health hazards frequently discussed. Children working in cocoa systems consistently complain about pain in the neck, back, shoulders and arms (Mull and Kirkhorn 2005; Thorsen 2012). The children are also more susceptible to pesticide poisoning than adults due to a larger relative surface area hence experience more severe toxicity effects (Mull and Kirkhorn 2005).

Table 10 shows the number of children involved in cocoa production including hazardous work in Ghana sourced from a survey conducted by Tulane University. In 2013/14, 43% of the children in Ghana's cocoa producing areas were working in cocoa production, 41% were involved in some form

of child labour while 39% were involved in hazardous work within the cocoa sector. However, the number of children in Ghana's cocoa growing areas involved in hazardous work decreased by about 6% between 2008/09 and 2013/2014 (Tulane University 2015).

Table 10: Estimates of children (5-17 years) working in child labour and in hazardous work in the cocoa sector in Ghana

Population	2008/09		2013/14		% change
	Number	*%*	*Number*	*%*	
All children aged 5-17 years	2,160,878		2,236,124		
Children working in cocoa production[8]	997,357	46.2%	957,398	42.8%	-4.0%
Child labourers working in cocoa production[9]	947,777	43.9%	918,543	41.1%	-3.1%
Children working in the cocoa sector in hazardous work[10]	931,005	43.1%	878,595	39.3%	-5.6%
Ratio of cocoa produced to working children (tons per child)	0.7 tons per child		0.9 tons per child		

Reproduced from Tulane University (2015) pg. 35 and pg. 72.

Further still, the Tulane University survey went ahead to identify whether the children working in Ghana' cocoa sector experienced some injuries or negative health conditions while working. Table 11 shows the proportion of working children who reported some injuries directly associated with working on the cocoa farms. Wounds/cuts and skin itchiness were the most reported forms of injuries by approximately 26% of the child workers. Insect bites were also experienced by about 19% of the children, and back pains were experienced by 11%. Other reported injuries include: muscle pains (7%), burns (2%), broken bones and snake bites (<1%).

Table 11: Health related injuries experienced by children aged 5-17 years working in cocoa production

Number of children working in cocoa production	**957,393**
Type of injury	**%**
Wounds/cuts	26.2%
Broken bones	0.3%
Snake bites	0.5%
Insect bites	18.9%
Back pains	11.2%
Muscle pains	6.7%
Other pains	2.2%
Burns	1.6%
Skin itchiness or scratches	25.9%
Other	0.2%

[8] According to ILO, working children are defined as children in employment and include those engaged in any activity falling within the production boundary for at least one hour during the reference period.

[9] children engaged in child labour include all persons aged 5 to 17 years who, during a specified period, were engaged in one or more of the following categories of activities: worst forms of child labour, employment below the minimum age and hazardous work.

[10] This includes children aged 5-17 years involved in activities designated as hazardous or working for long hours and/or night in occupations not designated as hazardous.

Adapted from Tulane University (2015)

In addition to the health issues affecting the working children, some of them are deprived off education. Approximately 10% of child laborers in Ghana' cocoa farms do not attend school which violates the International Labour Organization's (ILO) Child Labour Standards. Depriving these children of an education has many short-term and long-term effects. Without an education, the children of the cocoa farms have little hope of ever breaking the cycle of poverty.

There are efforts by the Government of Ghana to address the issue of child labour. One recent policy that has been implemented to curb this is offering free primary and secondary education which started in 2017[11]. This will ensure that every willing child including those from poor households go to school which in return reduces the prevalence of child labour. In addition to the existing laws and policies on child labour, the existing certification standards for cocoa in Ghana highly discourage employing child labour in cocoa production. Although all certification schemes prohibit child labour explicitly, there is lack of data on the effectiveness of the schemes in eliminating child labour completely (Camargo and Nhantumbo 2016). Similarly, despite the different labels on chocolate bars such as various fair trade and the Rainforest Alliance Certification; no single label can guarantee that the chocolate was made without the use of exploitive child labour.

4.1.3.2. Gender issues in cocoa production

Do women involved in cocoa production have equal access to production resources (land, credit and other resources) as the men?

Cocoa is produced largely in traditionally structured societies, where women experience great difficulty to obtain legal land titles, even when their husbands die and they would run the farm themselves. Without land titles, they are often excluded from saving and credit systems, as well as from access to training and certification schemes (Cocoa Barometer 2015). They are also often underrepresented in farmers' organisations, public meetings and leadership roles in communities even though women are increasingly running the cocoa farms. According to Cocoa Barometer (2018), in West Africa women run approximately a quarter of the cocoa plantations. Although there are differences between the tasks of men and women, women are engaged in most of the steps of cocoa production, from preparing seedlings to selling beans. In addition, the women employed in the cocoa farms generally earn lower wages and the best jobs are for men; this is justified by saying that women are physically weaker, and the more physically demanding jobs are better paid (UTZ Certified 2009). Jobs for hired female labour often are the sorting and sifting of the beans on the drying tables. Similarly, women hardly participate in cooperatives. Constraining factors for participation include; lack of awareness of the benefits of cooperative membership, lack of time and not being invited to meetings. This has a negative effect on access to better markets for the female cocoa farmers (UTZ Certified 2009). However, according to UTZ certified (2009) some of the cocoa certification programs have included a requirement for gender inclusiveness aimed at addressing these differences between men and women in cocoa production and marketing. The most common certification program that addresses gender inclusiveness is the UTZ certification. Among the standards required for this certification are equal wage rates for both genders, health and safety for pregnant and breast-feeding women, maternity leave, child care and representation of women in unions and cooperatives.

[11] https://www.voanews.com/a/ghana-launches-free-high-school-education-nationwide/4030588.html

4.2. Flows

4.2.1. Outputs

4.2.1.1. Agricultural and food outputs at production stage

Table 12 presents various agricultural, food and non-food outputs from cocoa agroforestry systems in Ghana. A comparison is made with outputs from full-sun cocoa systems and high-tech systems (cocoa grown under highly intensive systems with high use of external inputs). The yield quantities are derived from various studies conducted within Ghana and are valued at the prevailing producer price in Ghana. Cocoa yield was largely obtained from long-term yield regression analyses for shaded and full-sun cocoa systems (Gockowski *et al.* 2011; Gockowski *et al.* 2013; Asase *et al*. 2014) and field estimates (e.g. Wade *et al.* 2010). The cocoa yields were lowest in shaded cocoa (approximately 366 kg per ha) compared to full sun cocoa (451 kg per ha) and high-tech cocoa (1041 kg per Ha). These yield levels compare favourably with the levels reported in FAO (2016) of 510 kg per ha and those reported elsewhere. For example, Foundjem-tita *et al.* (2016) reported a yield of 540 kg per ha, and Asare (2016) reported a yield of 450-539 kg per ha. The cocoa was valued at USD 4.85 per kg which is the PPP equivalent of the 2017 cocoa price issued in Ghana by COCOBOD (Ghana cedi 7.42).

However, for the shaded cocoa systems, in addition to cocoa, there are other products including plantain, timber, fruits and other food products. Since cocoa agroforestry is often combined with timber production, it was assumed that moderate shade agroforestry contains in addition to cocoa, 30 fruit trees and approximately 10 timber trees per hectare (Namirembe *et al*. 2015). This gives an average timber yield of 0.65 M^3/ha based on data from (Obiri *et al*. 2007; Gockowski *et al*. 2011; Gockowski *et al*. 2013; Asare *et al*. 2014). We also included the value of plantain within the shaded cocoa systems valued at USD 3,130 per ha as well as other food products valued at USD 2,822 per ha (Gockowski *et al*. 2013; Namirembe *et al.* 2015). Cumulatively, the total value of all the products was highest for the cocoa agroforestry systems (USD 8,139 per ha). Similarly, in addition to cocoa, plantain is grown within the full-sun cocoa system and was valued at USD 3,130 per ha (Gockowski et al. 2013). The total product value was almost equal for high tech cocoa systems (USD 5,049 per ha) and full sun cocoa systems (approximately USD 5,319 per ha). Figure 10 also presents a comparison of the agricultural and food outputs from the three cocoa production systems in Ghana.

Table 12: Agricultural and food outputs for various cocoa systems in Ghana (per hectare per year)

System	Service	Amount	Value USD per ha	References and comments
Moderate shade cocoa	Cocoa (kg)	280		Gockowski *et al.* (2013)
		403		Gockowski *et al.* (2011)
		321		Wade *et al.* (2010)
		380		Nunoo *et al.* (2015)
		448*		Abdulai *et al.* (2018)
	Average cocoa	*366.4*	*1,777*	*Valued at USD 4.85 per kg***
	Plantain (kg)	3500	3130	Gockowski *et al.* (2013)
	Fruit tree products (kg)	348.9	339.73	Namirembe *et al.* (2015)
	Other food crops		2,821.65	Namirembe *et al.* (2015)
	Timber (m^3)	1.04		Gockowski *et al.* (2011)
		0.48		Gockowski *et al.* (2013)
		0.23		Obiri *et al.* (2007)
		0.85		Asare *et al.* (2014)
	Average timber	*0.65*	*70.5*	
	Litter (kg)	600		Asase (2008)
		546.67		Dawoe *et al.* (2010)
	Average litter	*573.3*		
	Total		**8,139**	
Unshaded (full sun)/low shade system	Cocoa (kg)	519		Gockowski *et al.* (2011)
		318		Obiri *et al.* (2007)
		517*		Abdulai *et al.* (2018)
	Average	*451.3*	*2,189*	*Valued at USD 4.85 per kg***
	Plantain (kg)	3500	3130	Gockowski *et al.* (2013)
	Litter	200		
	Total		**5,319**	
High tech	Cocoa (kg)	1235		Gockowski, *et al.* (2013)
		1053		Gockowski *et al.* (2011)
		927		Obiri *et al.* (2007)
		949		Asare *et al.* (2014)
	Average cocoa	***1041***	***5,049***	

* these figures from Abdulai et al. (2018) are averages from dry, mid and wet cocoa growing regions in Ghana

** cocoa pricing was at Ghana cedis 7.42 per kg (equivalent to USD 4.85 applying the 2017 PPP conversion factor) https://www.reuters.com/article/ghana-cocoa/update-2-ghana-sets-2016-17-season-farmgate-cocoa-price-at-1914-per-tonne-idUSL8N1C70DK

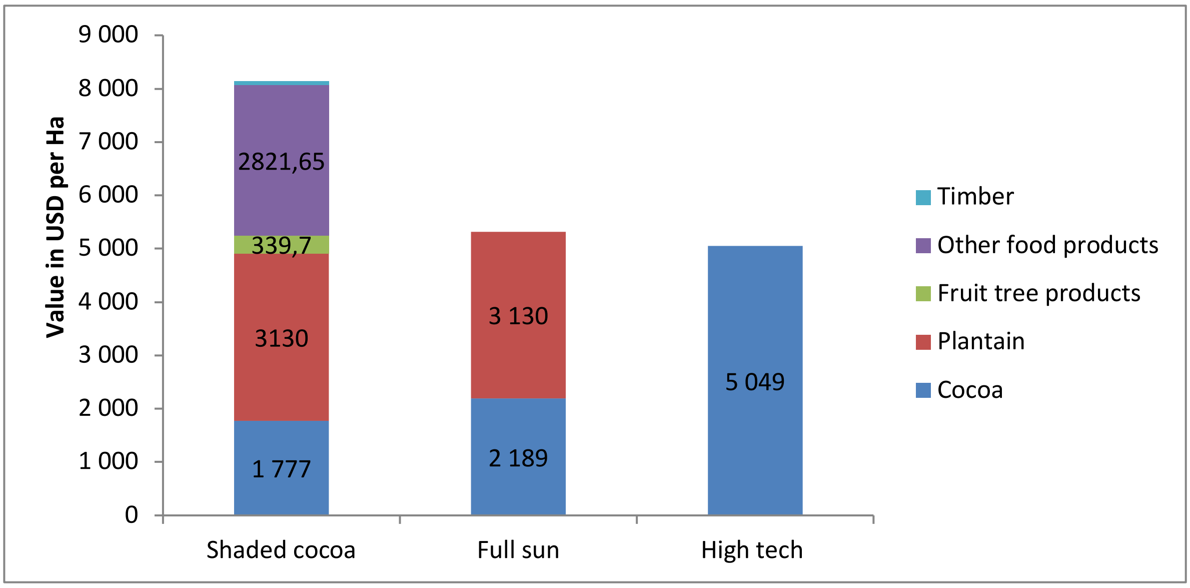

Figure 10: A comparison of the agricultural and food outputs among the three cocoa production systems in Ghana

4.2.1.2 Gross margins in the production stage

For this we compare profit margins for cocoa between shaded cocoa and full sun cocoa as well as other profitability measures reported by existing studies. Table 13 presents financial profitability estimates of cocoa production systems -both shaded cocoa systems and full-sun cocoa systems in Ghana sourced from (Gockowski and Sonwa 2011; Namirembe et al. 2015). These studies however do not consider other provisioning services. In terms of financial benefits, the full-sun cocoa systems were more profitable (almost twice as profitable) than the shaded cocoa systems. However, in recognition of the environmental benefits from shaded cocoa there are efforts to pay these farmers certification premium to make it as profitable as the full-sun cocoa.

Table 13: Profitability in the cocoa production stage

System	**Policy regime**	**Amount USD/ha/year**	**References**
Shade cocoa	No tax or fertilizer subsidy	1,377	Gockowski and Sonwa (2011)
	Tax and fertilizer subsidy	955	
	Reduced tax and subsidy	1,148	
	No tax or subsidy	850	Namirembe *et al.* (2015)
Full sun cocoa	No tax or fertilizer subsidy	2,376	Gockowski and Sonwa (2011)
	Tax and fertilizer subsidy	1,647	
	Reduced tax and subsidy	1,980	
	No tax or subsidy	3000	Namirembe *et al.* (2015)

4.2.1.3 Certification premiums from growing shaded cocoa

Concerns over the environmental impact of cocoa farming and its sustainability in Ghana have been raised in recent times. Major sustainability standards active in the global cocoa sector include Organic, Fairtrade, UTZ Certified and Rainforest Alliance (Potts *et al.* 2014). Organic focuses on a healthy planet, ecology and care for future generations; Fairtrade emphasises farmer empowerment, social development and long-term business relationships; Rainforest Alliance concentrates on biodiversity conservation; and UTZ certified on sustainable agricultural practices and sourcing. All four however, promise better incomes for producers and prohibit child labour with the aim of improving both producer and child welfare (Akoyi and Mitiku 2018).

However, most cocoa certifications and other initiatives to promote sustainability mostly focus on social issues (e.g. labour), as the environmental aspects are not yet so clear to consumers (Camargo and Nhantumbo 2016). Nonetheless, climate change awareness has begun to change that as for example, the Rainforest Alliance aims to promote environmentally sustainable cocoa production. To become certified, the Rainforest Alliance dictates that farmers adhere to the production and social standards promulgated by the Sustainable Agriculture Network (Gockowski *et al.* 2013). The Rainforest Alliance has specific requirements for farmers to maintain existing shade trees or plant new ones. Producer benefits of certification depend on (1) the extent to which consumers are willing to pay premiums for process attributes such as 'child labour-free' or 'shade-grown' cocoa; (2) the efficiency of market actors in adapting to the demands of differentiated markets; and (3) the productivity of the proposed system (Gockowski *et al.* 2013).

According to (Gockowski *et al.*, 2013), the Rainforest Alliance Certified cocoa farmers in Ghana were paid a premium of 72 Ghana Cedis (approximately 15.25 USD) per tonne of cocoa. Different studies have argued that the amount of certification premium paid to farmers is not enough to make the agroforestry cocoa systems as profitable as the full sun cocoa systems. For example (Gockowski et al. 2013) argues that even with a premium of USD 40 per ton, the profitability of Rainforest Alliance certified cocoa agroforestry systems will still be less that of an intensive monoculture, owing to the higher productivity within the intensive system.

4.2.1.4 Benefit share to the various actors in the cocoa value chain

Benefit share within the cocoa value chain in Ghana

Following the partial liberalization of the cocoa industry, cocoa farm gate prices have been more closely correlated with global prices (Kolavalli and Vigneri 2018). However, this has resulted in greater fluctuation of farm gate prices in most cocoa-producing countries over the past 20 years. In Ghana, the price that producers receive for their cocoa is determined by a multi-stakeholder platform known as the Producer Price Review Committee (PPRC). The PPRC fixes producer prices annually at the start of the cocoa harvesting season in October, and these prices are expected to be maintained for the period of one year (Bymolt *et al.* 2018). These prices are usually the floor prices and have been increased over the years as incentives to increase cocoa production in Ghana.

Figure 11 presents the benefit share as a proportion of the Free-on-Board price (FOB)[12] among the various actors within Ghana. Ghana has set a fixed price that farmers receive at the beginning of the year. Since 2001, the Ghana Producer Price Review Committee (PPRC) has set aside a portion of the projected revenues for the delivery of services to arrive at a net Free on Board (FOB). Then the net FOB is allocated to various stakeholders, including producers. The annual producer price[13] increased from 56% of the FOB in 1998/99, up to 70 % in 2004/05 (Camargo and Nhantumbo 2016). For the 2017/2018 season, the producer price was set at 75% of net FoB price (Bymolt *et al*. 2018). The increase is aimed at encouraging more cocoa production in Ghana.

The remaining percentage of the net FoB value is used for cost items such as a buyers' margin, crop finance, hauliers cost, storage and shipping, disinfection and grading, inspection and government/COCOBOD revenue. These costs can be broken down into direct and indirect costs (Kolavalli and Vigneri 2018). Direct marketing costs include the margins paid to licenced buying companies (LBCs) to procure from producers; costs of haulage, storage, and shipping incurred by the CMC (the marketing unit of COCOBOD), costs of grading and quality control of the Quality Control Company (QCC); and expenditures on crop finance, scale inspection, phytosanitary concerns, and the stabilization fund. Indirect costs on the other hand consist of COCOBOD's operational costs. These include the costs of maintaining its head office and the costs of various services and programs that it operates: The Cocoa Swollen Shoot Virus Disease program, the Seed Production Unit, the Cocoa Services Division, the Cocoa Research Institute of Ghana (CRIG), and the Cocoa Clinic. Industry costs include expenditure towards disease and pest control; jute sacks and related items; cocoa fertilizer application and child labour program.

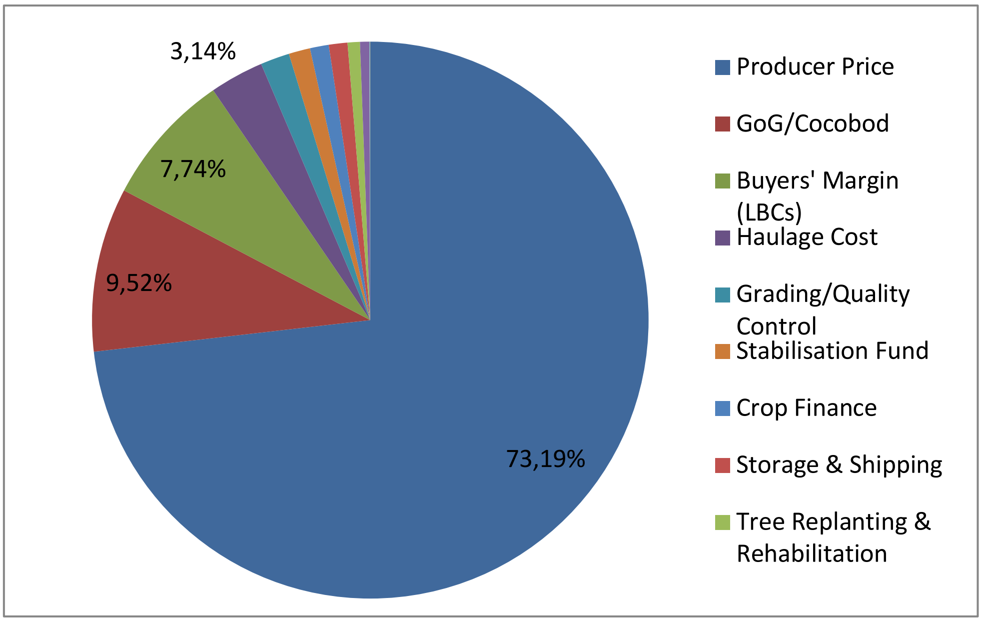

Figure 11: Benefit sharing of the FOB in the cocoa value chain in Ghana (as proportion of FOB)
Adapted from IFPRI/COCOBOD (2014).

[12] FOB is the price of a tonne of cocoa once it is loaded on a ship in the producing nation's port. Term of sale under which the price invoiced or quoted by a seller includes all charges up to placing the goods on board a ship at the port of departure specified by the buyer. Also called collect freight, freight collect, or freight forward (Laven *et al.* 2016).

[13] Producer price: Also known as the farm-gate price, this is the price farmers receive for their cocoa (Laven *et al.* 2016)

Benefit share among actors within the global chocolate value chain

Figure 12 presents the share in global sales revenue among global cocoa actors for every tonne of cocoa sold as estimated in the Cocoa barometer (2015). Although within Ghana farmers take up a large part of the FOB price, globally there are massive imbalances within the cocoa value chain. Cocoa and chocolate companies and retailers take up the bulk of the share - 35% and 42%, respectively - while West African farmers takes up only about 7%. The share of revenue to farmers fell from 16% in the 1980s to just 7% in 2015 (Sommeregger and Wildenberg 2016). Despite being the largest cocoa producers, Côte d'Ivoire and Ghana process only around 25% of their production, missing out on value that could be extracted from the chain. This highlights the need to promote cocoa value addition within Ghana and the other cocoa producing countries. The majority of the cocoa processing and manufacturing companies are based in Europe, especially in the Netherlands, Germany, UK and Switzerland (Ecobank 2013) indicating the dominance of the European Union in the chocolate value chain. Similarly, most of the retailers are in Europe. According to Cocoa Barometer (2015), the largest component of the value addition for retailers is made of marketing costs.

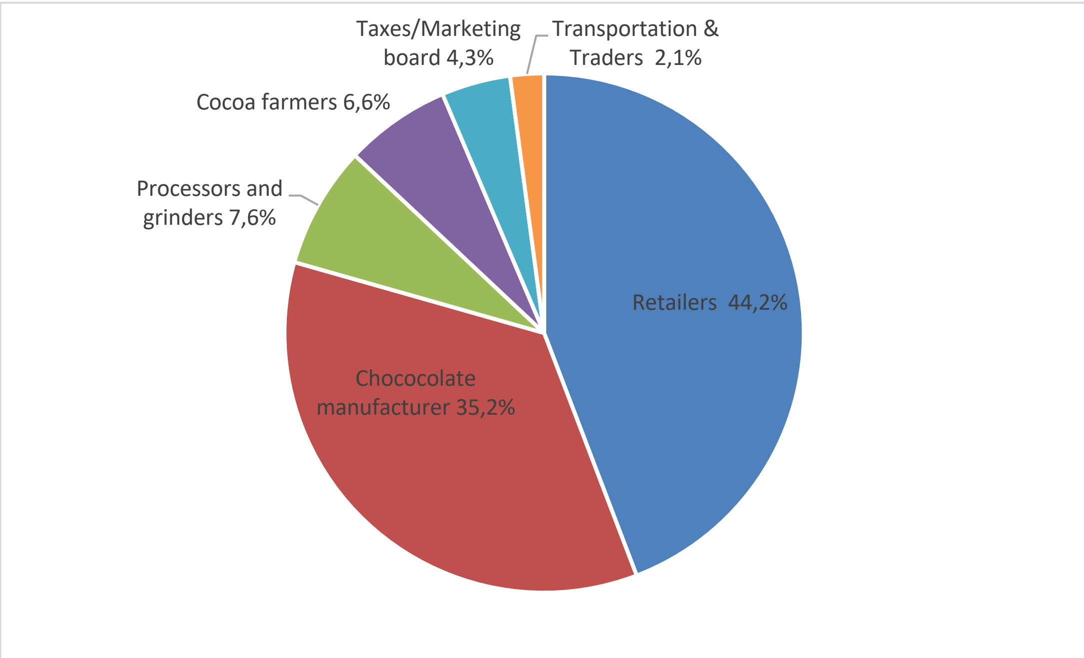

Figure 12: Share in global sale revenue per tonne of sold cocoa
Reproduced from: Cocoa barometer (2015) pg. 34-35.

4.1.1. Purchased inputs

4.1.1.1. Inputs in the cocoa production stage

Table 14 shows the inputs used in the production of cocoa in Ghana. We compare three cocoa farming systems; shaded cocoa, full sun cocoa and high-tech cocoa. The quantities are imputed from studies across Ghana and then valued at the current market price. For all the three cocoa production systems, labour cost constitutes the greatest component of input cost; it was estimated at 1,494 USD per ha for shaded cocoa, 1,565 USD per ha for full sun cocoa and about 2,359 USD per ha for high tech cocoa. Use of fertilizer and agrochemicals was substantially low for agroforestry cocoa estimated at 18 USD and 21 USD per ha

respectively but, as expected is highest for high tech cocoa systems, estimated at 551 USD per ha and 165 USD per ha, respectively. Cumulatively, the total costs are highest for the high-tech cocoa system (approximately USD 3,427 per ha), followed by the full sun cocoa system (USD 1,996 per ha) and are lowest for the shaded cocoa systems (USD 1,885 per ha). Figure 13 shows a comparison of the various cost component among the three cocoa production systems.

Table 14: Input use in cocoa production systems

System	Inputs	Unit	Quantity	Value (USD per ha)	References
Moderate shaded coffee	Fertilizer	Kg ha–^{1}	144		Nunoo *et al.* (2014)
		Kg ha–^{1}	37*		Abdulai *et al.* (2018)
	average		90.5**	35.30	
				0.00	Gockowski *et al.* (2013)
	Average fertilizer cost			***17.65***	
	Herbicides	Litres ha–^{1}	1.85	7.98	Nunoo *et al.* (2014)
	Fungicides	Grams ha–^{1}	171.75	2.53	
	Pesticides	Litres ha–^{1}	2.22		
	Pesticides	Litres ha–^{1}	4.4*		Abdulai *et al.* (2018)
	Average pesticides		3.31***	10.98	
	Total agrochemicals			21.49	
	agrochemicals			21.12	Gockowski *et al.* (2011)
	Average agrochemicals cost			***21.31***	
	Labour	Person day ha–^{1}	206	908.46	Owusu-Anankwah (2015)
				2250.58	Gockowski *et al.* (2013)
				1321.92	Obiri *et al.* (2007)
	Average labour cost			***1,493.65***	
	Other inputs			***351.95***	Namirembe *et al.* (2015)
	Total input cost			**1,884.56**	
Full sun/ low shade system	Fertilizer	Kg ha–^{1}	215.25		Nunoo *et al.* (2014)
			50*		Abdulai *et al.,* (2018)
		Average	***132.63***	***51.72***	
	Herbicides	Litres ha–^{1}	2.28	9.84	Nunoo *et al.* (2014)
	Fungicides	Grams ha–^{1}	213	3.13	
	Pesticides	Litres ha–^{1}	2.35		
		Litres ha–^{1}	6.07*		Abdulai *et al.* (2018)

	Average		4.21	13.93	
	Total agrochemicals cost			***26.9***	
	Labour	Person day ha–1	217	956.97	Owusu-Anankwah (2015)
				2,385.78	Gockowski *et al.* (2011)
				1,353.98	Obiri *et al.* (2007)
	Average labour cost			***1,565.58***	
	Other inputs			***351.95***	Namirembe *et al.* (2015)
	Total input cost			**1,996.35**	
High-tech	Fertilizer	Kg ha–1	371	551	Gockowski, *et al.* (2013)
	Agrochemicals			164.80	Namirembe *et al.* (2015)
	Labour			2,358.78	Gockowski *et al.* (2011)
	Other inputs			***351.95***	Namirembe *et al.* (2015)
	Total input cost			**3,426.53**	

*these figures from Abdulai et al. (2018) are averages from dry, mid and wet cocoa growing regions in Ghana

**fertilizer prices are valued at USD 0.39 per kg. Average annual price in Ghana 2017/2018, source https://africafertilizer.org/national/

*** We value pesticides at USD 3.31 per litre and herbicides at USD 4.32 per litre and fungicides at USD 0.74 per 50g source MoFA (2016).

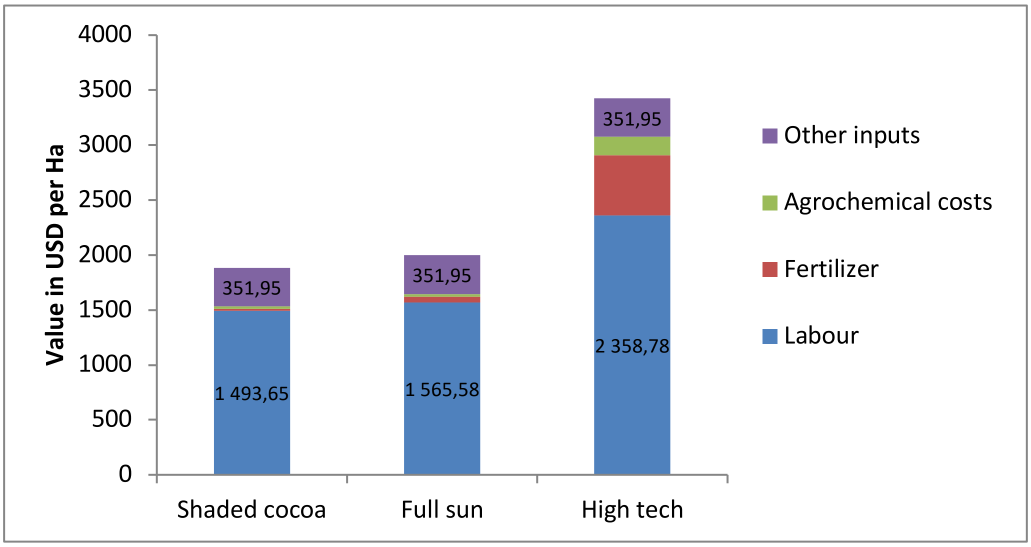

Figure 13: A comparison of input costs in the cocoa production by cocoa production system

4.1.1.2. Energy costs in the processing and manufacturing of cocoa beans

Table 15 provides estimates of energy consumed in the processing of cocoa beans. The energy quantities were adapted from a study that conducted a life cycle analysis of cocoa in Ghana (Ntiamoah and Afrane 2008). We applied the current market price of energy sources to value the energy costs.

The total energy cost incurred in processing one tonne of cocoa beans is estimated at approximately USD 89. This comprises of electricity cost (USD 9.3), diesel cost (USD 67.2) and petrol cost (USD 12.3).

Table 15: Input use (energy) during cocoa processing and manufacturing (inputs in processing 1 tonne of cocoa beans)

Inputs/outputs	**Unit**	**Amount**	**Value**	**Source**
Energy inputs				
Electricity (from national grid)	Kwh	88.06	9.3 USD**	Ntiamoah and Afrane (2008)
Diesel	Litres	64	67.2 USD***	
Petrol	Litres	11.7	12.3 USD	
Total energy costs			**88.8**	
Materials inputs				
Water	Litres	5.13		Ntiamoah and Afrane (2008)

**Source of this value (45 GH cedis) http://www.ecgonline.info/index.php/customer-care/services/tariff.html

*** Price of diesel 1.05 USD per litre and petrol

4.1.1.3. Water footprint in chocolate and other cocoa products

Table 16 shows the total water footprint in litres per kg of chocolate. The water footprint is an indicator of direct and indirect appropriation of freshwater resources. The term "freshwater appropriation" includes both consumptive water use (the green and blue water footprint) and the water required to assimilate pollution (the grey water footprint) (Mekonnen and Hoekstra 2011). The blue water footprint refers to the volume of surface and groundwater consumed (evaporated) because of the production of a good; the green water footprint refers to the rainwater consumed. The grey water footprint of a product refers to the volume of freshwater that is required to assimilate the load of pollutants based on existing ambient water quality standards (Mekonnen and Hoekstra 2011). The water footprint estimates were sourced from two studies: 1) which estimated the water footprint for chocolate manufactured in the UK which is one of the major markets of cocoa from Ghana sourced from Konstantas *et al.* (2018), and 2) a study which estimated the global water footprint for different food items including chocolate (Mekonnen and Hoekstra 2011).

The blue water footprint indicated by Konstantas *et al.* (2018) is composed of water used in raw material production, in manufacturing and in packaging. The blue water footprint level was estimated at 458 litres per kg of chocolate averaged for three types of chocolates consumed in the UK. Of the three, packaging is the main hotspot (55%–73%), followed by the raw material production (16%–30%) and manufacturing (7%–13%). To value the water footprint, we applied the shadow price of water. However, for Ghana due to missing data on water shadow prices specific to Ghana, we applied the shadow price estimated in Ethiopia by Gezahegn and Zhu (2014) at USD 0.0109 per M^3. The value of water footprint per tonne of chocolate was estimated at USD 187.

Table 16: Water foot print per tonne of chocolate

Water footprint	**Quantity of water (M^3 per tonne)**	**Value of water footprint USD/tonne chocolate**	**References**
Blue water footprint	458**		Konstantas *et al.* (2018)

Water consumption (green and blue water footprint)	9,830**		
Green water footprint	16,805		Mekonnen and Hoekstra (2011)
Blue water foot print	198		
Grey water footprint	726		
Total water footprint	17,196	187.4	

*in the case the raw material production is not exclusive for cocoa. The figure constitutes water levels used in other raw materials in chocolate as well such as milk powder, sugar and palm oil.
**the amount is the average of the blue water footprint incurred for 3 types of chocolate. The blue water footprint is the volume of freshwater that is evaporated from the global blue water resources (surface and ground water) to produce the goods and services consumed by the individual or community.

In addition, to chocolate, there are other products manufactured from cocoa beans. Table 17 and Figure 14 present the water footprint for various cocoa products (cocoa beans, cocoa paste, cocoa butter and cocoa powder) in M^3 per tonne adapted from Mekonnen and Hoekstra (2011). The green water footprint (rain water) takes up a greater proportion of the total water footprint while blue water footprint is the least for all the cocoa products. The water footprint is highest for cocoa butter (33,938 M^3) and lowest for cocoa powder (15,638 M^3). The cost of the water footprint for the various cocoa products were estimated at 217 USD per tonne of cocoa beans, 264 USD per tonne of cocoa paste, 370 USD per tonne of cocoa butter and 170 USD per tonne of cocoa powder. Figure 14 also shows a comparison of water footprint (in M^3) for five cocoa products.

Table 17: Water footprint for other cocoa products

	Water footprint for some cocoa products (M^3 per tonne)				**Value in USD per tonne**
	Green water footprint	**Blue water footprint**	**Grey water footprint**	**Total water footprint**	
Cocoa beans	19,745	4	179	19,928	217.2
Cocoa paste	24,015	5	218	24,238	264.2
Cocoa butter, fat and oil	33,626	7	305	33,938	369.9
Cocoa powder	15,492	3	141	15,638	170.5

Extracted from Mekonnen and Hoekstra (2011)

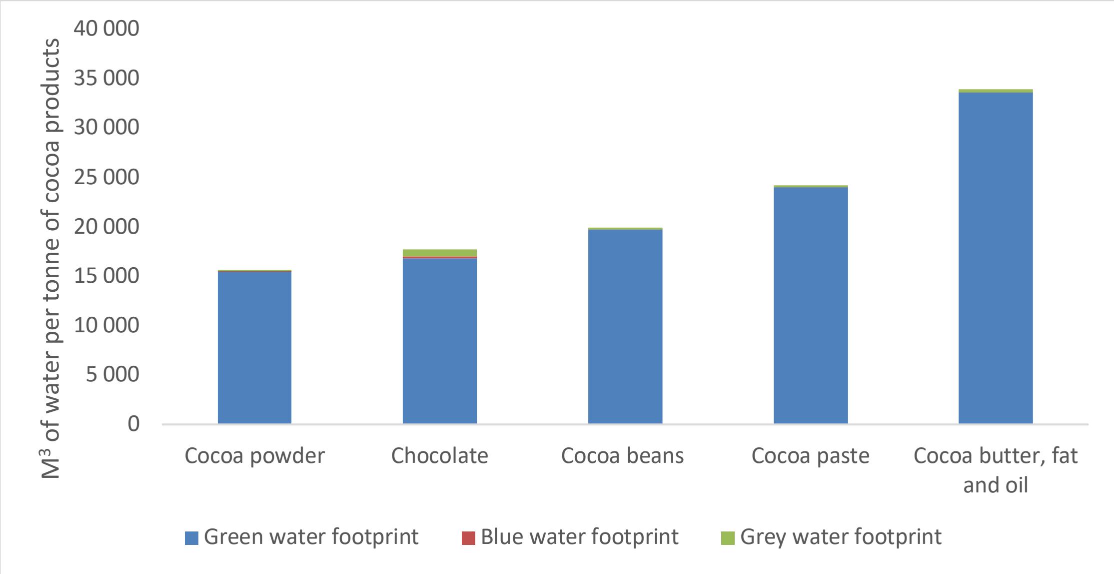

Figure 14: Comparison of water footprint for different cocoa products

4.1.1.4. Transport cost within the Ghanaian cocoa value chain

Table 18 presents the estimated transportation cost within the cocoa value chain from cocoa beans in Ghana to chocolate within Europe (the UK is used as a point of reference). We use the distances estimated by Konstantas *et al.* (2018) and applied the relevant rates for the specific countries. To compute the transportation cost within Ghana, we used a rate of USD 0.25 per km per tonne sourced from Teravaninthorn and Raballand (2009). We adjusted the reported rate of USD 0.03 per km per tonne as of 2001 for inflation to reflect the 2017 real price of approximately USD 0.25 per km per tonne. The shipping cost from Ghana to Europe was fixed at an average price of USD 45 per tonne.

Table 18: Transport cost in the Ghanaian cocoa value chain

Value chain stage	**Transport step**	**Distance (km)**	**Cost USD per tonne**	**Source**
Raw material	Cocoa beans within Ghana	500km (by lorry)	12.5**	Konstantas *et al.* (2018)
	Cocoa beans (Ghana to UK)	7370 km (freight)	45***	
	Cocoa beans within UK	200 km		
Manufacturing, distribution	Chocolate within UK *	550 km (lorry)		

*captures the cost of transport from manufacturing to distribution centres (150km), from distribution centres to retailers (200km). It also captures the cost of packaging to manufacturers (200km). Sourced from; Konstantas *et al.* (2018)

**the price per km per tonne was sourced from Teravaninthorn and Raballand (2009) pg. 99.

***the price of shipment per tonne of cocoa is sourced from https://af.reuters.com/article/commoditiesNews/idAFL8N1WE6FA

4.1.2. Ecosystem services

4.1.2.1. Biological pest control

Agroforestry practices have been found to reduce the severity of diseases in Ghana's cocoa plantations, particularly the cocoa swollen shoot virus disease (CSSVD). CSSVD affects cocoa plants at any development stage and the only current treatment method which is known to be effective at tackling this disease is to fell infected trees. The number of cocoa trees infected with CSSVD in Ghana is estimated to be over 300 million, which have been cut down on regular incomes for farmers with entire crop fields being lost in some cases (Andres *et al.* 2018). Agroforestry has been found to reduce the incidences of CSSVD through decreasing pest species (diseases vectors) populations as well as favouring natural pest predators which feed on the disease vectors (Andres *et al.* 2018).

We estimated the value of biological pest control in the cocoa agroforestry systems in Ghana by applying an avoided loss approach. The economic value of the biological pest control is equated to the value of avoided loss attributable to biological pest control. The proportion of avoided loss was sourced from Maas *et al.* (2013) who estimated the value of avoided yield loss in Indonesian cocoa agroforestry systems and reported it at 31%. This avoided loss in yield of 31% is the loss prevented by biological agents (birds and bats) and may not necessarily be fully attributable to agroforestry. However, higher bird species richness (both forest and non-forest bird species) has been reported in shaded cocoa systems compared to the unshaded systems (Asase *et al.* 2008). Hence, biological pest control is expected to be higher in the shaded systems compared to the unshaded systems. The economic value was computed as the cocoa producer price in Ghana[14] (USD 1.91 per kg) multiplied by the avoided yield loss (31% of the cocoa yield within shaded systems sourced from Table 12). This was estimated at USD 216 per ha.

4.1.2.2. Pollination

Following the FAO Array for the economic valuation of the contribution of insect pollination to agriculture and impact on welfare[15], cocoa is one of the crops for which pollination is classified as essential with a pollinator dependency factor of 0.95. The pollinator dependency factor is an indicator of the pollination contribution to production value per hectare and is influenced by the variation in richness and abundance of pollinators in the cocoa fields. The value of bees or the total economic value of pollinating services delivered to cocoa by bees is calculated by multiplying the value of cocoa yield (USD/ha) by the pollination dependency factor (Gallai and Vaissière 2009; Munyuli 2014). We sourced the pollination dependency factor from the FAO Array for the economic valuation of the contribution of insect pollination to agriculture. We estimated the economic value of insect pollinators in cocoa systems at approximately USD 665 per hectare that is 0.95 pollination dependency factor for cocoa in Ghana multiplied by the producer price of cocoa in Ghana (USD 1.91 per kg) and the cocoa yield in shaded systems (366 kg per ha) sourced from Table 12. However, the economic value of cocoa systems may vary depending on the production systems. Pollination is expected to be higher within shaded cocoa systems compared to monoculture systems since insect and pollinators biodiversity is higher within agroforestry systems and forest systems (Claus et al. 2018).

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[14] https://www.reuters.com/article/ghana-cocoa/update-2-ghana-sets-2016-17-season-farmgate-cocoa-price-at-1914-per-tonne-idUSL8N1C70DK

[15] http://www.fao.org/fileadmin/user_upload/pollination/docs/POLLINATION_VALUE_ARRAY.xls

4.1.3. Residuals

4.1.3.1. Greenhouse gas emissions

Overall, almost all phases of the cocoa value chain generate externalities. One of the most important externalities is greenhouse gas (GHGs) emissions (Camargo and Nhantumbo 2016).

Greenhouse gas emissions along the value chain

To assess the amount of greenhouse gases along the cocoa value chain, various studies (e.g. (Ntiamoah and Afrane 2008; Perez Neira 2016; Konstantas *et al.* 2018; Recanati *et al.* 2018) have applied the life cycle assessment (LCA) approach. Life cycle assessment (LCA) is a standardized methodological tool that enables the assessments of the main environmental impacts associated to a product "from the cradle to the grave". It allows for studying the environmental behaviour of the overall agri-food system from production to consumption (Perez Neira 2016). As most of the cocoa produced in Ghana is exported for processing, manufacturing and packaging, mostly in Europe, we sourced the quantity of greenhouse gases emitted from those activities in studies conducted outside of Ghana.

Table 19 presents the amount of greenhouse gases emitted during the processing, transport and packaging of cocoa in kg CO2e per kg of chocolate produced. Post-production, the manufacturing stage emits the highest amount of GHGs averaging at 0.67 kg CO2e per kg of chocolate, followed by packaging (0.34 kg CO2e per kg of chocolate) and transportation (0.31 kg CO2 equiv per kg of chocolate). The total GHG emissions for the cocoa value chain were estimates at 3.48 kg CO2e valued at USD 23-143 per kg of chocolate produced.

The bulk of the GHG emissions in the chocolate/cocoa value chain is at the production stage (Ntiamoah and Afrane 2008; Konstantas *et al.* 2018). The quantity of GHGs at the production stage depends on the amount of cocoa beans in a bar of chocolate. The amount indicated in Table 19 (0.323 kg CO2e) represents emissions per kg of cocoa beans produced. On average, 300-600 cocoa beans are used in the production of 1kg of chocolate and each bean weighs between 0.5grams to 1.5 grams.

Table 19: Greenhouse gas contribution during cocoa transportation processing and manufacturing

Activity	Quantity kg CO2e per FU (I kg chocolate)	Value (USD per kg of chocolate)	Source
Cocoa transportation	0.22		Recanati *et al.* (2018)
	0.22-0.39		Perez Neira (2016)
	Average (0.305)	***1.98-12.5***	
Packaging production	***0.34***	***2.21-13.94***	Recanati *et al.* (2018)
Manufacturing	0.28-1.91		Perez Neira (2016)
	0.74		Recanati *et al.* (2018)
	Average (0.668)	***4.34-27.39***	
The entire value chain	3.6 kg		Büsser and Jungbluth (2009)
	3.36 kg		Konstantas *et al.* (2018)
	Average (3.48)	***22.62-142.68***	
Cocoa production and processing**	0.323 kg		Ntiamoah and Afrane (2008)

Values are per 1 functional unit (FU). In this case 1 FU= 1kg of chocolate packaged in 100g chocolate bars

Transportation of cocoa beans to the processing industries and industrial processing of the beans to cocoa butter, liquor, cake and powder are also included.
***this shows the greenhouse gas emission for the production and production of 1 kg cocoa beans in Ghana For valuation we use the market price of carbon (6.5USD per tonne of CO2e) and the social cost of carbon (41 USD per tonne of CO2e).*

4.1.3.2. Water and soil emissions from pesticides used in the production of cocoa

Insects, pests and diseases pose a major challenge to cocoa production in Ghana resulting in adverse consequences on the country's economy. In an attempt to reduce the incidence of insect pests and diseases, a large number of pesticides including organochlorines are usually applied on farm (Fosu-Mensah *et al.* 2016a). The regular application and indiscriminate use of chemicals have been associated with unintended environmental and human health consequence (Fosu-Mensah *et al.* 2016b).

Several studies have assessed the levels of pesticide residues in soils and drinking water sources from cocoa farms in Ghana (Fosu-Mensah *et al.* 2016a; Fosu-Mensah *et al.* 2016b; Okoffo 2015; Okoffo et al. 2016). The presence of pesticides in the water samples could be traced to direct overspray, atmospheric transport of volatilized pesticides or wind drift, direct spillage, pesticide misuse by farmers, leaching and run-off from application fields and surrounding areas during and after pesticide applications. From these studies, although most of the pesticide residues recorded in water were below the WHO MRLs for drinking water, some pesticides exceeded the WHO MRLs at some sampled sites. The results therefore suggest that pesticide residue concentrations in some of the wells from which samples were obtained for this study, may pose health hazard to farmer households and their entire community who utilize water from these same sources.

The pesticide residues in the soil also pose danger to soil organisms as well as contaminate surrounding water bodies through runoff and leaching. In addition, there is the likelihood of translocation of these residues from the soil into the cocoa beans and other crops (such as vegetables that are commonly intercropped with cocoa) through the root system, thereby posing health risks to consumers (Fosu-Mensah *et al.* 2016a).

Ntiamoah and Afrane (2008) and Afrane and Ntiamoah (2011) applied the life cycle assessment (LCA) approach to capture environmental and health effects in the production and processing of cocoa in Ghana as well as the pesticide effects in the cocoa food chain in Ghana. They assessed acidification and eutrophication levels as well as freshwater aquatic and terrestrial toxicity levels as shown in Table 20. Eutrophication or nitrification is a measure of the over-fertilisation of soils and contamination of water-bodies with nutrients. In waters, it causes excessive algae growth and negative modification of the aquatic ecosystems resulting in oxygen depletion and death of certain aquatic species. In soils, on the other hand, it promotes monocultures and loss of biodiversity (Afrane and Ntiamoah 2011; TEEB 2015). The eutrophication effect was found to be almost exclusively attributable to the production stage and almost negligible for the processing phase.

Similarly, the freshwater aquatic and terrestrial toxicity were almost exclusively attributable to the cocoa production stage. Regarding acidification on the other hand, the impact was found to be almost exclusively attributable to the processing stage (about 97%) while the production stage only

accounted for the remaining 3% (Ntiamoah and Afrane 2008). Acidification is an indication of the gradual degradation of the soil and it is caused by acid solution formed when pollutants generated from the combustion of fuels are released into the atmosphere.

Table 20: Environmental impact from the production and processing of cocoa in Ghana (1 tonne of cocoa beans)

Environmental impact	Impact score	Unit
Acidification potential*	8.424	kg SO2-equiv
Eutrophication potential**	1.048	kg PO4 3_-equiv
Freshwater aquatic Eco-toxicity potential**	5,849.6	kg DCB-equiv
Terrestrial Eco-toxicity potential**	7.122	kg DCB-equiv

Source (Ntiamoah and Afrane 2008)

*these effects are almost exclusive to the processing stage (about 97%)

** these effects are almost exclusive to the production stage mainly due to fertilizer and pesticide use (>96%)

In addition, Ntiamoah and Afrane (2008) estimated the quantity of pesticides residue and heavy metals that enter freshwater and soils either through runoff or leaching as shown in Table 21. Approximately 3.7kg and 0.95kg of pesticides are released to freshwater and soils respectively, during the production of one tonne of cocoa beans in Ghana. Similarly, about 0.042 kg of heavy metals are released to the agricultural soils in the production of one tonne of cocoa beans in Ghana.

Table 21: Pesticides emissions to freshwater and soil during the production of cocoa beans in Ghana (1 tonne of cocoa beans)

Emissions	Quantity (kg per tonne of cocoa beans)	Reference
Pesticides to freshwater	3.69	Ntiamoah and Afrane (2008)
Pesticides to soil	0.945	
Heavy metals to agricultural soil	0.042	

Table 22 also presents the quantity and chemical properties of waste residues released into the water during the processing of one tonne of cocoa beans. Biological oxygen demand (BOD) and chemical oxygen demand (COD) are indicators of the chemical characteristics of the waste water. BOD indicates the amount of oxygen needed to biologically break down organic wastes in water while COD indicates the amount of dissolved oxygen required to combine with chemicals in the waste water. The largest component of waste is the heavy metals residue to fresh water estimated at 0.748 kg per tonne of cocoa beans processed in Ghana.

Table 22: Waste residues into the water from processing 1 tonne of cocoa beans in Ghana

Waste properties	Quantity (kg per tonne of cocoa beans)
Biological oxygen demand (BOD)	5.04E-9
Chemical oxygen demand (COD)	9.82E-9
Nitrates	3.75E-12
Oil and grease	1.00E-11
Phosphates	4.42E-11
Total dissolved solids	5.15E-9

Total suspended solids	4.13E-9
Heavy metals to freshwater	0.748

Reproduced from Ntiamoah and Afrane (2008)

4.3 Summary

In this chapter we have discussed the costs and benefits within the agroforestry cocoa value chain in Ghana. This includes "visible" costs and benefits as well as positive and negative externalities within the value chain. This chapter is discussed under two sub-chapters; 1) outcomes, stocks and impacts on capital, and 2) flows. Under outcomes, stocks and impacts, we discuss the various levels of capital and the impact that activities within the cocoa value chain have on the different capitals including natural, human and social capital. However, due to data limitations, the discussion on levels of produced capital is missing. Essentially this captures the levels of productive assets within the cocoa value chains such as land, machinery, infrastructure and so on; data on these assets at a macro level was challenging to find. At the production stage of the value chain we compare costs and benefits between three cocoa production systems commonly practiced in Ghana; full sun systems, agroforestry systems and high-tech (plantation) cocoa systems. The key highlights from this chapter include:

- There are trade-offs between cocoa yields and other provisioning services among the different cocoa production systems in Ghana.
- Ecosystem services within the cocoa agroforestry systems include carbon sequestration, maintaining biodiversity, soil fertility, pollination, and biological pest and disease control.
- Pesticide use in cocoa production in Ghana has major negative effects on human health as well as on the environment (soils and water).

Greenhouse gases are emitted throughout the cocoa value chain, but the production stage captures the bulk of the GHGs resulting from fertilizer and pesticide use.

5. Coffee agroforestry in Ethiopia

5.1. Outcomes, stocks and impact on capital

5.1.1. Natural capital

Under natural capital, we discuss the following; above and below ground carbon stocks, soil nutrient levels within coffee agroforestry systems, biodiversity, impact of water pollution from coffee processing industries on water bodies and aquatic organisms. We also present the potential alternative uses of coffee waste such as in the production of bio-ethanol which can be used as a source of energy.

5.1.1.1. Carbon stocks

Agroforestry systems have received increased attention as potentially cost-effective options for climate change mitigation due to their importance in carbon storage and sequestration, while also maintaining livelihoods (De Beenhouwer *et al.* 2016; Denu *et al.* 2016). Ethiopia's semi forest coffee retains 75% of the carbon stored in natural forests, but it retains significantly more long-term carbon stocks than alternative forms of agricultural land use (pasture and cropland) (Denu *et al.* 2016). Due to the carbon retained in trees, shrubs and soils, agroforestry has the potential to offset greenhouse gas emissions from conversion to more intensive forms of land use (De Beenhouwer *et al.* 2016), particularly in the case of traditional coffee farmin which typically retains a high degree of canopy cover and associated carbon (Tadesse *et al.* 2014; Vanderhaegen *et al.* 2015a; De Beenhouwer *et al.* 2016). Soil organic carbon pool on the other hand is affected by land use types, as disturbance and management intensities cause variations in the amount of carbon stored in the soil (Vanderhaegen *et al.* 2015a; De Beenhouwer *et al.* 2016).

Table 23 presents the quantity and value of above ground carbon and below ground carbon stocks in semi-forest coffee systems and garden coffee systems for comparison purposes. The levels of carbon stocks were sourced from different studies conducted in Ethiopia (Negash *et al.* 2013; Tadesse *et al.* 2014; Negash and Kanninen 2015; Negash and Starr 2015; Vanderhaegen *et al.* 2015a; De Beenhouwer *et al.* 2016; Denu *et al.* 2016). We valued the carbon quantities using the market price as well as the social price of carbon. On average, the above carbon stock levels were higher in semi forest coffee systems estimated at 208 tonnes C per ha valued at USD 4,964-31,314 while that of the garden coffee systems was estimated at 158.8 tonnes C per ha valued at USD 3,788-23,892. On the other hand, the below carbon levels were lower in semi-forest coffee systems estimated at 95 tonnes C per ha valued at USD 2,254-14,219, while in the garden coffee system 123 tonnes C per ha valued at USD 2,940-18,545. According to Blaser et al. (2018), for the case of perennial cropping systems such as cocoa and coffee, adding shade trees may not have the same potential for soil carbon sequestration as in annual cropping systems. This may be because the litter produced by shade trees in perennial cropping systems might not significantly increase carbon inputs to levels above those of the perennial crops alone.

Table 23: Biomass carbon stocks and soil carbon stock in coffee semi-forest and garden systems in Ethiopia

C stock	System	Quantity tonnes C ha^{-1}	Value USD ha^{-1}	References
C stock (total biomass)	Semi-forest	204		Tadesse *et al.* (2014)
		179.92		Vanderhaegen *et al.* (2015a)
		387		De Beenhouwer *et al.* (2016)
		61.5		Denu *et al.* (2016)
	Average	***208.1***	***4,964-31,314***	
	Garden /semi-plantation	258		De Beenhouwer *et al.* (2016)
		91.42		Vanderhaegen *et al.* (2015a)
		163		Negash (2013)
		77.5		Negash and Starr (2015)
		204		Negash (2015)
	Average	***158.8***	***3,788-23,892***	
C stock soil	Semi-forest	89		Vanderhaegen *et al.* (2015a)
		100		De Beenhouwer *et al.* (2016)
	Average	***94.5***	***2,254-14,219***	
	Garden coffee	110		De Beenhouwer *et al.* (2016)
		85		Vanderhaegen *et al.* (2015a)
		122.5		Negash (2013)
		175.5		Negash (2015)
	Average	***123.3***	***2,940-18,545***	

For valuation we use the market price of carbon (6.5 USD per tonne of CO2e) and the social cost of carbon (41 USD per tonne of CO2e). Conversion rate from tonnes C to tonnes CO2e is 3.67.

5.1.1.2. Impact of coffee processing waste on water bodies

Coffee processing plants are among the major agro-based industries responsible for water pollution in Ethiopia. The most commonly used processing method in Ethiopia is wet processing, which is expanding in the country (Minuta and Jini 2017). Wet processed coffee is considered superior in quality in comparison to dry processed coffee. In Ethiopia, there are more than 400 wet coffee processing installations, all of which are located at the vicinity of rivers (Woldesenbet *et al.* 2014; Olani 2018). This is because a lot of water is needed for washing the beans, removing the pulp and the mucilage, but also to use the water bodies for direct disposal of the wastewater released from the wet coffee processing plants. All in all, wet coffee processing industries in Ethiopia do not re-use the water, which is used once for de-pulping and fermentation. Thus, all the generated wastewater is directly released to downstream water bodies, and sometimes in disposal pits (Olani, 2018). On average, coffee processing results in effluent wastewater to an extent of about 3,000 litres per tonne of coffee processed (Murthy *et al*. 2004). In addition, coffee by-products of wet processing constitute around 40% of the wet weight of the fresh fruit (Woldesenbet *et al.* 2016).

The rise in the number of wet coffee refineries has thus resulted in an enormous disposal of waste effluents which are discharged unwisely into nearby natural waterways that flow into rivers and/or infiltrates ground water, becoming a main threat to surface and ground water qualities (Woldesenbet *et al.* 2014; Tekle 2015; Ejeta and Haddis 2016). Wastewater directly discharged to the nearby water

bodies also causes many severe health problems including spinning sensations, eye, ear and skin irritations, stomach pains, nausea and breathing problems among the residents of nearby areas (Woldesenbet *et al.* 2014). Table A5 in the annex presents the World Health Organization (WHO) and Ethiopia's specific permissible levels for effluent discharges on land for irrigation and to receiving water bodies. The WHO permissible levels are; (300 mg/l) chemical oxygen demand (COD), (100 mg/l) biological oxygen demand (BOD), 200 mg/l for total suspended solids (TSS), 5 mg/l for phosphates and nitrates and a neutral PH (6.5-7.5). Ethiopia's permissible levels are even lower; BOD (60Mg/L), COD (250mg/L), TSS (50Mg/L), a neutral PH and 5mg/L for nitrates and phosphates.

However, as shown in Table 24, the levels of effluent concentration reported at the discharge points of the Ethiopian coffee processing plants by various studies (e.g. Haddis and Devi 2008; Beyene *et al.* 2012; Tilahun *et al.* 2013; Tekle *et al.* 2014; Ejeta and Haddis, 2016; Olani 2018), are substantially higher than the acceptable limit indicating high pollution levels in the wastewaters. The average observed BOD level is approximately 3,417 mg/L and ranges from 436 mg/L to 7,800 mg/L. Similarly, the observed COD levels range from 1,268 mg/L to 9,780 mg/L and averages at approximately 6,288 mg/L. The high levels of BOD and COD indicate that large amounts of chemical and biological oxygen demanding substances in the effluent are released from the coffee processing wastewater into the rivers. Hence, the amount of oxygen available is low for living organisms in the wastewater, when utilizing the organic matter occurs.

Furthermore, high levels of total suspended solids (TSS) were also observed by the various studies ranging from 598 to 2,280 mg/L and averaging at 1,883 mg/L. The high concentration of solids in suspension (TSS) may lead to negative impacts in the ecosystem. TSS is a measure of turbidity; in turbid waters, light penetration is reduced, leading to a decrease in photosynthesis. The resultant decrease in primary production reduces food availability for aquatic organisms higher up the food chain. Suspended solids may interfere with the feeding mechanisms of filter-feeding organisms and the gill functioning, foraging efficiency (due to visual disturbances) and growth of fish (Olani 2018). Sensitive species may be permanently eliminated if the source of the suspended solids is not removed. In addition, suspended solids may affect the use of water for various purposes by exacerbating the dissolved oxygen problem by sedimentation and forming oxygen demanding sludge deposits, which may alter the habitat of aquatic microorganisms (Tekle *et al.* 2015).

In addition, the reported PH levels were lower than the WHO and Ethiopia's recommended level (neutral) thus creating an acidic environment in the river bodies. The average PH level of the observed studies is 4.8 ranging between 3.6 and 6.2. The acidic environment is not conducive for most of the aquatic life as well as for the health of the people living in nearby communities. Similarly, the observed phosphate and nitrate levels in the water bodies were higher than the recommended levels of 5mg/L.

Table 24: Characteristics of water at effluent discharge points from wet coffee processing industries in Ethiopia

BOD (mg/L)	COD (mg/L)	TDS (mg/L)	TSS (mg/L)	Phosphate (mg/l)	Nitrate (mg/l)	PH	Source
7,800	9,780	-	2280	4.0	7.5	5.15	Haddis and Devi (2008)
1401	1268	1257	770.34	9.81	4.99	4.8	Ejeta and Harris (2016)

5749	8421	6191	3414	8.16	-	3.57	Tekle *et al.* (2014)
1697	5683	1801	1975	3.39	3.32	4.13	Tilahun *et al.* (2013)
436	-	170	598	-	6.8	6.2	Beyene *et al.* (2012)
			2,260				Olani (2018)
3,417	**6,288**	**2,355**	**1883**	**6.34**	**5.65**	**4.77**	**Average**

BOD (Biological oxygen demand) COD (Chemical oxygen demand) TDS (Total dissolved solids) TSS (Total suspended solids)

Figure 15 shows a comparison of the observed parameters of water quality measures with the WHO and Ethiopia's permissible levels. For all the parameters, the observed levels are much higher than the recommended levels indicating very high pollution levels in these water bodies.

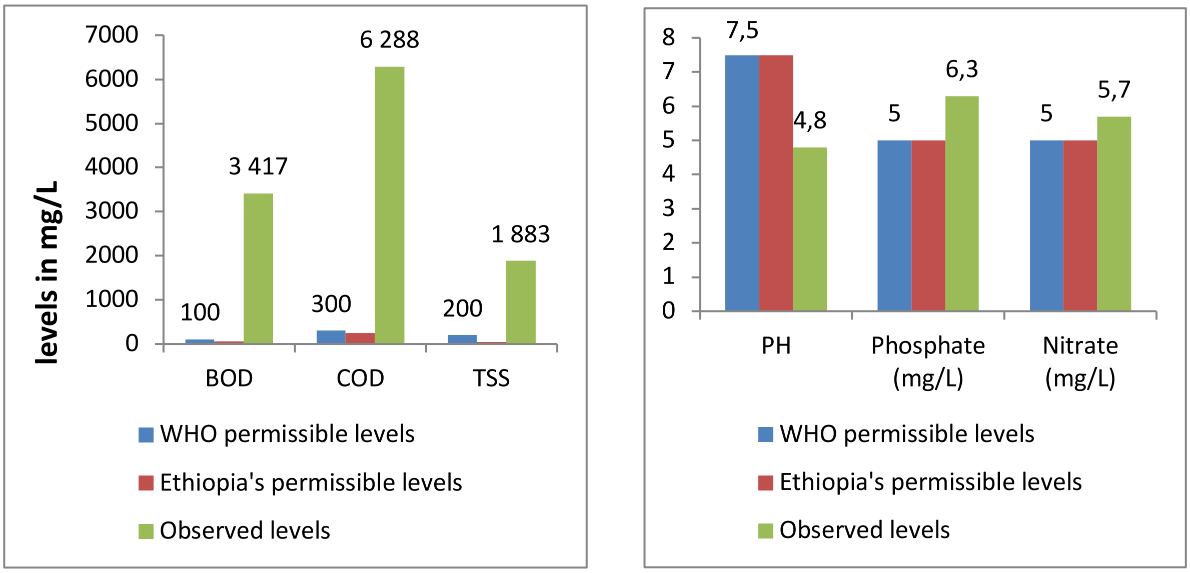

Figure 15: Comparison of observed water quality levels in Ethiopian rivers with waste water discharge with the WHO and Ethiopia's recommended levels

To value the cost of water pollution from wet coffee processing in Ethiopia, we applied the cost of treating the wastewater as a proxy. This is a minimum estimate as the impacts of water pollution to human health and downstream industries are likely to be much higher. There are several approaches to chemically treat wastewater from coffee processing, most of which are applied in industrialized countries (Devi *et al.* 2008). For this study, we use the cost of wastewater treatment using a bioreactor which was designed to treat wastewater from coffee processing plants to permissible levels for irrigation and domestic use. The estimated cost of a bioreactor was adapted from a case study in India conducted by Murthy *et al*. (2004). The bioreactor was designed to handle approximately 8 tonnes of coffee in a day meaning about 24,000 litres of waste water effluents in a day. In addition, the working life for the bioreactor was estimated to be 25 years thus the construction cost was spread over the 25 years to generate the annual capital costs. Table 25 presents the annual treatment cost for the wastewater from coffee processed. The cost comprises of the construction costs of the bioreactor (2,356 USD) and the total annual operating cost (2,998 USD). Thus, the total annual cost of treating wastewater from coffee processing industries which we used as the proxy for water pollution was estimated at 5,354 USD (assuming 8 tonnes of coffee are processed daily). We adjusted the cost values for inflation using Ethiopia's consumer price index to reflect the real value as of 2017.

Table 25: Cost of treating wastewater from coffee processing industries

Cost component	Amount in USD from source	Real value 2017 (USD)	Annual treatment cost**
Construction cost of bioreactor* (2002)	8,210	58,902	2,356
Annual operating costs (2003)	475	2,998	2,998
Total cost			**5,354**

Adapted from Murthy *et al.* (2004)

*The construction cost of the bioreactor was spread over its estimated working life (25years), we assumed straight-line depreciation

**the annual treatment cost is based on the cost of processing 8 tonnes of coffee (24,000 litres of wastewater) per day

Potential of bio-ethanol production from wet coffee processing waste in Ethiopia

Instead of disposing the coffee waste from wet processing into the rivers and water bodies, there is also potential to produce bio-ethanol from the coffee waste (Janissen and Huynh 2018). The bio-ethanol can be utilized as an alternative energy production which reduces the environmental pollution and dependence on oil and petroleum in Ethiopia. It can also provide alternative energy solutions for smallholders. The cost of producing bio-ethanol from the Ethiopian wet coffee processing was estimated at USD 0.45 per litre while the benefit cost ratio was estimated to be >1.05, indicating that the investment in the production of bio-ethanol production from Ethiopian wet coffee processing waste would be economically profitable (Woldesenbet *et al.* 2016). However, despite it being a financially feasible enterprise, there is no bio-ethanol production investment in the Ethiopian wet coffee processing factories which is an area than could be exploited (Woldesenbet *et al.* 2016).

5.1.1.3. Impact of waste discharge from coffee processing on aquatic life

Water pollution has a major ecological impact on aquatic systems in coffee producing countries including Ethiopia (Haddis and Devi 2008; Awoke *et al.* 2016). Water discharge from wet processing coffee industries in Ethiopia has a negative effect on the species diversity in Ethiopia. Beyene *et al.* (2012) provides a comparison of macroinvertebrate diversity in rivers in the Jimma region in Ethiopia between streams that had waste from coffee processing discharged in them (impacted) and those without waste discharge (un-impacted). Macroinvertebrates have proven to be useful bio-indicators to determine the status of freshwater ecosystems, as their community consists of a broad range of species with different tolerances to water pollution and they also respond rapidly to pollution (Troyer *et al.* 2016). Figure 16 shows a comparison of the macroinvertebrate diversity index (Shannon, Alpha and Simpson) for both the impacted and un-impacted streams as reported in Beyene *et al.* (2012). The macroinvertebrate diversity was significantly reduced in the impacted (polluted) streams compared to the un-impacted streams.

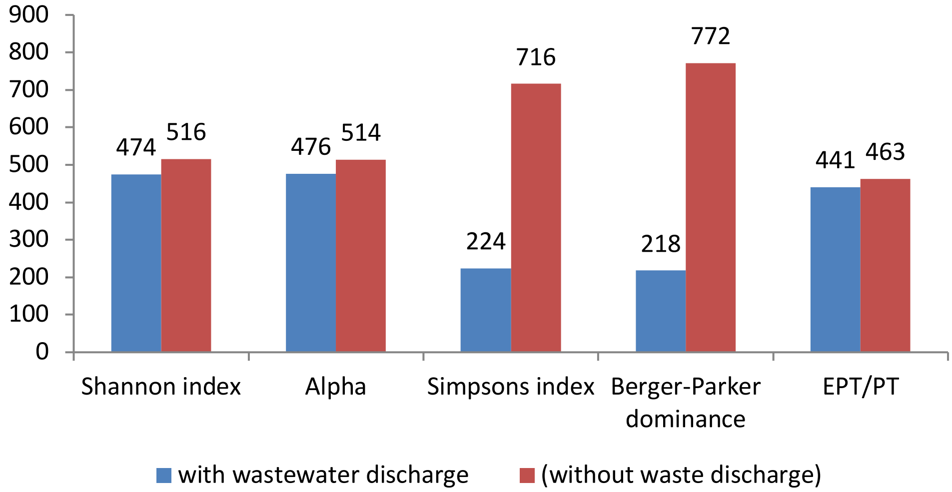

Figure 16: A comparison of aquatic species diversity between polluted (by coffee waste) and non-polluted stream

* EPT Ephemeroptera, Plecoptera, and Trichoptera, PT pollution tolerant. Reproduced from Beyene *et al.* (2012)

Similarly, Awoke *et al.* (2016) compared the aquatic life diversity between rivers that were polluted with coffee waste, and reference rivers (un-polluted) in Ethiopia (mainly rivers in forested areas in Ethiopia). The biological indicators they considered include both diatoms and macroinvertebrates, which are key indicators of water quality and are widely used worldwide for water quality monitoring and assessment. As shown in Table 26, both diatoms and macroinvertebrates indices were much lower for the polluted river points compared to the un-impacted sites, for example, the diatom richness index was 25 times higher within the un-polluted sites compared to the polluted sites. This implies that the coffee processing waste results in loss of aquatic life within the rivers.

Table 26: Effect of water pollution from coffee processing waste on aquatic biological diversity

Diversity indices	**Polluted sites from coffee processing waste**	**Reference sites (un-impacted)**
Macroinvertebrate families		
Richness	5	30
Evenness	0.2	2.0
Simpson diversity	0.3	0.6
Alpha	1.0	1.6
%PT (% of pollution tolerant group)	74.4	13.4
Family Biotic index	9.6	4.5
Diatom species		
Richness	10.0	250.0
Evenness	0.3	0.9
Simpson diversity	1.0	1.6
Alpha	1.3	8.5
%PT (% of pollution tolerant)	52.2	19.5
Biological Diatom Index (IBD)	4.5	14.1
Specific pollution sensitivity index (IPS)	8.8	15.0

Source: Awoke *et al.* (2016)

5.1.1.4. *Impact of agroforestry coffee on the vegetation diversity*

Table 27 presents the vegetation diversity for coffee agroforestry systems compared with vegetation diversity for forests and garden coffee systems in Ethiopia. Vanderhaegen *et al.* (2015) compared vegetation diversity in forest systems, semi-forest coffee systems and garden systems in Ethiopia. As indicated by the biodiversity indices (Shannon's H, observed species richness and the Simpsons diversity index), the vegetative diversity was richest in forest systems followed by semi-forest (agroforestry) coffee systems, and was lowest for the garden coffee. The vegetation diversity (Shannon's H Index) is nearly half in semi-forest coffee (1.28), nearly one third (0.78) in garden coffee compared to forest and forest coffee (2.06) systems (Vanderhaegan *et al.* 2015). Similarly, Tadesse *et al.* (2014) found the total number of forest species in semi-forest coffee systems to be 50% of those found in forests while garden and plantation coffee systems in Ethiopia contain only 21% of the forest species. This highlights the ecological importance of agroforestry systems in maintaining vegetative diversity.

Table 27: Vegetation diversity in coffee agroforestry systems and garden coffee systems

System	Biodiversity index measures	References and comments
Forest	Shannon H -(3.0)	Tadesse (2013)
		Tadesse *et al.* (2014) 137 tree species were identified in the forest systems
	Shannon H (2.06)	Vanderhaegen *et al.* (2015)
	Observed species richness (11.75)	
	Simpsons diversity index (0.82)	
Semi-forest coffee		Tadesse *et al.* (2014) 50% of the tree species found in forests were identified in the semi-forest coffee systems.
	Shannon H (1.28)	Vanderhaegen *et al.* (2015)
	Observed species richness (5.31)	
	Simpsons diversity index (0.64)	
Garden/plantation coffee	Shannon- H (1.9)	Tadesse (2013)
		Tadesse *et al.* (2014) only 21% of the tree species found in forests were identified in garden coffee systems
Home gardens	Shannon H (0.78)	(Vanderhaegen *et al.* (2015)
	Observed species richness (3.11)	
	Simpsons diversity index (0.44)	

5.1.1.5. *Soil nutrient and soil fertility stocks*

Table 28 presents the soil nutrient stocks within the coffee agroforestry systems in Ethiopia. A study by Aerts *et al.* (2011) estimated that there is 0.42-0.46% N in the soils within semi-forest coffee production systems.

Table 28: Soil fertility and soil nutrient stocks in the Ethiopian coffee systems

Service	System	Quantity	Reference
Soil nutrients stocks	Semi-forest	0-42-0.46% N 0.25-0.65 cmol/kgK	Aerts *et al.* (2011)
	Shaded coffee	0.38-0.48% N 1.59-4.98 mg/kgK	Ebisa (2014)
Soil fertility (nutrient flux)	Garden coffee	257 N kg/ha/yr 3828 C kg/ha/yr	Negash *et al.* (2013)

5.1.2. Produced capital

5.1.2.1 Coffee genetic resources

Ethiopia is well noted as the center of origin and diversity of many domesticated crops including Arabica coffee. It possesses all three categories of the gene pool for *C. arabica* (Tewolde 1990). In efforts to collect and document the use of coffee genes in breeding programs, researchers have collected a total of around 11,691 Arabica coffee germplasm accessions from different coffee growing areas throughout Ethiopia. The collections are conserved *ex situ* in field gene banks at Jimma Agricultural Research Center and its sub-centers (5,960 accessions) and in Choche (5,731 accessions), in the Jimma zone of Oromia state, Ethiopia (Gole *et al.* 2002). The collection at Choche is mainly for conservation purposes and is managed by the Ethiopian Biodiversity Institute. If there is market for the diverse coffee genetic resources globally, Ethiopia can earn up to USD 1.5 billion per year, to provide useful genes to the major producers worldwide (Hein and Gatzweiler 2006).

5.1.3. Impact on Human capital

5.1.3.1. Ailments due to processing waste discharged at water bodies

Processing waste from effluent discharges by wet processing coffee plants is one of the causes of negative health effects among the people who reside within the vicinity of these plants (Haddis and Devi, 2008). The World Health Organization (WHO) standard for effluent discharges on land for irrigation and to receiving water has a limit value of (300 mg/l) chemical oxygen demand (COD) and (100 mg/l) biological oxygen demand (BOD) (Haddis and Devi 2008; Tekle *et al.* 2015). The levels of BOD and COD in the water bodies near the processing industries are much higher compared to the WHO recommended levels[16] which would most likely cause negative effects among the surrounding population. Wastewater directly discharged into the nearby water bodies from wet processing industries causes many severe health problems including spinning sensations, eye, ear and skin irritations, stomach pains, nausea and breathing problems among the residents of nearby areas (Haddis and Devi 2008; Woldesenbet *et al.* 2014). A study by Haddis and Devi (2008) found that people residing in the vicinity of a wet coffee processing plant in the Jimma zone in Ethiopia were using stream water which was contaminated. The majority of the population within the vicinity of the river (at least 89%) reported to be suffering from at least one health problem. Table 29 shows the proportion of people who reported having some health problems. About 89% reported having spinning sensations, 85% experienced skin irritation, 75% had breathing problems and 42% had stomach problems. Other less reported ailments include eye irritation (32%) and nausea (25%).

[16] The observed levels are presented earlier in Table 24.

Table 29: Health impact on the community residing in the vicinity of a coffee processing plant, case study of Jimma Zone, Ethiopia

Impacts	**% of population affected**
Spinning sensation	89
Eye irritation	32
Skin irritation	85
Stomach problem	42
Breathing problem	75
Nausea	25

Source: Haddis and Devi (2008).

To estimate the health costs due to the water pollution from coffee processing effluents in Ethiopia, we use the treatment cost as a proxy. Table 30 presents estimates of the cost of treating different ailments which residents within the vicinity of the coffee processing plants reported. The majority of the farmers treat these illnesses with over the counter prescription, hence we apply the approximate costs of these prescriptions. The total treatment cost per person was estimated as follows:

$$Ttc = \sum Ac * prob\ affected$$

Where: Ttc= Total treatment cost per person per dosage

AC=Average cost of treatment per person per dosage

Prob affected=Probability that a random person in the area will be infected with a specific illness.

Hence, the total health cost of water pollution will be the estimated cost per person multiplied by the number of people residing within the vicinity of the coffee processing industries. We estimated the total health cost at approximately USD 54 per person per dosage. However, this cost still does not capture all the costs related to illnesses including hospital visits if any, labour days lost due to the sickness, and potential shortened lifespan. There is therefore a need for more detailed studies to capture all the health costs from water pollution.

Table 30: Cost of the health effects caused by waste from wet coffee processing

Impacts	**Probability a person will be infected**	**Over the counter treatment (drug class)**	**Average cost of one dosage**	**Treatment cost per person per dosage (USD)**
Spinning sensation	0.89	Antiemetics	11	9.79
Eye irritation	0.32	Antihistamines	32	10.24
Skin irritation	0.85	Corticosteroids	18	15.3
Stomach problem	0.42	Antifolate (for diarrhoea)	8	3.36
Breathing problem	0.75	Corticosteroids for asthma and allergies	18	13.5
Nausea	0.25	Antihistamines	8	2

Total treatment costs				54.19

Source of these drugs and cost was global and not specific to Ethiopia https://www.goodrx.com/

5.1.4. Social capital

5.1.4.1. Cultural value of coffee in Ethiopia

Ethiopians are heavy coffee drinkers, ranked as one of the biggest coffee consumers in Sub Saharan Africa. Nearly half of Ethiopia's coffee produce is locally consumed. Coffee in Ethiopia has both social and cultural value and it is mainly consumed during social events such as family gatherings, spiritual celebrations, and at times of mourning (Amamo 2014). The domestication and use of coffee in Ethiopia dates back some 2000 years ago. Some legends of its early consumptions even date it back, around 1000 BC (Illy and Illy 2015). During the early period of domestication, coffee was only used as food by the native Oromo people. The Oromo's in Ethiopia were consuming coffee for centuries and have their own legend of its discovery: "Once upon a time, Waqa, the supreme sky God, punished one of his loyal men with death. The next morning, Waqa visited the burial place, and tears dropped off his eyes. A plant emerged from the soil watered by Waqa's tears, and that was coffee. From this legend, it is believed that all other plants are watered by rain, but coffee is with tears of God. Coffee is always green". In Oromo tradition green symbolizes fertility through which a supreme God, Waqa manifests himself to the people. Hence, coffee has special value in Oromo culture (Wayessa 2011; Gole *et al.* 2013). The Oromo use coffee as a stimulant as well as food (Wayessa 2011). Coffee became known to the rest of the world only during the beginning of the last millennium. It was first brought by traders to Yemen around year 600 (Illy and Illy 2015). The Arabs developed its present use as liquor, and the culture of drinking coffee reached Turkey and Syria during the late 1400s and early 1500s.

Today, the culture of drinking brewed coffee is deep-rooted and widespread, known almost among all ethnic groups in Ethiopia. It is a social drink and is normally shared with neighbours. Every time coffee is made, it is freshly roasted. The coffee ceremony involves sorting, washing and roasting the beans, and preparing boiled coffee in a clay pot known as 'Jabana'. It is often served by a younger woman in the household, in a ceremony that takes an hour or two, and up to three times a day (in the morning, at noon and in the evening). Coffee ceremonies can also be organized at any time of the day if a guest comes, on mourning, conflict mediation or other social events (Gole 2015). The Ethiopian coffee ceremony has been described in detail in Bacha *et al.* (2019).

5.1.4.2. Inequalities within the global coffee value chain

Even though coffee plays such a significant role within the Ethiopian culture, there are wide inequalities in the distribution of the economic benefits. Within the global coffee industry, coffee producers in developing countries including Ethiopia get the least share of benefits among the actors. According to the Coffee Barometer (2018), even though the global coffee industry is increasingly

lucrative with a retail value of USD 200 billion as of 2015, only less than 10% of the aggregate wealth stays in the producing countries. Whereas coffee companies are busy conquering markets, cutting costs and driving efficiency, coffee farmers on their end are struggling to get their fair share of the total value added in the coffee industry. The economic inequality is rising, as prices paid to farmers have been falling for decades often reaching levels well below the poverty line. The coffee sector needs fair prices for farmers, for their livelihoods and for investments to ensure the long-term viability of their farms. Coffee's image as a poverty crop will not help to attract rural youth as they aspire a better future and seek employment outside the coffee sector (Coffee Barometer 2018).

5.2. Flows

5.2.1. Outputs

5.2.1.1. Agricultural and food outputs within the production stage

Table 31 shows the quantities and values of the various agricultural and food outputs compared across three coffee production systems in Ethiopia; semi-forest (agroforestry systems), garden coffee and plantation systems. Garden coffee systems have more intensive management as coffee plants are mostly regenerated from selected wild seedlings or with nursery-raised cultivars. The original forest species are mostly limited to shade trees and in addition a variety of other crops, such as fruit trees, tubers, spices and false banana (*Enset ventricosum*) are grown (Wiersum *et al.* 2007; Abebe *et al.* 2013).

The yield values are sourced from various studies conducted in Ethiopia using either household and plot surveys (e.g., Mitiku *et al.* 2018) or systematic reviews in Ethiopia (e.g. Reichhuber and Requate 2012; Sutcliffe *et al.* 2012). The coffee yields were lower for the agroforestry systems compared to garden coffee. For example, a recent study by Mitiku *et al.* (2018) using household and plot-survey data in Southwest Ethiopia found that intensified garden coffee plots bring about higher yields (858 kg per ha) compared to less intensified semi-forest coffee plots (531 kg per ha). Simillarly, a comparison by Wiersum *et al.* (2007) shows that coffee yields were highest for plantation coffee (750 kg), followed by garden coffee (450kg per ha) and was lowest in semi-forest coffee (150 kg per ha). On average from the various sources, coffee yield was estimated at 850 kg per ha, 594 kg per ha and 395 kg per ha in plantation, garden and semi-forest systems, respectively.

However, there are trade-offs between the amount of coffee produced and other provisioning services among the three productions systems. In addition to coffee, the semi-forest and garden coffee system have other food (honey, enset - false bananas) and non-food outputs (e.g. timber, wood fuel and medicinal plants). The value of wood fuel and timber was higher within the semi-forest systems compared to garden coffee, but the value of non-timber food products was higher within the garden systems compared to the semi-forest system. However, plantation coffee systems tend to be pure monocultures with the objective of maximizing coffee yields. The outputs from semi-forest coffee systems in Ethiopia include timber valued at USD 313 per ha, honey valued at USD 54 per ha, wood fuel valued at USD 209 per ha and other non-timber products valued at USD 4 per ha. Similarly, other products reported in garden coffee systems include; enset-false banana (USD 527 per ha), timber (USD 3), honey (USD 51), wood fuel (USD 13) and medicinal products (USD 0.06 per ha).

Cumulatively, the value of products was highest within the garden systems (USD 927 per ha), followed by the semi-forest systems (USD 808 per ha) and was lowest within the plantation systems (USD 476 per ha). Figure 17 shows a graphical comparison of the various outputs among the three systems.

Table 31: Agricultural and food outputs from agroforestry coffee and garden coffee in Ethiopia

System	Service	Amount	Value (USD per ha)	References and comments
Semi-forest coffee system	Coffee (kg)	531		Mitiku *et al.* (2018)
		150		Wiersum *et al.* (2007)
		450		Agrisystems Ltd. (2001)
		450		ECTA (2018)
		31*		Schmitt *et al.* (2009)
		2020*		Aerts *et al.* (2011)
		2130*		Bote and Struik (2011)
	Average	***395.25***	***221.34***	*Value at USD 0.56 per kg; source Mitiku et al. (2017) ***
	Timber (m3)	1.44	165.37	Sutcliffe *et al.* (2012)
		4	459.36	Reichhuber and Requate (2012)
	Average	***2.72***	***312.36***	
	Wood fuel (m3)	4	277.67	Reichhuber and Requate (2012)
		3.12	18.07	Sutcliffe *et al.* (2012)
	Average		***208.76***	
	Honey		65	Reichhuber and Requate (2012)
			42.63	Sutcliffe *et al.* (2012)
	Average		***54.02***	
	Other non-timber products		***4.37***	Reichhuber and Requate (2012)
	Total		**800.85**	
Garden coffee	Coffee (kg)	858		Mitiku *et al.* (2018)
		450		Wiersum *et al.* (2007)
		318		Tadesse (2013)
		592		Abebe (2005)
		750		ECTA (2018)
		3100*		Bote and Struik (2011)
	Average	***593.6***	***332.42***	
	Timber		3.06	Tadesse (2013)
	Wood fuel		13.19	Namirembe *et al.* (2015)
	Honey		51.19	Abebe (2005)
	Enset false bananas	4395	527.4	
	Medicinal plants		0.06	
	Total		**927.32**	
High tech coffee systems	Coffee (Kg)	750		Wiersum *et al.* (2007)
		950		ECTA (2018)
	Average	**850**	**476**	

*the values were considered outliers and were not used in computing the averages. **the price was sourced from Mitiku *et al.* (2017); farmgate prices of I kg of dry coffee (15.5 ETB per kg, conversion rate=1USD=27.6ETB).

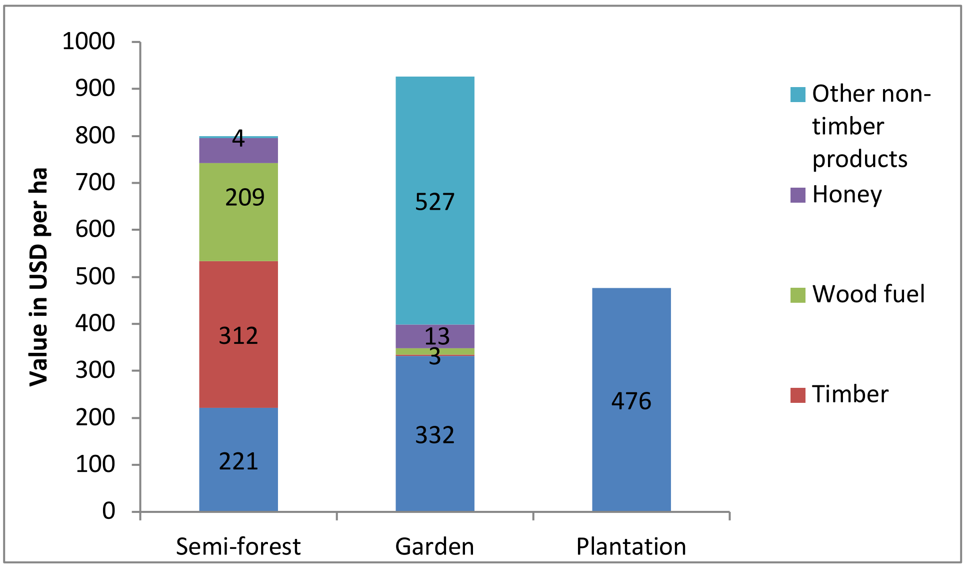

Figure 17: Comparison of agricultural and food products among different coffee production systems

5.2.1.2. Profits in the coffee production stage

Table 32 presents a comparison of the profitability of coffee between shaded coffee and garden coffee adapted from various studies. Following a household survey conducted in Ethiopia by Mitiku *et al.* (2018) among farmers who produced coffee in shaded[17] and unshaded systems, higher economic returns and profits were reported on semi-forest coffee plots[18] compared to garden coffee plots. This was largely attributed to the better prices received by the certified semi-forest coffee farmers due to certification premiums. Namirembe *et al.* (2015)[19] also estimated the gross margins of semi-forest coffee systems and garden coffee in Ethiopia without certification. They however reported higher gross margins in garden coffee compared to semi-forest coffee. This implies that certification of semi-forest coffee might create the right incentives towards farmers for land-sharing between less intensive coffee production and semi-natural forest conservation.

Table 32: Profitability and returns to land and labour at coffee production stage in Ethiopia

System	Financial measure	Value (USD)	References
Semi-forest	Return to land (USD per ha)	415.04	Mitiku *et al.* (2018)
	Return to labour* (USD per person day)	7.72	
	Profits (USD per ha)	331.12	
Garden	Return to land	389.53	

[17] Some of the farmers who produced under the semi-forest system were certified.
[18] The profits and returns estimated by Mitiku *et al.* (2018) were slightly underestimated since benefits from other forest products such as timber, honey, spices and medicines were not accounted for.
[19] The gross margin estimates from Namirembe *et al.* (2015) may be overestimated since they lacked enough data on all the inputs used during production.

	(USD per ha)		
	Return to labour (USD per person day)	4.38	
	Profits (USD per ha)	194.57	
Semi-forest	Gross margin (USD per ha)	571	Namirembe *et al.* (2015)
Garden	Gross margin (USD per ha)	887	

5.2.1.3. Certification premium paid to coffee farmers for maintaining shade trees

In Ethiopia, coffee certification emerged in the early 2000s to certify democratically organized smallholder producer cooperatives mostly through cooperative unions. Fairtrade and Organic certification schemes started in Southwestern Ethiopia in 2005 whereas Rainforest Alliance started in 2007 (Akoyi and Mitiku 2018). Rainforest Alliance certification programs seek to link environmental and economic goals by providing a premium coffee price to producers who maintain shade trees and thereby contribute to the protection of forest cover and biodiversity (Takahashi and Todo 2017). Although not all coffee producers within the semi-forest systems are certified, certified semi-forest coffee usually attracts better market prices (certification price premium) (Mitiku *et al.* 2018). Table 33 indicates estimates of certification premiums paid to coffee farmers. The certification premium in Ethiopia (estimated in 2007) was approximately 15-20% of the regular coffee price (Takahashi and Todo 2017). Similarly, a household survey conducted in South Western Ethiopia by (Mitiku *et al.* 2018) showed the coffee price of certified semi-forest coffee (18.3 ETB per kg) was significantly higher than that of uncertified garden coffee (14.92 ETB per kg). This translates to an estimated certification premium of approximately 22.7% of the regular coffee price. The value of the certification premium in USD per ha was computed as the percentage premium of the value of semi-forest coffee per ha (estimated at USD 46.5 per ha).

Table 33: Certification premium value for coffee in agroforestry systems in Ethiopia

Certification premium % of regular coffee price	Value of premium (USD per ha)	References
15-20%		Takahashi and Todo (2017)
22.7%		Mitiku *et al.* (2018)
21%	46.5*	Average

*The value of certification premium is estimated at 21% of the 221.34 which is the estimated coffee value per ha for semi-forest coffee in Ethiopia as reported earlier in Table 31.

5.2.1.4. Profits earned along the coffee value chain in Ethiopia

Figure 18 show the gross margins earned by the various actors along the coffee value chain in Ethiopia. Following a study by Shumeta *et al.* (2012), exporters take the largest profit margin (51%) in the coffee value chain while producers and local assemblers take the least profit margin (14%). Wholesalers in the town centres take up about 21% of the profit margin.

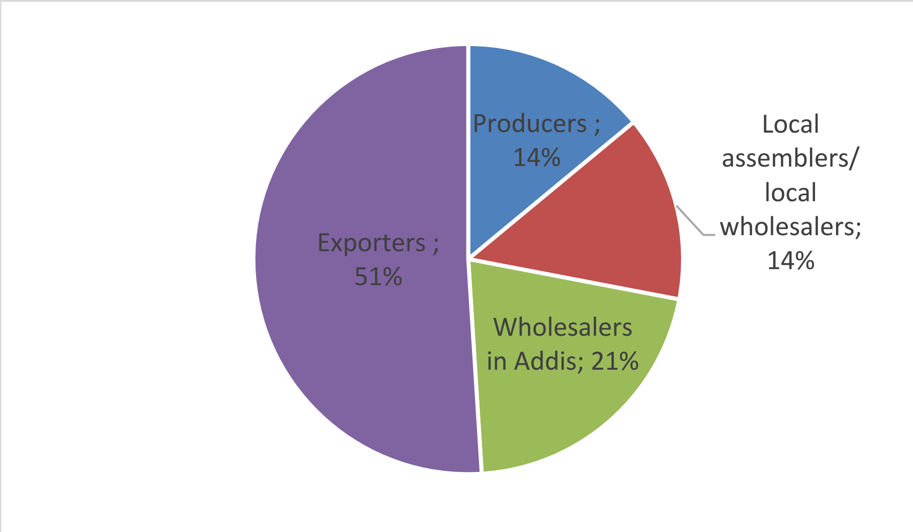

Figure 18: Benefit share of gross profit margins in the Ethiopian coffee value chain
Reproduced from Shumeta et al. (2012)

5.2.2. Purchased inputs

5.2.2.1. Inputs in the production of coffee

In Ethiopia, the use of inputs such as chemical fertilizers and pesticides in coffee production is very low, even in garden coffee systems. Hence, the process of coffee intensification is less associated with capital intensification, and different from the situation where shade coffee is converted into monoculture coffee plantations with high external input use, as observed in other countries (Mitiku *et al.* 2018). Hence for most of the studies on coffee production in Ethiopia, the often-reported input cost is the labour cost. The capital cost reported by Mitiku *et al.* (2018) includes costs such as plot audits for certified coffee plots, seedlings costs and transaction costs such as transportation costs. However, plantation coffee systems are becoming popular in Ethiopia and they are more intensified compared to semi-forest and garden coffee. Thus, input costs will be highest within plantation systems. However, due to data limitations we have not included it in the cost comparisons.

Table 34: Inputs use in the production of coffee

System	Input	Value (USD/ha)	Source
Semi-forest coffee	Labour	606.03	Reichhuber and Requate (2012)
		1,498.38	Sutcliffe *et al.* (2012)
	Average labour	***1,052.2***	
	Capital costs*	2.59	Mitiku *et al.* (2018)
	Total costs	**1,054.79**	
Garden coffee	Labour	1794.25	Ayele *et al.* (2014)
	Capital costs	4.74	Mitiku *et al.* (2018)
	Total costs	**1,799**	

* Capital cost includes costs such as plot audits for certified coffee plots, seedlings costs and transaction costs such as transportation costs.

5.2.2.2. Inputs in the processing of coffee

Water use during coffee processing

The coffee processing industries uses large quantities of water (an average of 147m3/day) for pulping, fermentation and washing of the coffee cherry with no recirculation (Tekle *et al.* 2015). For wet processed coffee (the most popular type in Ethiopia), about 5-15 litres of water are required to recover 1 kg of clean green coffee beans (the actual volume of water used depends on the pulping process, fermentation intensity and coffee bean transportation volume) (Woldesenbet *et al.* 2014; Woldesenbet *et al.* 2015). Similarly, Olani (2018) indicates that about 10-20 litres of water is required to process 1kg of coffee beans in Ethiopia. On average about 15 litres of water are needed to process 1kg of coffee beans. Since most coffee firms use river water from nearby river for processing, we use the shadow prices of natural water in Ethiopia adopted from Gezahegn and Zhu (2015) estimated at 0.30 ETB (USD 0.0109) per M^3. The estimated value is USD 0.16 per tonne of coffee beans processed.

Table 35: Water use during processing of coffee beans (wet processing)

Unit	Quantity	Value (USD per tonne of coffee beans)	References
Litres per kg of coffee beans	15		Woldesenbet *et al.* (2015)
Litres per kg	5-15		Woldesenbet *et al.* (2014)
Litres per kg	10-20		Olani (2018)
M3 per day	147		Tekle *et al.* (2015)
Average Litres per kg of coffee beans	***15***	***0.16***	

Water use in the coffee value chain (total water footprint of coffee)

Table 36 presents the water footprint for green coffee and roasted coffee. The values are sourced from Mekonnen and Hoekstra (2011). The total water footprint comprises of green, blue and grey water footprints, with green water footprints taking up the greatest share and blue water footprints the smallest share. Total water footprint for roasted coffee (18,925 M^3 per tonne) is higher than green coffee (15, 897 M^3 per tonne) (Mekonnen and Hoekstra 2011). Similarly, the total water footprint for roasted coffee as reported by Chapagain and Hoekstra (2007) is higher than that of green coffee. To value the reported water footprint level, we use the shadow prices of natural water estimated at 0.30 ETB (USD 0.0109) per M^3. The total water footprint for green coffee is valued at USD 155.7 per tonne while that of roasted coffee is valued at USD 185.3 per tonne.

Table 36: Total water footprint for coffee products

	Water footprint for coffee products (M^3 per tonne)				Value in USD per tonne of coffee
	Green water footprint	Blue water footprint	Grey water footprint	Total water footprint	
Coffee, green*	15,249	116	532	15,897	
Coffee, green**				12,749	
Average				14,323	155.7
Coffee, roasted*	18,153	139	633	18,925	

Coffee, roasted**				15,177	
Average				17,051	185.3

*the figures are the coffee global water footprint level, extracted from (Mekonnen and Hoekstra 2011)
**the figures are coffee water footprints from Ethiopia, extracted from (Chapagain and Hoekstra 2007)

5.2.2.3. Other direct costs incurred from farm gate to export market

Cost incurred by coffee traders from farm gate to wholesalers/ECX Addis Ababa

After production, Ethiopian farmers sell their coffee to traders who eventually sell it to wholesalers or take it to the ECX. Table 37 presents cost estimates incurred by traders from farm gate to wholesalers adapted from a study by FAO (2014). The costs are estimates for one tonne of coffee from the Jimma region of Ethiopia to wholesalers/the regional ECX in Addis Ababa. For this case, we focus more on the cost distributions than the absolute cost incurred as shown in Figure 19. Processing and handling costs constitutes the largest share of costs (37%), followed by the traders' margins (24%). The major component of processing and handling cost is the impurity loss during cleaning which accounts for approximately 26%. Transport costs in this case only accounts for about 4%. Other administrative costs include; bank and commission (11%), tax and admin costs (13%) and other licensing and operating expenses (11%).

Table 37: Costs incurred by traders from farm gate (Jimma region) to ECX (Addis Ababa)

Cost item	**ETB per tonne**	**%**
Handling and processing cost		**36.84%**
Bags	412	5.97%
Cost of quality inspection at Woreda	3	0.04%
Samplers	6	0.09%
Commission for Agent	312.4	4.53%
Cost of sample coffee (6 kg at district and ECX)	33	0.48%
Impurity loss during cleaning (8% of the producer price)	1776.6	25.74%
Tax and Admin cost		**12.82%**
Municipality tax	91.8	1.33%
Development tax/tax paid to finance	129	1.87%
Warehouse fee (ECX warehouse after 2008)	314	4.55%
Salary for accountant	350	5.07%
Bank and Commission		**11.36%**
Interest on capital	703.8	10.2%
Bank charge	80.6	1.17%
Other costs		**10.39%**
Other operating Expenses	31.6	0.46%
Licensee renewal fee	16	0.23%
Agent commission at trading floor	587	8.50%
Others	82.6	1.20%
Transport cost from farm-gate to wholesale/ECX	**295.8**	**4.29%**
Estimated margins for traders, observed (5% total costs)	***1677.6***	**24.3%**
Total Observed Access Cost from FG to PoC	6902.8	

Source FAO (2014) average 2008-2013

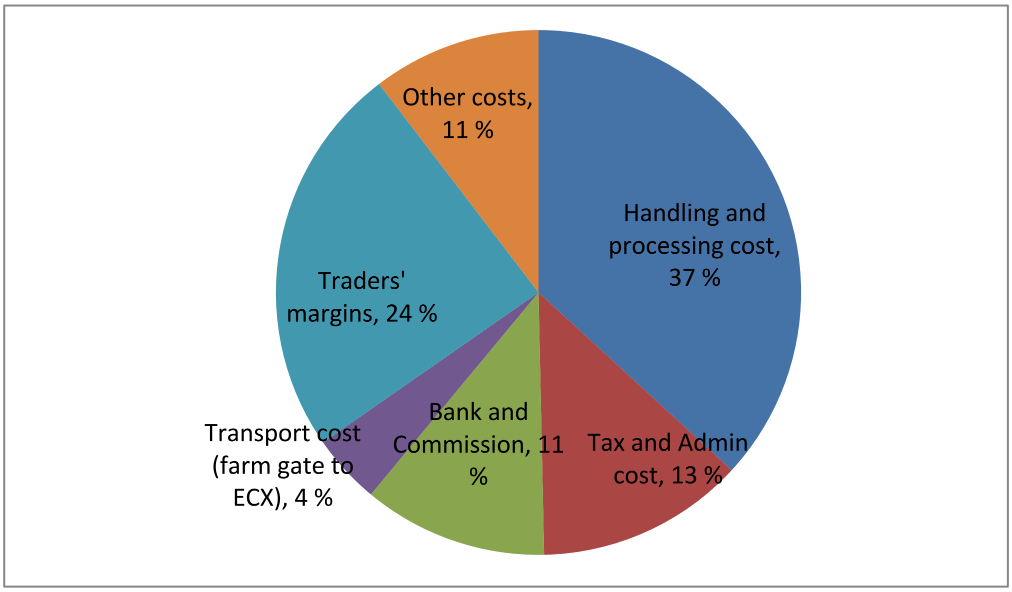

Figure 19: Distribution of costs by incurred by traders from farm gate to ECX centre
Reproduced from FAO (2014)

Cost incurred from the ECX centre to the border (Djibouti)

Since Ethiopia is landlocked, its coffee is exported through the Djibouti border in Somalia. Table 38 and Figure 20 present the distribution of costs incurred in moving coffee from the ECX centre (Addis Ababa) to the border in Djibouti as adapted from FAO (2014). The largest share of these costs are the processing and handling costs (47%), followed by the wholesalers' margin (20%) and transport costs (16%). Again, the largest component of the processing and handling costs is the impurity losses (about 31%). Other cost components include; bank charges (10%), ECX costs (2%), port costs (3%) and other costs (2%).

Table 38: Costs incurred moving coffee from wholesale market and ECX (Addis-Ababa) to border (Djibouti)

Cost item	ETB per tonne	% of total costs
Processing and handling costs		**46.52%**
Cleaning and reprocessing cost	337.4	3.03%
Weight loss during cleaning (1.5% of wholesale price)	427.6	3.83%
Impurity losses (14% of FOB)	3510.2	31.47%
Loading and unloading	52	0.47%
Costs of jute bags	431	3.86%
Marking bags/levelling bags	87.5	0.78%
Storage costs and warehouse fees	199.4	1.79%
Samplers (Wogiwoch) fee	8.034	0.07%
Liquoring Fee/Quality Inspection	19	0.17%
Cost of coffee drawn for sample	116.4	1.04%
Transport cost		**16.37%**
Transport costs from regional ECX warehouse to Addis	870	7.80%

Transport cost from Addis Ababa to port (Djibouti) (and related port costs)	956.2	8.57%
Bank Charges		**10.15%**
Interest on capital	1052	9.43%
Service charge	80.4	0.72%
ECX costs		**2.04%**
Trading fee on value of purchase (0.4%)	176.4	1.58%
Warehouse charge (2.10/bag)	27	0.24%
VAT on services charges	24.4	0.22%
Port costs		**3.32%**
Insurance	68.8	0.62%
Postage, telephone, fax and interest	14	0.13%
Port handling and transit charges	287.8	2.58%
Other costs		**1.68%**
ECEA promotion fee	20	0.18%
Other Miscellaneous expenses*	167	1.50%
Estimated margins for wholesalers (observed 5% total costs)	2221	**19.91%**
Total Observed Access Costs from Border to PoC	11,153.2	

Source (FAO 2014) average (2008-2013)

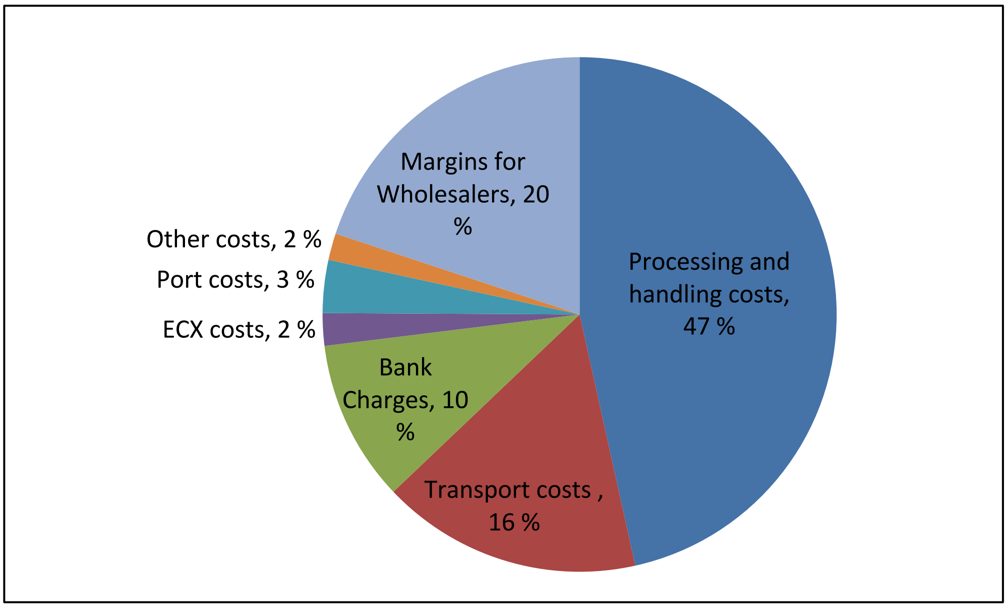

Figure 20: Distribution of costs incurred from wholesale market and ECX (Addis-Ababa) to border (Djibouti)

5.2.3. Ecosystem services

5.2.3.1. Soil erosion control and nutrient cycling

The values for soil erosion control, soil formation and nutrient cycling were adapted from Temesgen *et al.* (2018) which provides values for ecosystem services in agroforestry systems relative to barren lands in the Goedeo region in Ethiopia using the benefit transfer approach. The values were reported in 2007 USD value, using Ethiopia's CPI reported by World Bank (2018) we adjusted them to 2017 USD equivalents.

Table 39: Value for soil erosion control and nutrient cycling within coffee agroforestry systems in Ethiopia

Service	Value (USD per ha)	References
Soil erosion control	773.8	Temesgen *et al.* (2018)
Soil formation	27.42	
Nutrient cycling	136.27	

*at source the values were in 2007 USD; using Ethiopia's consumer price index (CPI) from World bank data we adjusted them to 2017 USD equivalent

5.2.3.2. Pollination services

To impute the economic value of pollination services across the various coffee systems, we infer from values estimated in similar coffee systems in Uganda. The value of bees or the total economic value of pollinating services delivered to coffee by bees in each of the coffee fields was calculated by multiplying their coffee yields by local market prices of coffee beans (USD/kg) and by the pollination dependency factor (Munyuli 2014). The pollination dependency factor for coffee is classified as modest (0.25) according to the FAO array for the economic valuation of pollination[15]. The pollinator dependency factor is an indicator of the pollination contribution to production value per hectare and is influenced by the variation in richness and abundance of pollinators in the coffee fields. The value estimated by Munyuli (2014) were highest for garden coffee (USD 940 per ha), compared to the semi-forest coffee (USD 670 per ha) and highly shaded coffee systems (USD 422 per ha).

Applying the same approach, the pollination value for semi-forest coffee systems in Ethiopia can be estimated by multiplying the pollination dependency factor (0.25) by value of coffee per ha (221.3), approximately (USD 55.3 per ha). Similarly, adapting from Temesgen *et al.* (2018) the value for pollination services in agroforestry systems in the Goedeo region of Ethiopia was estimated at 79 USD per ha. This value was generated by comparing agroforestry systems with barren land.

Table 40: Value of pollination services across various coffee systems

System	Value (USD/ha)	References
Semi-forest (11-50% shade)	668.8	Munyuli (2014) case of central Uganda
Highly shaded (>51-70% shade)	421.6	
Garden coffee	939.5	
Semi-forest coffee	55.3*	Ethiopia
Agroforestry	78.9**	Temesgen *et al.* (2018) Ethiopia

*pollination dependency factor (0.25) * value of coffee (USD 221.3 per ha from Table 31)
**at source the values are in 2007 USD; using Ethiopia's consumer price index (CPI) from World bank data we adjust them to 2017 USD equivalent

5.2.3.3. Water regulating services

Trees regulate the amount of water available in the soil by controlling soil–plant–atmosphere water relations. Soil water content is often higher on farms with trees rather than without trees due to increased infiltration rate, reduced soil evaporation and reduced transpiration (Kuyah *et al.*, 2016). We adopt values from Temesgen *et al.* (2018) indicating the value of water regulation and water treatment in agroforestry systems relative to that of barren lands in Ethiopia. The values were

estimated at approximately USD 10 per ha and USD 83 per ha for water regulation and water treatment respectively.

Table 41: Value of water regulation and water treatment services in agroforestry systems

Service	Value (USD per ha)	Reference
Water regulation	10.13*	Temesgen *et al.* (2018)
Water treatment	82.69*	

*at source the values are in 2007 USD using Ethiopia's consumer price index (CPI) from World bank data we adjust them to 2017 USD equivalent.

5.2.3.4. Biological pest control and coffee berry disease reduction

Shaded coffee has been shown to significantly reduce the incidences of coffee berry disease; the losses as a result of coffee berry disease are significantly higher under full sun coffee compared to shaded coffee Bedimo *et al.* (2008). For example, as presented in Table 42 a study by Bedimo *et al.* (2008) in Cameroon estimated yield loss due to coffee berry disease in full sun coffee system to be about 50% while that in shaded coffee was estimated at about 30%. The 20% yield difference can be interpreted as the value of avoided loss owing to shaded coffee systems. Using the proportion of avoided loss 20%, we computed the value of biological disease control in shaded coffee systems (20% of the total coffee yield value in shaded coffee, USD 221 per ha). This was estimated to be approximately USD 44.2 per ha. The value adopted from Temesgen *et al.* (2018) for biological pest control in agroforestry coffee in Ethiopia relative to barren land is however lower (USD 27 per ha). In another study in Costa Rica, Karp *et al.* (2013) estimated the avoided yield loss due to pests in shaded coffee systems to be approximately 50%. However, this proportion is the loss preventable by biological agents (birds and bats) and may not be fully attributable to agroforestry.

Table 42: Value of biological pest control and coffee berry disease in shaded coffee systems in Ethiopia

System	Quantity (% avoided loss due to pests or CBD)	Value USD per ha	Reference
Shaded coffee	29.59		Bedimo *et al.* (2008)
Full sun (Cameroon)	49.89		
Avoided loss from coffee berry disease	20.3	44.2*	
Shaded coffee (Jamaica)	13.96		Johnson *et al.* (2010)
Various shade levels (Jamaica)	2.06		Kellermann *et al.* (2008)
Shaded (Costa Rica) **	50%**		Karp *et al.* (2013)
Agroforestry		26.58	Temesgen *et al.* (2018)
Garden coffee (Tanzania)	9		Classen *et al.* (2014)

* the value was computed as the proportion of avoided loss (%) of value of coffee agroforestry yield per acre from Table 31 (USD 221.4 per ha)

**the avoided loss is loss prevented by biological agents (birds and bats) and not necessarily attributable to an agroforestry effect.

5.2.4. Residuals

5.2.4.1. Greenhouse gas emissions along the coffee value chain

Table 43 shows greenhouse gas emissions along the coffee value chain in Ethiopia- post production. The GHG emission quantities were sourced from different studies and valued using the market and social price of carbon. Cumulatively, the total emissions from processing, transportation and post-export emissions is approximately 5.75 tonnes CO2e per tonne of coffee beans. Of the three stages, post-export processes have the highest emissions (53%) while transport represented the least emissions (3.6%) (Figure 21).

For GHGs attributed to the processing stage, the quantities of emissions were adapted from a study conducted in neighbouring Kenya aimed at assessing greenhouse gases along the coffee value chain. The total amount of greenhouse gases emitted at the processing stage (wet processing) is estimated at 2.51 tonnes CO2e/tonne of coffee beans (Maina *et al.* 2015) and valued at approximately 16.32-102.91 USD per tonne of coffee beans. Of the total GHGs attributed to processing, the highest proportion (98%) is due to the generation of wastewater from pulping, fermentation and washing of coffee cherry since the fermentation process results in generation of methane which is more potent than CO_2 as far as GHGs go. The rest arises from transport (1.4%) and energy use (0.7%) during processing.

Table 43: Greenhouse gases emission attributable to the coffee value chain

Source of emission	**Quantity (tonnes CO2e /tonne of coffee beans)**	**Value USD /tonne of coffee beans**	**Reference (for quantities)**
Greenhouse gases attributable to wet coffee processing			
Energy use	0.017(0.7%)		Maina *et al.* (2015) (case of Kenya)
Wastewater	2.46 (97.9%)		
Transport	0.036 (1.4%)		
Total processing emissions (wet processing)	***2.51***	***16.32-102.9***	
GHGs from coffee transport (Domestic and International transport) Europe as destination			
Domestic transport	*97.5 kgCO2e/tonne (650km @0.15)*		Hassard *et al.* (2014)
International transport	*110.7 kgCO2e/tonne (12,200km @0.00907)*		
Total transport emissions	***0.208***	***1.35-8.54***	
Post export emissions			
Roasting	0.19 (6%)	1.25-7.79	Killian et al. (2013)
Packaging	0.13 (4%)	0.85-5.33	
Distribution	0.15 (5%)	0.98-6.15	
Grinding +purchasing	0.29 (9%)	1.89-11.89	
Consumption	2.15 (71%)	13.98-88.15	
Disposal	0.14 (5%)	0.91-5.74	
Total post export emissions	***3.05***	***19.825-125.15***	
Total (per tonne of green coffee)	***5.77 tonnes CO2e***	***37.5-236.6***	

Emission during domestic and international coffee transport

Table 43 presents the estimated emissions for transporting Ethiopian coffee, both domestically and internationally (assuming Europe as the destination) sourced from Hassard *et al.* (2014). The total domestic transport emissions were estimated at 97.5 kgCO2e per tonne of green coffee bean based on an estimated distance of 650 km while the international transport emissions were estimated at 110.7 kg CO2e per tonne based on a distance 12,200 km. The emission rate per km is however lower for international transport (by flight at 0.00907 kgCO2e per tonne per km) compared to the domestic transport rate (by lorry at 0.15 kgCO2e per tonne per km). The total value of GHG emissions for both domestic and international transport is estimated at 13.53-85.36 USD per tonne of coffee beans.

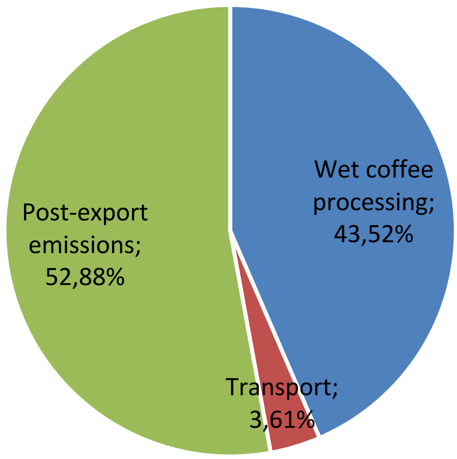

Figure 21: Distribution of GHGs along the Ethiopian coffee value chain (post-production)

Greenhouse gas emissions after coffee export (Europe as destination)

Most of Ethiopian export coffee (>50%) is exported to Europe (Minten *et al.* 2014; ECTA 2018). Thus, Table 43 presents post-export greenhouse gases related to coffee emitted in Europe as estimated by (Killian *et al.* 2013). The carbon footprint related to the processes in Europe is estimated at 3.05 tonnes CO2e per tonne of green coffee and constitute the greatest proportion of the post-production emissions (53%) as shown in Figure 21. The emissions are released during the roasting process (6%), packaging (4%), distribution (5%), grinding and purchasing (9%); the emission at consumption are the greatest (71%), and from the end of phase (disposal) (5%). The consumption stage is the most intensive source of emission and has a big impact on the overall carbon footprint; emissions at this stage come from the high demand of energy required for the preparation of coffee with an automatic coffee machine (Killian *et al.* 2013). The total value of the post-export coffee emissions was estimated at 19.83-125.15 USD per tonne of coffee.

5.3 Summary on Agroforestry coffee in Ethiopia

In this chapter we have provided detailed costs and benefits within the agroforestry coffee value chain in Ethiopia. These include “visible” costs and benefits as well as positive and negative externalities within the value chain. At the production stage of the value chain, we have compared costs and benefits among three coffee production systems commonly practiced in Ethiopia; semi-forest coffee, garden coffee and plantation coffee systems. Key findings include;

- There are trade-offs between coffee yields and other provisioning services among the different coffee production systems in Ethiopia.
- Ecosystem services attributable to the coffee agroforestry systems include carbon sequestration, biodiversity, soil fertility, pollination, soil erosion control, water regulation and treatment, biological pest and disease control.
- Waste water from wet coffee processing constitutes a major environmental cost within the coffee value chain in Ethiopia in terms of human health costs and loss of aquatic life.
- Greenhouse gases are emitted throughout the coffee value chain. Post-production, wet coffee processing constitutes 44% of the GHGs, post-export emissions, 53%, while transport only constitutes 3% of the GHGs within the value chain.

6. Limitations of the study and research gaps

6.1. Limitations of the study

- Data limitations exist especially for the monetary valuation for some ecosystem services and some services along the value chain. Since we did not collect primary data for this study and relied on data from secondary sources, data limitation was a challenge. As a result, for some of the invisible costs and benefits we had to use proxies as approximation of the monetary value. For example, in valuing health costs we applied the treatment costs in estimating the costs. However, this only captures the minimum health costs as it does not capture the cost of hospital visits, opportunity cost of labour days lost as well as the cost of quality of life lost due to the illnesses. Ideally, estimating health costs using DALYs and QALYs gives a more comprehensive estimate of the value of health effects but were constrained by data availability.
  In addition, due to data limitations we could not show the spatial and temporal trends for carbon stocks in both cocoa and coffee production systems.
- There is no consistency in the definition of agroforestry. Since the data was gathered from different studies, we did not have a consistent definition of agroforestry in both cocoa and coffee production systems. The proportion of forests within the cocoa and coffee varies with the various studies of references considered.

6.2. Research gaps

- Assessing the economic value of health-related issues.

There are serious health issues emanating from pesticide use in cocoa farms and cocoa processing in Ghana as well as from the wet coffee processing in Ethiopia. We use the treatment cost as a proxy to value these negative health effects. However, our approach does not capture all the relevant costs. There is need for a more comprehensive study on the health effects probably applying the DALYs and QALYs approach.

- Capturing environmental costs from processing waste and pesticide residues.

For this study, due to data limitations, we used proxies to capture environmental costs due to waste water from coffee processing. For example, to capture the environmental cost of water pollution in Ethiopia, we used the cost of treating the waste water as a proxy. However, this may not fully capture the total environmental cost arising from the waste water. Other aspects such as loss of biodiversity were also not captured in the valuation of the cost of water pollution from coffee processing waste. There is need for a detailed study to fully capture these environmental and ecological costs.

7. Conclusion and policy recommendations

We identified and valued the costs and benefits within agroforestry cocoa and coffee value chains in Ghana and Ethiopia, respectively. This was achieved by applying "The Economics for Ecosystem and Biodiversity for Agriculture and Food (TEEBAgriFood)" Framework. In addition to the "visible" costs and benefits within the agroforestry value chains, there are also externalities that are rarely accounted for due to the lack of a market or price for the goods, services or impact, hence their "invisible" nature. While the visible costs and benefits mostly affect the producer only, invisible costs and benefits may affect or benefit either the person producing the externality, the local community or the global community in some instances. Thus, while assessing the profitability of these different systems, it is important to consider these externalities along the value chain. Some of the negative externalities identified within the value chains include greenhouse gas emissions, waste water from coffee processing, pesticide residues on soils and water, water footprint, and child labour. We have presented a summary of the visible and invisible benefits for both cocoa and coffee in the annex, Table A3 and A4. The tables also present the person and/or community affected or benefitting from these benefits and costs that is either the farmer (producer) or the rural community or the global community.

The majority of the positive externalities identified in this report are within the production stage of the value chain. One of the invisible benefits for both cocoa and coffee agroforestry value chains is biological pests and disease control; agroforestry in cocoa systems in Ghana is a biological control mechanism for cocoa swollen shoot virus disease which is one of the most challenging disease affecting cocoa plants in Ghana. In coffee systems, it is a biological control mechanism for the coffee berry disease. Other benefits associated with agroforestry systems in cocoa and coffee include carbon sequestration, maintaining biodiversity, improving soil fertility, pollination services and soil erosion control.

Owing to the positive and negative externalities within these value chains, there is need for policies that will ensure sustainable value chains. These policies should aim to enhance the positive externalities' "invisible benefits" and reduce the negative externalities' "invisible costs" within these value chains. Table 44 presents a summary of the key externalities identified and policy recommendations for each. A detailed explanation of these policies is also provided later in this section.

Table 44: Policy recommendation from the positive and negative externalities within the value chains

Externalities	Recommended policies
Ecological benefits associated with agroforestry such as: biological pest/disease control, improving soil fertility, pollination services, maintaining biodiversity, carbon storage and so on	-Have policies that encourage paying agroforestry farmers a certification premium in recognition of the ecological benefits associated with agroforestry. This would make agroforestry systems more financially attractive to the farmers. -Need to sensitize consumers on the ecological and environmental benefits from shaded cocoa to increase their willingness to pay shaded cocoa farmers a higher premium.

	-Policies that encourage sustainable intensification practices to maximize these ecological benefits.
Carbon storage within agroforestry systems	-Governments of Ghana and Ethiopia can tap in to the REDD+ programme so that agroforestry farmers can benefit from the carbon storage
Waste from wet coffee processing in Ethiopia	Promote policies that encourage either: -Treating of the waste water before releasing it to the water bodies (rarely happens in Ethiopia since there are no policies or regulations in Ethiopia that require processing industries to treat the waste). -Generating bio-ethanol from the waste which is a financially feasible venture but has not yet been adopted in Ethiopia.
Pesticides effects on human health, soils and water bodies	-Need to train farmers on the proper use of protective gear while applying pesticides. -Strengthen enforcement of existing country's regulations on the type of pesticides to be used.
Child labour effects	-Need to strengthen the policies that the Government particularly Government of Ghana has put in place to curb child labour. -Need to strengthen the enforcement of existing child labour laws and the international labour organization (ILO) regulations on child labour
Imbalances in the global value chains. Producers earn a relatively small margin compared to other actors within the value chain	-Policies that encourage more processing locally particularly in the case of cocoa in Ghana may help increase the share of cocoa benefits accruing to Ghana.

Agroforestry is also a potential for REDD+ (Reducing Emissions from deforestation and forest degradation) as a policy measure. Given the ecological role of agroforestry systems in carbon sequestration such systems could potentially be an interesting climate change mitigation option under the United Nations Framework Convention on Climate Change (UNFCCC). Coffee and cocoa agroforestry systems would provide opportunities to engage millions of smallholder farmers in REDD+ schemes with co-benefits in terms of climate change adaptation, mitigation, and restoration of degraded landscapes (Minang and Duguma 2017). There is thus potential for the governments of Ghana and Ethiopia to tap in to this. The Intergovernmental Panel on Climate Change (IPCC) recommends that countries report forest cover loss and greenhouse gas emissions using an internationally recognized definition, such as that of the UNFCCC. Depending on how a country defines what constitutes a forest, there are several options for relating agroforestry to the REDD+ activities (Minang *et al.* 2014). For Ethiopia, UNFCC defines a forest as having 20% minimum tree cover, minimum area of 0.5 ha and minimum tree height of 2 metres, while for Ghana, the minimum requirement are; 15% tree cover, 1 ha of area and tree height of 5 metres. Based on these country definitions, agroforestry is not by default excluded from being officially regarded as a 'forest'. Rather, it depends on the size of the land, the extent of tree cover and the tree height. For example, when looking at coffee and cocoa agroforestry systems in Ethiopia and Ghana respectively, they meet both countries' definitions of a forest. In contrast, full-sun/low-shade coffee and cocoa plantations often

do not meet the forest definitions in both cases due to the minimum tree height criterion (Minang and Duguma 2017).

Certification premiums are important in enhancing the profitability of agroforestry systems and as a result make the agroforestry production systems economically attractive to the farmers. In Ethiopia, shaded coffee farmers who are certified under the rain-forest alliance certification schemes earn higher returns compared to garden coffee production systems despite the lower yields in shaded coffee. This is because these certified farmers earn a premium of about 21% the price of regular coffee in the market in recognition of the environmental benefits from agroforestry systems. However, within the cocoa production systems in Ghana, full-sun (intensive) cocoa production systems are more profitable than the agroforestry systems. The certified shaded cocoa farmers are paid a premium of approximately USD15 per tonne. There are arguments that the amount of certification premium paid to farmers is not enough to make the cocoa agroforestry systems as profitable as the full sun cocoa systems that even when such premiums are tripled, the profitability of Rainforest Alliance certified cocoa agroforestry systems will still be less than that of an intensive monoculture. Thus, there is need to revisit the certification premium agenda and sensitize consumers within the cocoa value chain on the environmental and ecological benefits of shade trees to increase their willingness to pay for these benefits.

There are massive imbalances in the global cocoa value chain. Cocoa and chocolate companies and retailers take up the bulk of the share-35% and 42%, respectively- while West African farmers (in countries including Ghana) take up only 6.6%. Despite being the largest cocoa producers, Côte d'Ivoire and Ghana process only around 25% of their production, missing out on value that could be extracted from the chain. The majority of the cocoa processing and manufacturing companies are based in the EU especially in the Netherlands, Germany, UK and Switzerland indicating the dominance of the EU in the chocolate value chain. Similarly, most of the retailers are in Europe. This highlights the need to promote cocoa value addition within Ghana and other cocoa producing countries. Similarly, for the benefit share within the coffee value chain in Ethiopia only approximately 16% of the net value goes to the producers (farmers). A greater proportion (about 50%) goes to the exporters. There are efforts within these countries to venture in to higher levels of the value chains through increased processing capacity for example in Ghana, the proportion of cocoa processed from its raw from to other products up to 34% and it targets to increase its efforts to attain 50% of processed cocoa exports[20].

Waste water from wet coffee processing industries constitutes major environmental and health costs. Wet coffee processing industries in Ethiopia are increasing due to the high demand of wet processed coffee compared to dry processed coffee. The wet coffee processed industries are located within the vicinity of river bodies since the process is highly water-intensive and the rivers also serve as discharge points for the waste water from processing. A comparison of the chemical properties of water at these discharge points with the WHO and Ethiopia's recommended levels indicate very high pollution levels in these water bodies. The waste water disposed-off in the rivers has resulted in the loss of aquatic biodiversity within these water bodies and negative health effects among people living near. Although this waste water can be treated prior to being discharged into the river bodies, the coffee firms in Ethiopia do not treat the waste water since there are no regulations in Ethiopia that require them to.

[20] https://goodmanamc.blogspot.com/2017/05/ghanas-cocoa-processing-industry.html

In addition, there is potential to generate bio-ethanol from the waste for energy purposes instead of disposing the waste in to water bodies. Financial projections show that this would be profitable and feasible in Ethiopia. Currently, there is no bio-ethanol production investment in the Ethiopian wet coffee processing factories which is an investment area than can be exploited and promoted. There is also need for policies and regulations within Ethiopia that require the wet coffee processing industries to treat the waste water.

Pesticide use in the cocoa production in Ghana also constitute huge environmental and health costs. Health costs are mainly during pesticide application since the majority of farmers do not use protective gear while applying the pesticides. Environmental costs are also attributable to the pesticide residues in the soils and water bodies. Cocoa processing has also been found to cause soil degradation through the acidification process from the pollutants released in the air. Ghana has put policies in place that promote the safe use of pesticides and discourage the use of organochlorines. There is therefore a need to strengthen the enforcement of these policies as well as offering regular training to the farmers on safe handling of pesticides.

Child labour in the cocoa sector comprises a huge social cost to Ghana's economy. In 2013/14, 43% of the children in Ghana's cocoa producing areas were working in cocoa production, 41% were involved in some form of child labour while 39% were involved in hazardous work within the cocoa sector. This poses high costs including health costs since these children acquire injuries while working in the farms. In addition to the health issues affecting the working children, some of them are deprived of education. Without an education, the children of the cocoa farms have little hope of ever breaking the poverty cycle. In addition to the existing laws on child labour, the existing certification standards for cocoa in Ghana highly discourage employing child labour in cocoa production. Although all certification schemes prohibit child labour explicitly, no single certification label can guarantee that the chocolate was made without the use of exploitive child labour, probably because information on child labour or forced labour use is not always readily available. However, the government of Ghana has made efforts to address this. For example, recently (2017), the government of Ghana implemented a policy for free primary and secondary education in Ghana. This move is expected to encourage all the children including those from poor backgrounds to attend school and this will in return reduce the prevalence of child labour within Ghana's cocoa farms. However, there is still a need to strongly enforce the current laws and policies around child labour in Ghana.

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Annex

Table A1: TEEBAgriFood evaluation framework for agroforestry cocoa value chain in Ghana

CHECKLIST TO ASSESS COVERAGE OF A GIVEN TEEBAGRIFOOD FRAMEWORK APPLICATION		**Value chain**			
		Agricultural production	Manufacturing & processing	Distribution & marketing	Household consumption
Stocks / Outcomes (change in capital stock)					
Natural capital	Water (incl. quality, quantity)	Water footprint; Pesticides leaching and chemical fertilizers runoff and leaching	Water pollution from processing waste in to the water bodies; water used during processing		
	Soil (incl. quality, quantity)	Erosion control, Nutrient cycling & soil fertility Soil carbon stocks			
	Air (discussed under residuals)				
	Vegetation cover and habitat quality	pollination, biological pest control			
	Biodiversity	Vegetative diversity	Loss of aquatic organisms from water pollution		
	Other				
Produced capital	Buildings				
	Machinery and equipment		Machinery used in manufacturing and processing	Transportation equipments; machinery used in packaging and branding	
	Infrastructure				
	Research and development				
	Finance				
	Other				

Human capital	Education / skills				
	Health	Ailments due to use of pesticides	Human health effect due to waste from processing		Improved nutrition from the benefits of growing cash crops
	Working conditions (decent work)	Creation of employment opportunities	Employment opportunities	Employment opportunities	Employment opportunities
	Other				
Social capital	Land access/tenure (private, public and communal)				
	Food security (access, distribution)				
	Opportunities for empowerment (gender and minority)	Gender aspect Inequalities within the global cocoa value chain			
	Social cooperation (incl networks/unions)				
	Institutions				
	Laws and regulations (e.g. child labor)	Child labour and forced labour within cocoa production in Ghana			
	Other				
Flows					
Agricultural and food outputs	Agricultural and food products	Cash crops, wild fruits, medicine, honey			
	Income: value added, operating surplus	income flows from production, timber, charcoal, wood fuel, wild fruits	Incomes from value addition		income flow from exports and domestic markets

		Profits from sale of coffee/cocoa timber, wild fruits and so on. Certification premium paid to cocoa famers for maintaining shade trees			
	Subsidies, taxes and interest				
Purchased inputs	Labour inputs (incl skills)	Labor inputs (hired and family) in land preparation, fertilizer & pesticides application, crop management, harvesting and post-harvest handling	Labor incurred during cleaning, drying, transportation, processing and packaging	Labour incurred during transportation and marketing	
	Intermediate consumption (produced inputs such as water, energy, fertilizers, pesticides, animal health and veterinary inputs)	Inputs-land, water, fertilizers, seeds, pesticides, herbicides, machinery, oxen	Inputs-water, machinery, energy costs i.e fuel costs, wood &solar, packaging materials,	Inputs-fuel costs, Water use certification fees, transaction costs in negotiating contracts, branding costs, transportation costs	Water use
Ecosystem services	Provisioning (e.g. biomass growth, freshwater)				
	Regulating (e.g. pollination, pest control, nutrient cycling)	Soil erosion control, biological pest control, pollination	Aquatic biodiversity loss from water pollution		
	Cultural (e.g. landscape amenity)				
Residuals	Agricultural and food waste	Pre-harvest, harvest and Post-harvest handling losses at farm level	Losses during storage and processing	Storage and distribution losses	Food waste at consumption level
	GHG emissions	GHG flows	GHG emissions	GHG emissions	
	Other emissions to air, soil and water	Chemical residues- N& P residuals from inorganic			

		fertilizers; pesticides runoffs			
	Wastewater		Waste water		
	Solid waste and other residuals				

Table A2: TEEBAgriFood evaluation framework for agroforestry coffee value chain in Ethiopia

CHECKLIST TO ASSESS COVERAGE OF A GIVEN TEEBAGRIFOOD FRAMEWORK APPLICATION		**Value chain**			
		Agricultural production	Manufacturing & processing	Distribution & marketing	Household consumption
Stocks / Outcomes (change in capital stock)					
Natural capital	Water (incl. quality, quantity)	Water footprint; Pesticides and chemical fertilizers runoff and leaching	Water pollution from processing waste in to the water bodies; water used during processing		
	Soil (incl. quality, quantity)	Erosion control, Nutrient cycling & soil fertility Soil carbon stocks			
	Air	Change in GHG concentration	Change in GHG concentration	Change in GHG concentration	Change in GHG concentration
	Vegetation cover and habitat quality	pollination, biological pest control			
	Biodiversity	Vegetation diversity	Loss of aquatic organisms from water pollution		
	Other				

Produced capital	Buildings				
	Machinery and equipment		Machinery used in manufacturing and processing	Transportation equipments; machinery used in packaging and branding	
	Infrastructure				
	Research and development	Coffee genetic resources in Ethiopia			
	Finance				
	Other				
Human capital	Education / skills				
	Health	Ailments due to use of pesticides	Ailments due to waste from processing		Improved nutrition from the benefits of growing cash crops
	Working conditions (decent work)	Creation of employment opportunities	Employment opportunities	Employment opportunities	Employment opportunities
	Other				
Social capital	Land access/tenure (private, public and communal)				
	Food security (access, distribution)				
	Opportunities for empowerment (gender and minority)				
	Social cooperation (incl networks/unions)	Certification premium paid to coffee famers for maintaining shade trees		Benefits accruing from involvement in marketing co-operatives	
	Institutions				

	Laws and regulations (e.g. child labor)				
	Other				Cultural value of coffee in Ethiopian households
Flows					
Agricultural and food outputs	Agricultural and food products	Cash crops, wild fruits, medicine, honey			
	Income: value added, operating surplus	income flows and profits from production, timber, charcoal, wood fuel, wild fruits Certification premium from shade coffee	Incomes from value addition		income flow from exports and domestic markets
	Subsidies, taxes and interest				
Purchased inputs	Labour inputs (incl skills)	Labor inputs (hired and family) in land preparation, fertilizer & pesticides application, crop management, harvesting and post-harvest handling	Labor incurred during cleaning, drying, transportation, processing and packaging	Labour incurred during transportation and marketing	
	Intermediate consumption (produced inputs such as water, energy, fertilizers, pesticides, animal health and veterinary inputs)	Inputs-land, water, fertilizers, seeds, pesticides, herbicides, machinery, oxen Water footprint	Inputs-water, machinery, energy costs i.e fuel costs, wood &solar, packaging materials,	Inputs-fuel costs, certification fees, transportation costs	
Ecosystem services	Provisioning (e.g. biomass growth, freshwater)				
	Regulating (e.g. pollination, pest control, nutrient cycling)	Soil erosion control, biological pest control, pollination	Aquatic biodiversity loss from water pollution		
	Cultural (e.g. landscape amenity)				

Residuals	Agricultural and food waste	Pre-harvest, harvest and Post-harvest handling losses at farm level	Losses during storage and processing	Storage and distribution losses	Food waste at consumption level
	GHG emissions	GHG flows	GHG emissions	GHG emissions	GHG emissions
	Other emissions to air, soil and water	Chemical residues- N& P residuals from inorganic fertilizers; pesticides runoffs			
	Wastewater		Waste water		
	Solid waste and other residuals				

Key

	Monetized information available
	Quantitative information available
	Descriptive information available
	No information yet/not included

Table A3: Summary of visible and invisible costs and benefits within the agroforestry cocoa value chain in Ghana

Service	**Visible benefit**	**Invisible benefits**	**For Whom (Farmer F, Rural community RC, Global community GC)**	**Data from Ghana**	**Benefit transfer (outside Ghana)**	**Value chain stage (Production P processing PR, Distribution &marketing D, Consumption C)**	**Monetary valuation**
Cocoa	X		F	X		P	X
Timber	X		F	X		P	X
Non-timber food products (NTFPs)	X		F	X		P	X
Biological pest control		X	F, RC		X	P	X
Pollination services		X	F, RC		X	P	X
Carbon storage		X	F, GC	X		P	X
Soil nutrient stocks		X	F	X	X	P	
Biodiversity		X	F, RC, GC	X		P	
Gross margins/ benefit share among actors	X		F, GC	X	X	P, PR, D	X
Certification premium from shaded cocoa	X		F	X		P, C	X
Costs	**Visible Costs**	**Invisible Costs**	**For Whom (Farmer F, Rural community RC, Global community GC)**	**Data from Ghana)**	**Benefit transfer (outside Ghana)**	**Value chain stage (Production P processing PR, Distribution &marketing D, Consumption C)**	**Monetary valuation**
Fertilizers	X		F	X		P	X
Agrochemicals	X		F	X		P	X
Labour	X		F	X		P	X
Energy costs during processing	X		GC	x		PR	X
Water footprint	X	X	F, GC		X	P, PR, D, C	X

FOB cost share	X		F, RC	X		P, D	X
Transport cost	x			X	X	D	X
Human health effects from pesticides and processing waste		X	F, RC	X		P, PR	X
Children health effects from child labour		X	RC	X		P	
Child labour effects		X	F, RC	X		P	
Greenhouse gases from production		X	GC	X	X	P	X
GHGs emissions from processing		X	GC		X	PR	X
GHGs emission during transport		X	GC		X	D	X
GHGs emissions during packaging		X	GC		X	C	X
Water pollution from pesticides & cocoa processing waste		X	RC	X		P, PR	
Water pollution (Eutrophication)		X	RC	X		P	
Waste emissions to soil from pesticide use		X	RC	X		P	

Table A4: Summary of visible and invisible costs and benefits within the agroforestry coffee value chain in Ethiopia

Service	**Visible benefit**	**Invisible benefits**	**For Whom (Farmer F, Rural community RC, Global community GC)**	**Data from Ethiopia**	**Benefit transfer (outside Ethiopia)**	**Value chain stage (Production P processing PR, Distribution &marketing D, Consumption C)**	**Monetary valuation**
Coffee	X		F	X		P	X
Timber	X		F	X		P	X
Non-timber food products (NTFPs)	X		F	X		P	X
Carbon storage		X	F, GC	X		P	X
Biodiversity		X	F, GC	X		P	
Soil erosion control		X	F, RC	X		P	X
Soil formation		X	F, RC	X		P	X
Nutrient cycling		X	F, RC	X		P	X
Pollination services		X	F, RC	X	X	P	X
Water regulation & water treatment		X	F, RC	X		P	X
Biological pest control		X	F, RC	X	X	P	X
Profit margins for various actors within the value chain	X		F, RC, GC	X	X	P, PR, D	X
Certification premium from shade trees	X		F	X		P, C	X
Costs	**Visible Costs**	**Invisible Costs**	**For Whom (Farmer F, Rural community RC, Global community GC)**	**Data from Ethiopia**	**Benefit transfer (outside Ethiopia)**	**Value chain stage (Production P processing PR, Distribution &marketing D, Consumption C)**	**Monetary valuation**
Labour costs at production	X		F	X		P	X
Capital costs at production	X		F	X		P	X
Water use during processing	X		RC	X		PR	X
Water footprint	X	X	RC	X	X	P, PR, D, C	X

Direct costs from farm gate to wholesalers/ECX	X		RC, GC	X		PR, D	X
Direct costs from wholesalers/ECX to export border	X		RC, GC	X		PR, D	X
Water pollution from coffee processing waste		X	RC	X	X	PR	X
Loss of aquatic life from processing waste		X	RC, GC	X		PR	
Human health effects from processing waste		X	RC	X	X	PR	X
Greenhouse gases from coffee processing		X	GC		X	PR	X
Greenhouse gases from coffee transport		X	GC		X	D	X
Greenhouse gases post-export		X	GC		X	D, C	X

Table A5: **World Health Organization (WHO) and Ethiopia's permissible limits for the treated effluents to be discharged on land/water for irrigation**

Parameter	WHO permissible levels	Ethiopia's permissible levels
PH	6.5-8.5	6-9
Biological oxygen demand (BOD) mg/L	100	60
Chemical oxygen demand (COD) mg/L	300	250
Total suspended solids (TSS) mg/L	200	50
Phosphate (mg/L)	5	5
Nitrate (mg/L)	5	5

Source: Haddis and Devi (2008)