Evaluating the implications of the "National Comprehensive Program for the Substitution of Illicit Crops" in Colombia.

By Juanita Barrera Ramirez

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In partial fulfillment of the requirements for the degree of Master of Science in Industrial Ecology at Leiden University and Delft University of Technology.

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ABSTRACT

The peace treaty of Colombia has promised to end over fifty years of armed conflict, which has been significantly financed by the cultivation and processing of illicit crops. The treaty contemplates a substitution policy that offers financial incentives and social investment to the coca-growing communities to replace their illicit crops by legal alternatives. This study examines the substitution policy tradeoffs in the Putumayo-Caquetá and the Catatumbo regions, by applying Life Cycle Assessment framework coupled with socioeconomic indicators, to four scenarios. Implications of coca cultivation and its derivatives (Business-as-Usual scenario) were evaluated and contrasted with the successful implementation of the policy (Policy Success scenario), a partial substitution of the illegal crops (Conservative scenario) and the geographical displacement of coca cultivation (Balloon Effect scenario).

Compared to the Business-as-Usual scenario, Policy Success, and Conservative scenarios mitigate photochemical oxidation, ozone layer and abiotic resources depletion environmental impacts in both regions. In contrast, acidification and eutrophication in the Catatumbo region and toxicity impacts in the Putumayo-Caquetá region worsen. For both regions, Balloon Effect scenario increases the environmental burden in almost all the categories evaluated. The socioeconomic analysis reveals that for the Catatumbo region farmers, successful implementation of the policy implies a reduction on their income .For coca-growing farmers of Putumayo-Caquetá region, Policy Success scenario has a positive impact on the income and job generation, while Conservative and Balloon Effect reduce the profit. In general, it was observed that the dynamics of the illegal chain varies from region to region, influencing the environmental and socioeconomic outcome of the substitution policy.

ACKNOWLEDGES

At the end of 2016, I was finishing the LCA course, and at the same time, I started thinking about my thesis project. Reading about the great number of benefits the peace treaty would bring to my homeland and also the challenges that it would represent, gave me the idea of conducting an LCA of the peace treaty in Colombia. And that was the beginning of my thesis journey

I shared my thoughts with Valentina Prado and Havar Solheim, who were very enthusiastic about the idea and agreed to be my supervisors. Thanks to their guidance I managed to define the boundaries of my work. They always patiently listened to all my questions and concerns and helped me to find the best solution. Their invaluable feedback helped me to enhance the quality of my study.

I am very grateful with Hernando Bernal, Laura Castro and German Abaunza from UNODC in Colombia. Thanks for providing me all the data necessary for quantifying the environmental impacts of the cocaine production in Colombia. Without their help and time, this work could not be possible.

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Thanks to my brother for being the endless source of inspiration and admiration. My eternal gratitude to my parents and my grandma Julia, for always encouraging me to pursue my ideas and dreams. For their love and unfailing support, even from distance I knew you were always by my side.

I want to thank Carolina, Juanita, Mariana, Stella, Nana, and Naty, who made available their support in some many ways. To all my EI friends thanks for the interesting discussions that made me reaffirm that a sustainable world is possible. Thanks for filling my heart with so many warm memories.

Last but not least I want to thank my country for giving me the opportunity of being part of the “peace building generation.”

Muchas gracias!

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GLOSSARY

Biodiversity: the variety of different species of plant and animal in a place, habitat or environment.

Illegal crops: the plants that are grown for the manufacture of illegal narcotics

Balloon effect: analogy used to describe the displacement from one region to another of the illicit coca cultivation and drug production when policies and eradication efforts are taking place.

Regions: Refers to socioeconomic areas of the country that share economic, geographical, cultural, and characteristics

Substitution policy: term used in this paper for referring to the National Comprehensive Program for the Substitution of illicit crops

Alkaloid: a basic, nitrogen-containing natural product. Basic component of the coca leaves.

Raspachines: the coca leaf collectors

Jornalero: people employed on a temporary, day-to-day basis, especially as an unskilled laborer to work on agriculture.

Jornal: working day of the jornalero.

Guarapo: mother liquor from coca-paste precipitation. This liquid is dumped into the environment or used as fertilizer on the coca fields.

Tertiary roads: unpaved urban and suburban roads.

LIST OF ABBREVIATIONS

LCA-Life Cycle Assessment

FARC-Fuerzas Armadas Revolucionarias de Colombia

BACRIM- organized crime groups (Bandas Criminales)

ELN- Ejército de Liberación Nacional

EPL- Ejército Popular de Liberación

UNDOC-United Nations Office on Drugs and Crime

DNP- Departamento Nacional de Planeación

FIP- Ideas for Peace Foundation (Fundacion Ideas para la Paz)

USAID- United States Agency for International Development

OIM- International Organization for Migration

ADP- Alternative development programs

BAU-Business as Usual

PS-Policy Success

CO-Conservative

BE-Balloon effect

CT- Catatumbo

PC- Putumayo-Caquetá

COP $- Colombian pesos

MJD Ministerio de Justicia y del Derecho

SIA- Servicio de Información Agropecuaria

CCI- Corporación Colombia Internacional

1. INTRODUCTION

After almost four years of negotiations, the Colombian government and the guerrilla "Revolutionary Armed Forced of Colombia" (FARC-Fuerzas Armadas Revolucionarias de Colombia) have finally reached a structured peace treaty to end over five decades of armed conflict (*Acuerdo final para la terminación del conflicto y la construcción de una paz estable y duradera*, 2016). The treaty is a milestone in the Colombian history, promising to be the beginning of a transitional process, towards rural development, victims' reparation, and political inclusion. Throughout its history, this conflict has caused thousands of deaths including non-combat killings, abductions, extortion, forced displacements, landmine victims, the involvement of child soldiers, and actions that account for a significant number of casualties. The FARC also carried out attacks on several small towns and cities and infrastructure, especially oil pipelines and power towers (Otis, 2014; WOLA, 2016a). The conflict has contributed substantially to the economic stagnation of the country while fostering the expansion of drug trafficking. Currently, Colombia is the world´s largest producer of coca leaves (Dávalos et al., 2011). In 2015 alone an average of 450,000 metric tons was produced (UNODC, 2016a)

The FARC became involved in the illicit drug business in the 90´s as a way to finance its operations. In 2012 it provided them with an income between $2.4 billion and $3.5 billion (Otis, 2014; Ramsey, 2012), which is almost the same revenue generated by the coffee industry in Colombia in the same year (Federación Nacional de Cafeteros de Colombia, 2013). Profits from the drug business were used for the acquisition of weapons, military gear, supplies, and in general, to strengthen its military structure (Otis, 2014). Current reports indicate the FARC had almost six thousand rural fighters (El Tiempo.com, 2016; infobae, 2016), who were present in nearly all the coca's growing-processing areas in the country, i.e. the Catatumbo region and the Southern departments (Matiz Cortes, 2016). Through these rural fighters, the FARC was to exercise a monopoly over drug trafficking, comprising coca fields, processing laboratories, and smuggling corridors.

Regarded as the principal fuel of the conflict, illicit crops have also contributed to the social and environmental damage. In 2015, 31% of the total deforestation in Colombia was associated with coca cultivation. The loss of forest coverage was mainly concentrated in 7 departments: Nariño, Putumayo, Norte de Santander, Cauca, Caquetá, Meta and Antioquia (REDD+ Colombia, 2017). It is estimated that between one and two hectares are deforested for each hectare of coca planted (Jelsma, 2001; Suarez, Árias-Arévalo, & Martínez-Mera, 2017). Before the cultivation and harvesting process, the land is cleared by "slash and burn" techniques, increasing soil erosion and contributing to carbon dioxide emissions (UNODC, 2015). Apart from deforestation, the cleared land is not suitable for agriculture. Thus a considerable amount (The Guardian, 2008) of fertilizers, herbicides, and pesticides are needed to replant coca, broadening the impact on sensitive ecosystems (Rincon-Ruiz, Correa, Leon, & Williams, 2016). Additionally, to transform the coca leaves into cocaine, large quantities of gasoline, alkaline bases, sulfuric acid, ammonia and potassium permanganate are required. The waste generated during the processing is directly discharged into nearby water bodies (Count the cost, 2012; The Guardian, 2008; UNODC, 2015) affecting water resources and the broader ecosystems through infiltration and runoff (Policía Nacional, 2014). It is calculated that in Colombia nearly 6.8 kilograms of cocaine hydrochloride are produced per hectare of coca leaves harvested (UNODC, 2016a).

High levels of poverty, the absence of governmental institutions, unsatisfied basic needs, and precarious public infrastructure have helped to spread the coca cultivation throughout the country (Santamaría, 2015). For those lacking opportunities for education and jobs, coca harvesting and processing has become the only way through which earn a livelihood. However, coca cultivation is not only driven by economic incentives. Guerrilla movements and organized crime groups have threatened farmers to force them to participate in the cocaine production chain (Argüello, 2010; Brunner & Grande, 2017; Kraul, 2006). In 2015, 74,500 households (nearly 290,000 Colombians farmers) were involved in the coca cultivation and alkaloid extraction (UNODC, 2016a). The number of people that are engaged in the "coca enterprise" is comparable with the number of employees of PepsiCo in the USA.

The dissemination of the illegal crops contributed to massive displacement and land grabs, increasing the incidence of violence (Otis, 2014), child labor and school abandonment (Salgar Antolínez, 2016). Considering the ties of the illicit crops and the armed conflict in Colombia, illegal drug trafficking was one of the core points of the peace treaty. As a result, an innovative policy "National Integral Program for the Substitution of Illicit Crops" (referred in this study as substitution policy) was launched in 2017, focusing on crop substitution and manual eradication (Gobierno de Colombia, 2015; Redacción Política, 2017; Semana.com, 2017b). The goal of the substitution policy is to bring about a structural transformation of the regions affected by coca cultivation, by mobilizing resources for closing social gaps and increasing the job opportunities. During the first year, the policy foster the eradication and substitution of approximately 50,000 hectares of coca in the 40 municipalities with the greater presence of coca plantations (Acosta & Murphy, 2017). Along with the replacement of illegal crops, the policy considers the improvement of the living conditions of the communities involved, by infrastructure, education programs, access to sanitation and electricity and technical assistance (Gobierno de Colombia, 2015). The substitution policy contemplates the participation of the demobilized members of the FARC. They will help with the manual uprooting of coca plants (Otis, 2014) and give support to the community as a whole while substituting illicit crops (*Acuerdo final para la terminación del conflicto y la construcción de una paz estable y duradera*, 2016)

The substitution of the illegal plantations is a multifaceted challenge, because of the diversity of stakeholders involved and the different characteristics of the regions affected. The purpose of this study is to assess the environmental and socioeconomic effects of the implementation of the substitution policy in the Putumayo-Caqueta and Catatumbo regions. The Life Cycle Assessment framework will be applied to quantify the environmental burden caused by the coca processing and the substitution crops (cacao, coffee, and sugarcane). The socioeconomic impacts of the substitution policy will also be evaluated, taking into account the profit earned by farmers and daily workers (*jornaleros*) and the workforce demand (number of *jornales*).

The first part of this work reviews the background of the coca cultivation and trafficking in Colombia and strategies executed by the Colombian government to confront the drug production in the country. Then, geographical and socioeconomic characteristics of the Putumayo-Caquetá and Catatumbo region are presented, explaining how those aspects have been contributed to the dissemination of the coca cultivation.

The following section introduces the scenarios contemplated in this study, considering the different potential outcomes of the implementation of the substitution policy. Afterward, the Life Cycle Assessment methodology, along with the socioeconomic indicators are described and applied. Then, the socioeconomic and environmental analysis is performed within four scenarios.

A comparison of the environmental and socioeconomic results of the scenarios is presented, focusing on the trade-offs identified and the factors influencing the consolidation of each of the scenarios.

Finally, conclusions and recommendations for achieving the intended goal of the substitution policy are given.

2. HYPOTHESIS AND RESEARCH AIM

2.1. HYPOTHESIS

The Life Cycle Assessment (LCA) can serve as a policy support for indicating the possibility of environmental burden shifting in the implementation of the substitution policy. The application of this methodology will highlight environmental trade-offs and also will serve to identify the legal crop with the best environmental performance.

From an environmental perspective, the emissions associated with climate change, depletion of abiotic resources, and eutrophication are expected to be lower for the substitution crops than for coca processing. Standard agricultural practices used in legal crops, would reduce deforestation and the release of harmful chemical substances. However, a Balloon effect will entail higher environmental pressures, in contrast, it is expected to demand more workforce and generate a higher income for the communities of the Catatumbo and Putumayo-Caqueta regions.

It is predicted that coca cultivation and processing will be more profitable than legal crops for Colombian farmers and its families. On the other hand, the full implementation of the substitution policy and the peace treaty will reduce the number of victims of violence associated with the armed FARC-conflict. However, the success of the substitution policy will be determined by the capability of the government to close the social gaps between rural and urban areas of the country, and as well provide an integrated state presence in the coca growing zones.

2.2. RESEARCH AIM

Any alternative development policies need to minimize its environmental impact, engage the community, and link agricultural production to the market. This study intends to provide a clear picture of the environmental, social and economic implications of the substitution policy, to better inform its application. The boundaries of this study are set in the coca-growing communities of the Putumayo-Caqueta and Catatumbo regions. Coffee, cacao, and sugarcane are the substitution crops considered for this study. Those crops are extensively cultivated across Colombia and have a national and international growing demand, so any increase in the production has the potential to be absorbed. In addition, cacao, coffee, and sugarcane are being already part of successful Alternative Development Projects (ADP) (MJD, 2015) Through four scenarios; this study seeks to determine the possible environmental, social and economic consequences of the implementation of the substitution policy, under different assumptions. The following research question will be answered:

What are the socioeconomic and environmental tradeoffs of the implementation of substitution policy in Putumayo-Caquetá and Catatumbo region?

The sub-questions presented below will help to develop the research and answer the central research question:

- What is the environmental performance of the substitution crops as compared to the coca crops and their processing?

- What are the socioeconomic implications of the substitution policy for the communities involved in the illegal crops harvesting and processing?
- Which of the substitution crops could lead to greater social, economic and environmental benefits?
- What recommendations can be derived from applying both LCA framework and socioeconomic indicators, to achieve the successful implementation of the substitution policy in Colombia?

3. COCA CULTIVATION AND PROCESSING IN COLOMBIA

The coca plant is very versatile and adapts easily to different climatic conditions, growing at elevations from sea level up to 2,000 m. Depending on the variety, weather and age of the plant, between four and six harvests per year can be obtained. In Colombia, indigenous and peasants traditionally use coca as a stimulant, as a way to stifle hunger, and as part of rituals and traditional medicine. Coca is also the main raw material for the cocaine production; its alkaloid content is 0.6% (Biondich & Joslin, 2016). In the 80's the global cocaine consumption boomed. Bolivia and Peru, where most of the coca was cultivated, initiated an anti-drug campaign, causing the displacement of the plantations to Colombia (Figure 3-1). In the late 1980's adequate geographic and social conditions in Colombia, such as coasts on the Atlantic and Pacific oceans, weather, land distribution inequality, high rural levels of poverty, and low presence of the state in remote rural areas. These circumstances helped the establishment and expansion of the coca plantation throughout the country. By 2000 Colombia was the largest cocaine producer in the world (Ibañez & Vasquez, 2013)

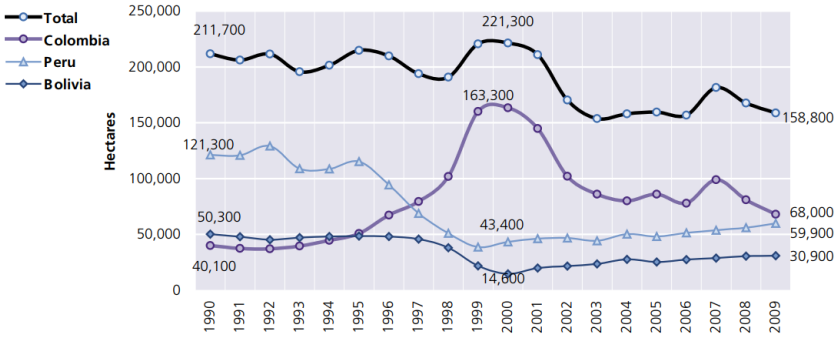


Figure 3-1. Coca plantation in the Andean region (UNODC, 2010b)

United Nations Office on Drugs and Crime (UNODC) and the Colombian government have monitored the dynamics and impact of illicit crops in the country since 2000. Eight regions have been defined by them (Figure 3-2) for analyzing the yield and prices of coca leaves and its derivatives and the socioeconomic situation of communities involved

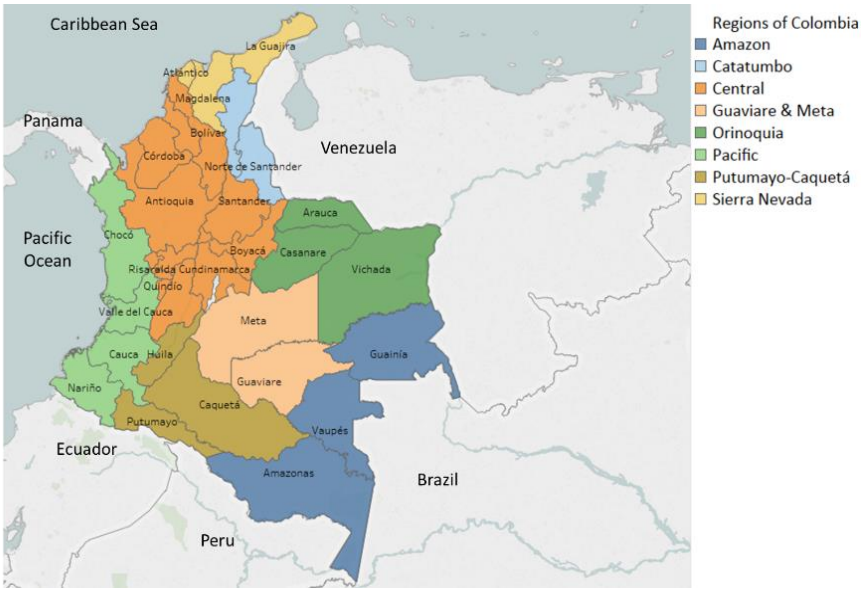


Figure 3-2. Regions of Colombia

Policies against coca growers were launched, by the Colombian government achieving mixed results. From 2001 to 2006 coca plantations were reduced by almost 46% (Reyes, 2014). However between 2010 and 2015 coca was present in nearly all the regions of the country (Figure 3-3). Eradication efforts continue, showing positive results in the Sierra Nevada, Orinoquia, and Amazon regions. In 2015 less than 1% of the country's coca crops were located in those regions. In contrast, in the Catatumbo and Putumayo-Caquetá regions, coca crops began increasing in 2013 and have steadily risen every year since. In 2015, 41% of the total coca crops of the country was concentrated in those areas. With 96,000 hectares dedicated to coca growing in 2015, the calculated potential production of coca leaves and cocaine hydrochloride was 454,000 and 646 metric tons respectively (UNODC, 2016a). In average one kilogram of cocaine hydrochloride was marketed in the country at price of COP 4,747,300 (US$ 1,732). Therefore, the total estimated value of the cocaine produced in 2015 is estimated in 3 billion of Colombian pesos.

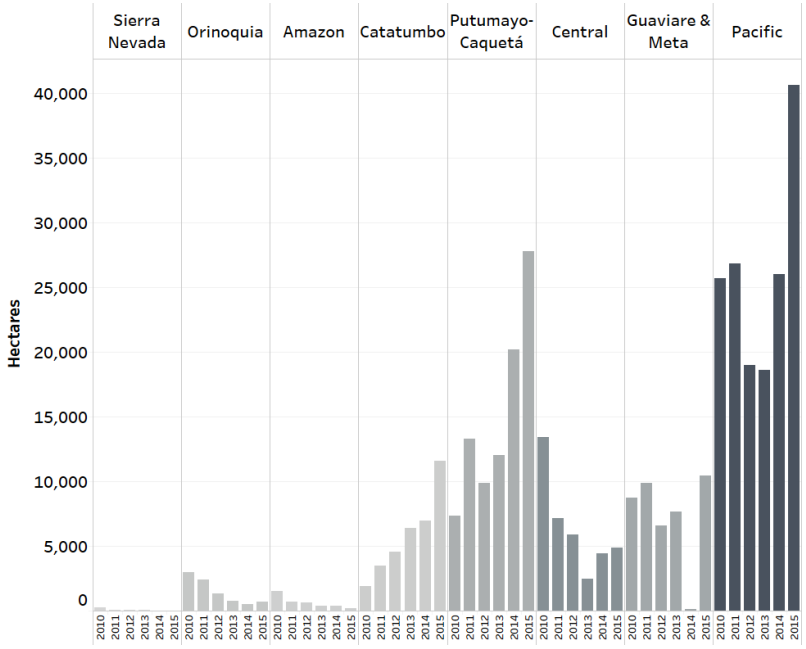


Figure 3-3. Area with coca plantations in Colombia per region, 2010 -2015 (hectares)

This research is focused on the Catatumbo and Putumayo-Caquetá regions; its characteristics have enabled the flourishing of the narco-business. The rural areas of those regions are under the control of guerrilla movements and organized crime groups, who have been profited from the illegal drug trade. Laboratories to transform coca base paste into cocaine can be easily hidden in the forested lowlands and jungle. The Caquetá, Putumayo, Catatumbo, Zulia and Tarra rivers have become the perfect unguarded routes for the illicit trafficking. Moreover, the rural areas of Catatumbo and Putumayo-Caquetá are vastly underserved by utilities. The lack of roadways has been an impediment to the development of formal agricultural markets, leaving coca cultivation and processing as the only source of subsistence for rural communities. In addition, the availability of up-to-date information was another reason for centering this research in those regions.

3.1. DESCRIPTION OF THE ZONES UNDER STUDY

This section presents the social and geographic characteristics of the Catatumbo and Putumayo-Caquetá regions. In addition, the issues that have allow the expansion of the illegal drug chain on the rural and isolated areas of those regions.

3.1.1. Catatumbo Region

This region is constituted by the departments of Norte de Santander and Cesar. Nevertheless, in 2015, all the coca plantations were concentrated in Norte de Santander, so the data and the analysis here presented corresponds to this department.

Norte de Santander is located in the northeast of Colombia and has an extension of 22,130 km^2, of which 49% was planted with illicit crops in 2015 (UNODC, 2016a). The department has geographic and social characteristics that have promoted the flourishing of the illegal drug supply chain. The border with Venezuela facilitates the creation of routes for agrochemicals trafficking, acquisition of cheap gasoline and cocaine trade. Also, the region is bathed by at least seven rivers that allow the mobilization of illicit drugs within the department, to other areas and Venezuela with almost no control by the national authorities (Wills Pedraza, 2015). The "cristalizaderos" or laboratories for transforming coca paste into cocaine are located near those rivers for disposing of the waste produced by the process.

The FARC, The National Liberation Army (ELN) and The Popular Liberation Army (EPL-) and the BACRIM organized crime groups were present in the region, disputing among themselves the control over the trafficking network and the use of the territory. These disputes have generated a wave of violence, human rights violations, forced displacements and a significant number of victims of landmines which are used for protecting the illegal crops. Before the peace treaty was reached, the FARC had the control over the coca producing areas (UNODC & MJD, 2016). The ELN and EPL were in charge of controlling the routes for obtaining the precursors used for the processing of coca leaves. The BACRIM were responsible for the sale and distribution of the cocaine. In general, the guerrilla movements and organized crime groups have been exerted influence in the whole drug supply chain and daily life of the region.

Social inequality is also present in the area; considerable differences exist between the rural and urban zones. The access to public services: water sanitation, waste collection, and sewer system are limited to the rural communities (Figure 3-4). Road infrastructure in the region is insufficient. The existent roads (amounting to less than 5000 km) to communicate the rural side is in precarious conditions, hindering the transport of legal and perishable crops to the markets, leaving almost no option for the farmers than participating in the coca cultivation (Leech Garry, 2012). Moreover, only 1% of the coca farmers hold a bachelor's degree, while 8% does not have any formal education and an almost half only have attended primary school.

Nearly 8454 rural families (each family has in average four members) participate in the coca plantation and processing for obtaining coca paste (own calculations, based on UNODC, 2016). Almost a quarter of these families is comprised by children under 9, 20 % are between 10 and 18, 17% over 40, and the largest percentage is represented by individuals between 19 and 40. Approximately one-quarter of the farmers sell the coca leaves directly to cocaine producers. The other 75% processes coca leaves into coca paste for selling it to the drug traffickers that control market of the area (UNODC, 2016a).

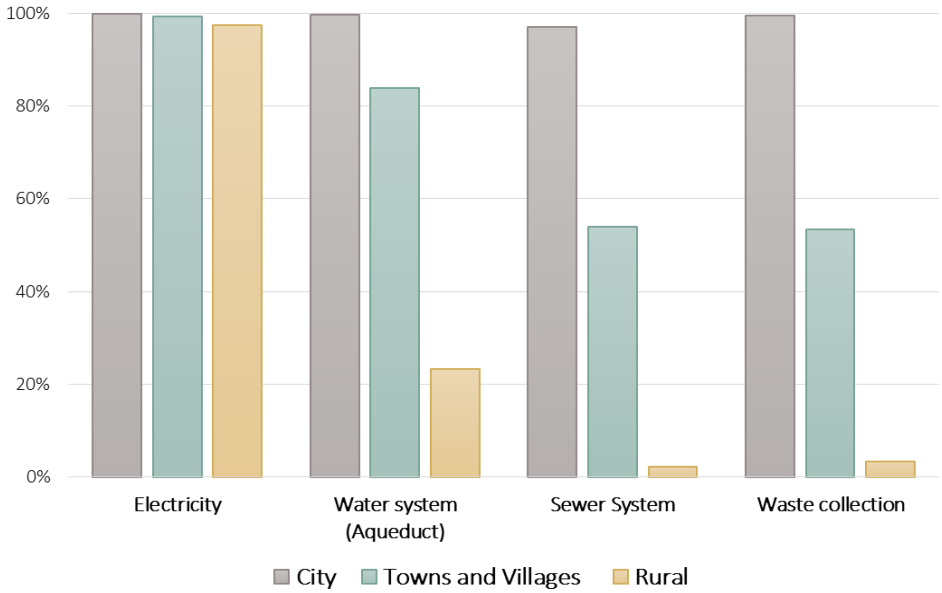


Figure 3-4. Percentage of households with access to public services. Catatumbo region. (DANE, 2016)

3.1.2. Putumayo-Caquetá Region

This region is located in the southwestern part of Colombia, with a total area of 113.850km^2, bordering with Ecuador and Peru. The terrain of these departments ranges from tropical rainforest "Amazonian Piedmont" too densely forested mountains, with a large variety of endemic ecosystems and high biodiversity.

It is drained by four main river systems. Those constitute the most important way of communication, not just within the country but also with the neighboring countries Ecuador, Peru, and Brazil. Despite that, an extensive part of the zone does not have proper infrastructure, like ports and docks. Also, sedimentation has affected the conditions of navigability of the rivers (UNODC & MJD, 2015a, 2015b). Only the 28% of the territory of the Caquetá department has access to land routes, limiting the access to goods and services, and increasing the transportation cost of agricultural products harvested in the department. In total, the region has 6,000 km of tertiary roads (DNP, 2016).

The Putumayo-Caquetá region has been the epicenter of a territorial dispute between the FARC guerrilla and organized crime groups BACRIM. This conflict left behind a high number of civilian victims, displaced people and child soldiers. However, before the peace treaty, the FARC and BACRIM had set an agreement for the control and mutual benefit of drug trafficking (Durán Núñez, 2015). The BACRIM was in charge of monitoring the traffic of armament in the region and taxing the cocaine that was exported from the area. The FARC also exerted the role of the State, regulating the dynamics of the daily life in the rural zones. They set a restriction on mobility, banned the relation with police and participation in any of the governmental programs to substitute the illegal plantations. Even the FARC guerrilla interfered in solving interpersonal conflicts of the community. In Putumayo, they create the

"Manual of coexistence for the proper functioning of communities," to maintain the dominion over the territory and exert political and military control (FIP, USAID, & OIM, 2015; UNODC & MJD, 2015b).

The strategic location of the region, the scarce presence of police or other state security agencies in the territory and abandonment by the national government, are factors that have helped to consolidate all the drug network in this region. In 2015, 24% of the total area of the region was affected by coca plantations, in which 21,600 rural families participate (own calculations, based on UNODC, 2016). Of the rural households involved in the coca chain, 15% are children under 9, 20 % are between 10 and 18, 29% are between 19 and 40, and people over 40 represent the great percentage. More than half of the farmers (64%) sell the coca leaves for further processing. The other families process the coca leaves for obtaining coca paste, which is sold to the cocaine producers (UNODC, 2016a).

The marginalization of the rural areas, the precarious routes and the lack of infrastructure have contributed to spreading and strengthen the coca phenomenon. Less than 1% of the rural population has access to the water system, while the services of waste collection and sewer systems are not available at all (Figure 3-5). As in the Catatumbo region, the education level of the farmers is low compared to the national level. More than half of the coca farmers only attended primary school, and none of the farmers hold a bachelor's degree. In Colombia as a whole 20% of the population has higher education (Letonturier, 2014)

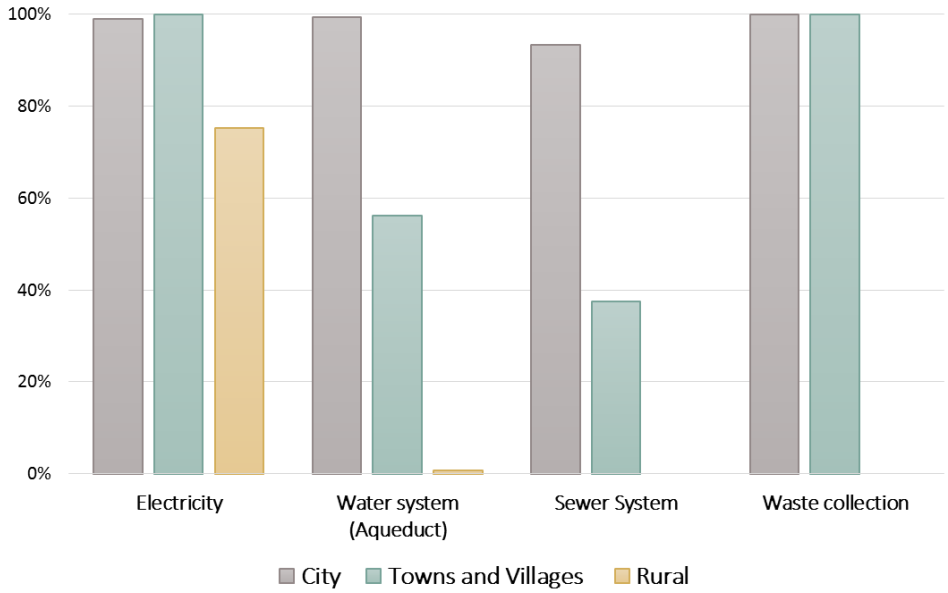


Figure 3-5. Percentage of households with access to public services. Putumayo-Caquetá region (DANE, 2016)

The signing of the peace agreement and the demobilization of the FARC has started to generate a dispute between other guerilla movements and organized crime groups to assume the FARC's role in the drug trade in the Putumayo-Caquetá and Catatumbo regions (Arenas Usme, 2016; Fundación Paz y Reconciliación, 2016). Also, social leaders promoting the peace treaty, land and human rights activist and indigenous leaders have been threatened and murdered. Most of this assassinations are happening in rural areas (teleSUR, 2017; WOLA, 2016b). The Colombian government has responded by forming "normalization and stabilization" units to curb the violence affecting the rural communities on the territories abandoned by the FARC guerrilla (Woody, 2016).

3.2. EXPERIENCES ERADICATING COCA PLANTATIONS

Coca crops and cocaine represents a great challenge not only for the Colombian government, as a supplier country, but also for the United States and Europe, which are the primary markets of Colombian cocaine. Forensic analysis has shown that more than 80% of the cocaine confiscated and consumed in the United States comes from Colombia (UNODC, 2010b). For that reason, the Colombian government in alliance with the United States and the European Union has made countless efforts to confront the illicit drugs problem. The tactics have evolved over time, from forced eradication and interdiction to ADP. Lately, the government has given priority and a greater percentage of the anti-drug funding to forced eradication and security measures than to ADP.

Manual and aerial spraying of glyphosate eradication by the police and other state security agencies was the first response to the problem. The main goal was to reduce the area planted with coca. Even though this was partially achieved because between 2001 and 2012 the levels of coca cultivation decreased by more than 50% (Rincon-Ruiz et al., 2016). Opportunities to migrate to a legal activity for the more than 50.000 families involved in the coca growing and processing were not present at all, causing the displacement of coca crops to new geographic areas (Count the cost, 2012; Rincon-Ruiz et al., 2016). In addition, aerial spraying of herbicides was severely criticized, because of its impacts on human health, animals, water sources and arable land. Dion & Russeler (2008) suggested that in 2001 and 2002 fumigation caused the forced migration of more than 75.000 people nationwide.

The government has also explored ADP. The base of these programs is to create legal alternatives and employment opportunities for coca-growing areas. Socioeconomic interventions, like access to education and health and technical assistance, were part of the ADP (Fukumi, 2013; UNODC, 2016a). The "Plan de Consolidación Integral de la Macarena" (PCIM) was a project implemented in six coca growing municipalities of the department of Meta. The PCIM envisaged the eradication of coca crops through the consolidation of legitimate state authority, access to public services, and property rights and territorial order (DeShazo, McLean, & Forman Mendelson, 2008). This program was a successful experience, not only achieving the reduction of coca plantation and the number of homicides but also incrementing the school enrollment rates and fostering the growth of the local economy (Mejía, 2016). Nevertheless, many of the ADP were not sustainable after the flow of the subsidies stopped, leaving almost no option to farmers than to go back to planting coca. Poor infrastructure, lack of continuity of the program and untitled lands for accessing to credits, and in general failures to address the socio-political dynamics of the regions are some of the bottlenecks that the ADP has faced.

3.3. NATIONAL COMPREHENSIVE PROGRAM FOR THE SUBSTITUTION OF ILLICIT CROPS

The substitution policy is a chapter of the Rural Reform, contemplated in the Colombian peace treaty. This policy will be shaped and adapted depending on the particular needs and socio-cultural characteristics of the corresponding regions. For doing this, a participatory process involving the affected communities will take place. Community assemblies and national and local authorities will jointly design, develop and monitor the alternative productive projects for ensuring the construction of efficient and long-lasting solutions.

The primary purpose of the substitution policy is the achievement of a national territory free of illicit crops. That will be accomplished by addressing the illegal drug chain from different angles, involving rural development, social investment and legalization and redistribution of the land (Gillin, 2014) By integrating the coca growing regions improving the national road network and guarantee access to local and domestic markets, the legitimate economic possibilities for the communities will increase. Moreover, the institutional presence of the state will help to ensure that farmers can freely join the

substitution policy without fear of reprisal while contributing to protect the physical integrity of civilians. Furthermore creating a permanent state security presence in coca-growing regions will prevent them from becoming an easy target for other guerrilla movements and organized crime groups in the future.

The peace treaty contemplates national plans for eradicating extreme poverty, reducing rural poverty by 50% and for the reintegration of the guerrillas' members. Next, the points that will support the implementation of the substitution crops are presented:

- As for infrastructure, plans to reconstruct the national road network, development of sanitation, potable water, irrigation systems and energy projects to increase the rural coverage. (DNP, 2017).
- For social development expansion of the rural education coverage, through:
    - Improvement and construction of educational infrastructure
    - To give a priority quota for people affected by the conflict for access to higher education.
    - Subsidies and credits for education.
- Creation of a Land Fund, aiming the distribution of land to rural people without or insufficient land. Also the actualization of the cadaster for formalizing the ownership of the land (OACP, 2016)

Farmers who commit to substitute the illegal crops voluntarily will receive a stipend of $USD340/month for up to 12 months for the manual eradication of the illicit crops and preparation of land for the legal crops. For the establishment of food security projects, $USD605 will be given per family. Finally, for the alternative productive projects up to $USD3300 per family will be provided along with technical assistance and support up to $USD1000 (CND Blog, 2017; Semana.com, 2017c).

To guarantee the national monetary resources for the enforcement of the peace treaty a legislation "Artículo 4 Acto Legislativo 01 de 2016" is in place. However, national resources are not enough for financing what is stated in the treaty. For that reason, a percentage relies on international cooperation. For the substitution policy and to tackle chain of illegal substances, 30% of the resources are waiting to be provided by International cooperation and 20% is pending funding (DNP, 2017; Morales, 2017)

4. METHODOLOGY

This research attempt to evaluate the environmental and socioeconomic tradeoffs of the recently launched substitution policy, addressing the cultivation of illicit crops in the Catatumbo and Putumayo-Caquetá regions of Colombia. For calculating the systemic environmental pressures of the policy implementation, Life Cycle Assessment (LCA) methodology is used, taking a "cradle-to-gate" approach. For assessing the socioeconomic impact, change on the income for farmers and *jornaleros*, workforce demanded by the crops and the market value are analyzed.

Differences in the management of illicit crops between regions are taken into account. However, due to lack of precise data on the quantity and size of the farms, the distinction between large and small coca producers is not considered in this analysis.

4.1. SCENARIOS

Scenarios have been widely used in environmental sciences and policy analysis (Alcamo, 2008). For assessing environmental changes of future societal developments, emphasizing on the relation between the implementation of a policy and its environmental, social and economic consequences. The primary goal of using this approach is to reveal crucial issues that otherwise would be missed or underestimated (UNEP, 2007). Scenarios can also serve as a guide to develop strategies, outline policies and support strategic decisions.

This research evaluates four scenarios (Figure 4-1): Business as Usual (BAU), Policy Success (PS), Conservative (CO) and Balloon Effect (BE). The purpose of these scenarios is to understand how the stakeholders can influence the outcome of the substitution policy implementation (Sheate, Partidário, Byron, Bina, & Dagg, 2008). Scenarios are also useful for studying the environmental and socioeconomic dynamics of the legal and illicit crops.

The BAU scenario reflects the situation before the peace treaty was signed, examining the socioeconomic characteristics of coca farmers and *jornaleros* in the Catatumbo and Putumayo-Caquetá regions. In this scenario the environmental impacts of coca cultivation and cocaine production are quantified, using data for the year 2015. In this scenario 49% (10,779 ha), of the total Catatumbo territory and 24% (27,089 ha) of Putumayo-Caquetá total land was sowed with coca crops (UNODC, 2016b).

The PS is the optimistic scenario, where 100% of the coca crops are substituted by cacao and coffee in the Catatumbo region, and by cacao and sugarcane in Putumayo-Caquetá region. The share of the substitution crops in each region was assumed to be 50/50. All the objectives set by the substitution policy are reached: establishment of local institutional; road infrastructure is built for supporting the marketing of legal crops; and expansion of the health service, education, and public services coverage reducing social inequality.

A new wave of violence caused by the confrontation between guerrilla movements and organized crime groups for controlling the FARC territory and the smuggling routes is prevented by the national and local government in the PS scenario. In accordance with the suggestion of Ávila (2016), security strategies are coordinated in the border regions with the participation of the neighboring governments.

The last two scenarios reflect the failure of the national government to materialize the substitution policy and reach all the farmers involved in the coca plantation and processing. These two scenarios (CO and BE) might occur due to the foreseen reduction of international financial support, chiefly from the United States (Escobar, 2017). In both scenarios, guerrilla movements (EPL, ELN) and BACRIM start exerting control and filling the power vacuum left by the FARC (Álvarez Vanegas, 2017), administering the drug trafficking routes and coca leaves processing laboratories.

In the CO scenario, a percentage of illicit crops are still present in the national scene. Although the national government makes efforts for succeeding in the implementation of the substitution policy, the farmers lose credibility in the national government and revert to planting illicit crops.

Displacement of the coca plantations is not a new scenario neither in Colombia nor Bolivia and Peru (Figure 3-1). In the BE scenario, a significant percentage of the coca farmers migrate to the legal crops, so that 60% of the illicit crops area is replaced. However, the demand for cocaine remains, and coca harvesting and processing is still a lucrative and attractive business. To meet the demand, coca cultivation expands to areas which had not been used for this purpose. The percentage of the expansion of the coca crops is an extrapolation of the behavioral trend of coca plantation in the last five years. The percentage of each of the crops for the PS, CO, and BE scenarios were arbitrarily set.

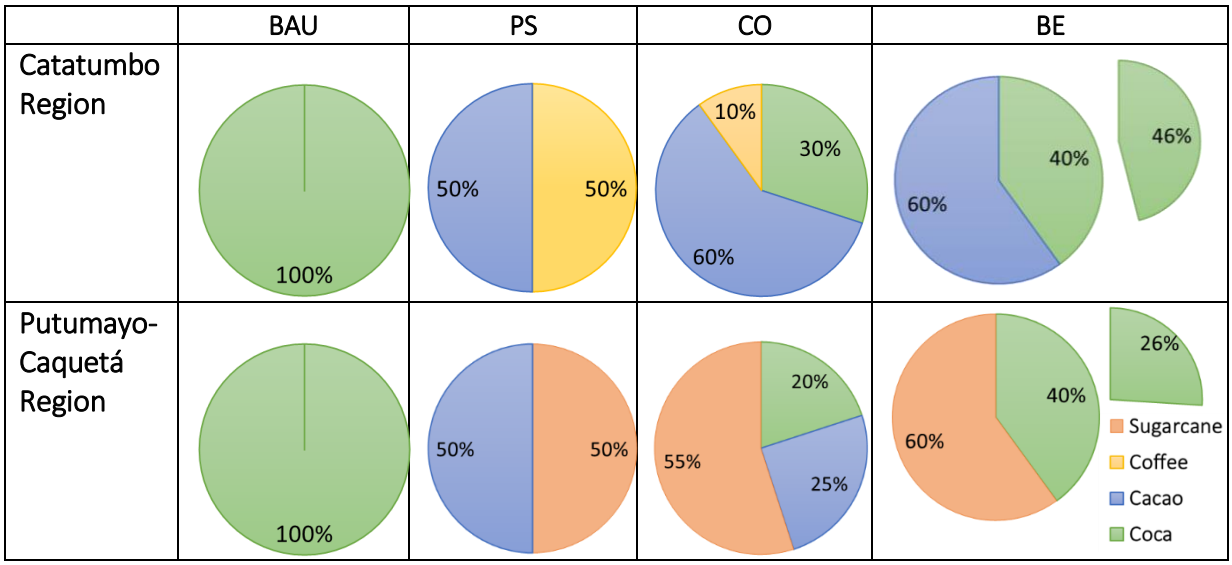


Figure 4-1 Scenarios proposed for the study. Total area in the Catatumbo region is 10,779 ha. Total area in the Putumayo-Caquetá region is 27,089 ha.

4.2. Life Cycle Assessment

Life Cycle Assessment (LCA) is an established methodology that presents a broad perspective on the upward and downward streams of environmental impacts attributed to each of the phases in the life of goods or processes (European Commission, 2016). This framework has been extensively adopted, used to identify hotspots, quantify and assess environmental pressures caused by a system.

LCA is a decision supporting framework for policy making because it gives an insight into the environmental performance of a product or service. An LCA analysis shows how a certain policy can shift the environmental burdens from one region to another or from one life cycle product's phase to another, hence allowing decision makers to understand both the positive and negative impacts of a policy (Sala et al., 2016). Governmental programs and regulations suggest the use of LCA for

demonstrating potential environmental benefits of products and services. For instance, the Energy Independence and Security Act of 2007 (EISA) of the United States and the Directives 2001/77/EC and 2003/30/EC in Europe establish the minimum GHG emission saving potential that biofuels should provide when compared to the traditional alternatives. Those directives mandate the use of LCA for accounting the savings in GHG emissions (Reed, 2012; Sala et al., 2016). In California and Massachusetts the program "Environmentally Preferable Purchasing (EPP)" provides environmental "cradle-to-grave" assessments of products and services, helping the federal purchasers choosing the ones with reduced environmental impact (Reed, 2012). Other European policies such as the Ecolabel Regulation, Green Product Procurement and Ecodesign Directive have also been supported by results derived from LCA studies (European Commission, 2015).

An LCA is an iterative process comprised of through four phases (Figure 4-2) described in the ISO 14040 guidelines: goal and scope definition, inventory analysis, impact assessment, and interpretation (Guinée et al., 2002)

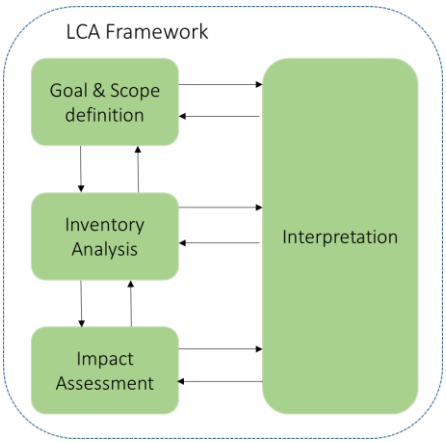


Figure 4-2. Phase of an LCA based on ISO 14040 (Rebitzer et al., 2004)

- Goal and scope: in this phase, the purpose, target audience and intended application of the study are presented. System boundaries of the analyzed system are introduced, as well the functional unit. The functional unit is the parameter that allows the comparison of different alternatives that fulfill the same function.
- Inventory Analysis: in this phase, the product/process system are described. The economic-environmental boundaries are set. The flow diagrams with all the unit processes that compose each of the alternatives are presented. Data regarding inputs and outputs of the unit processes is collected and reported along with the assumptions and methodological decisions. The outcome of this stage is the inventory table, which contains all the environmental flows related to the functional unit (Guinée et al., 2002).
- Impact assessment: In this phase, the inventory data is processed to quantify the potential environmental impacts of the alternatives that are being evaluated. The environmental flows of the inventory table are assigned to impact categories (Land use, Eutrophication, Abiotic resources depletion, Acidification, Photochemical oxidation, Climate change, Terrestrial ecotoxicity, Freshwater aquatic ecotoxicity, Human toxicity and Stratospheric ozone depletion), using the characterization models. Normalization and weighting of the results are optional. This can help for taking into account social and value preferences (Guinée et al., 2002).
- Interpretation: the aim of this phase is to evaluate and analyze the results of the study. The assumptions throughout each of the stages are validated. Conclusions and recommendations are drawn. Limitations of the study are also examined (Guinée et al., 2002).

In this research, the LCA framework is applied to quantify the environmental effects of the cocaine production and the substitution policy. First, the estimation of the environmental impacts is calculated per hectare of the crop (coca, cacao, coffee, and sugarcane) then is multiplied by the area occupied in each of the scenarios that were introduced previously.

4.2.1. Goal and scope definition

Taking a cradle-to-gate approach, a comparative attributional LCA was performed to estimate the environmental impacts of cocaine production, and for each of the crops (cacao, coffee, and sugarcane) that can be used as substitution crops in Colombia.

4.2.1.1. Goal

This study intends to highlight the environmental benefits and disadvantages of the implementation the substitution policy in the Putumayo-Caquetá and Catatumbo region by quantifying the cradle-to-gate impacts of cocaine processing and comparing it with the environmental pressures of the substitution crops. The evaluated crops are coffee, cacao, and sugarcane.

Additionally, this research aims to contribute to the LCA literature on the use of this methodology for policy support, giving an insight of the environmental impact and hotspots of cocaine production for the two regions analyzed.

The author of this research is an Industrial Ecology Master student. Reviews are executed by Dr. Prado and Dr. Solheim, professors of Leiden University. The target audience of this report is governmental institutions responsible for the implementation of the policy. It is hoped that the findings of this study can help improve the environmental outcome when implementing the substitution policy. Above all, this study aims to be used by policy makers who can prioritize measures to integrate the environmental dimension into the substitution policy

4.2.1.2. Scope

The scope of this assessment includes the agricultural phase of the coca leaves, the subsequent refining processes to obtain cocaine, plus the disposal of the waste generated. The foreground data is representative of the regions under study, from the year 2010 onwards. For the coca cultivation, the quantities of agrochemicals used are derived from the UNODC reports, as well the chemical precursors for the transformation of the leaves into cocaine. It is important to mention that not all the leaves and the coca paste are processed in the same region, but because this is an illicit activity, information is not available. For this reason, the transportation of the leaves and its derivate within the country is out of the scope of this study.

For the cacao, coffee and sugarcane the growing or nursery phase and the productive stage are reviewed. The data for those crops comes mainly from reports of FEDECACAO, Federación Nacional de Cafeteros, and Procaña, which are the existent agricultural associations in Colombia for each of these crops.

Background data (production of agrochemicals, gasoline, chemical precursors, and electricity) derives from Ecoinvent 2.2; information comes from 1992 to 2006. The systems were modeled using CMLCA 5.2 software with CML 2001 baseline impact assessment.

The geographical boundary for this study is set in the Colombian regions of Catatumbo and Putumayo-Caquetá. This study takes into consideration the areas of the regions categorized as agricultural land, leaving out of the scope the land that belongs to the National Natural Parks. The implementation of the substitution policy is a multifaceted challenge, conditioned by the availability of the financial resources, influence of the stakeholders and the dynamics of drug trafficking chain in the regions affected.

Regarding this fact, four scenarios are developed to analyze the possible outcomes of the substitution policy.

4.2.1.3. Function, functional unit, alternatives, reference flows

The function defined for the study is:

To provide an alternative to the coca harvesting regions of Colombia through the implementation of substitution policy

The functional unit of the analysis is "To provide an alternative to the total area of the coca harvesting regions of Colombia through the implementation of substitution policy." The alternatives contemplated in this study are the Catatumbo region (11148 ha) and the Caqueta-Putumayo region (27089 ha), evaluating four scenarios: Business as Usual (BAU), Policy Success (PS), Conservative (CO), and Balloon Effect (BE). The table below presents the reference flow for both alternatives.

Table 4-1. Reference flows

Scenario	Catatumbo Region (ha/year)	Putumayo-Caquetá Region (ha/year)
BAU	11148 ha of illicit coca crops	27089 ha of illicit coca crops
PS	50% cacao and 50% ha of coffee	50% sugarcane and 50% cacao
CO	60% cacao, 30% illicit coca crops and 10% coffee	55% sugarcane, 20% illicit coca crops and 25% cacao
BE	60% cacao and 40% illicit coca crops plus 46% additional.	60% sugarcane and 40% illicit coca crops plus 26% additional.

4.2.2. Inventory analysis

4.2.2.1. System boundaries

a. Economy-environment system boundary

The goods and services entering or leaving the system that have monetary value are known as economic flows. For that reason, almost all the inputs for the substitution crops are considered as economic flows. The production of the agrochemicals and energy are taken as a background process from *Ecoinvent v2.2.* Land used and transformed and irrigation water for cacao and coffee processing are part of the environmental system because the water is taken from the rivers. In the same way, for the coca crops, land occupation and transformation belongs to the environmental boundary. The emissions from the alkaloid extraction and purification enter to the environmental system.

b. Cut-off

When collecting the data for the unit process analyzed, cut off is unavoidable because of time constraints and availability of the data. For the cocaine processing, information about transportation of chemical precursors and coca paste within regions is not available since it is an illegal operation. Also, information on infrastructure and materials needed to build the "laboratories" where the coca leaves are processed is missing.

Application of fertilizers containing micronutrients as Iron (Fe), Manganese (Mn), Boron (B), Chlorine (Cl), Zinc (Zn), Copper (Cu), Molybdenum (Mo) is not a very frequent practice. The quantities needed by the crops are relatively small compared to primary and secondary nutrients (Nemecek & Kagi, 2007). For those reasons, micronutrients are not included in this study.

Capital goods for cacao and coffee processing are not part of the system boundaries of this research; their environmental contribution was judged to be minimal or negligible because of the long life span of it.

The Carbon Dioxide emissions associated with the composting process of the pulp and mucilage, in the coffee production system, are not modeled. The CO_2 uptake has a negative value in the productive phase and is accounted as a positive emission in the composting process, so the value is assumed to be canceled out (Guinée et al., 2002). Methane produced in this phase is neglected.

4.2.2.2. Flowcharts

The flow diagrams show the unit processes of the system and its interrelationships. Flowcharts for the substitution crops are presented next (Figure 4-4, Figure 4-5 and Figure 4-6) with all the stages that are being modeled in the study. For cocaine, the cultivation and processing phase is showed in Figure 4-3. Environmental interventions are excluded from the graphs.

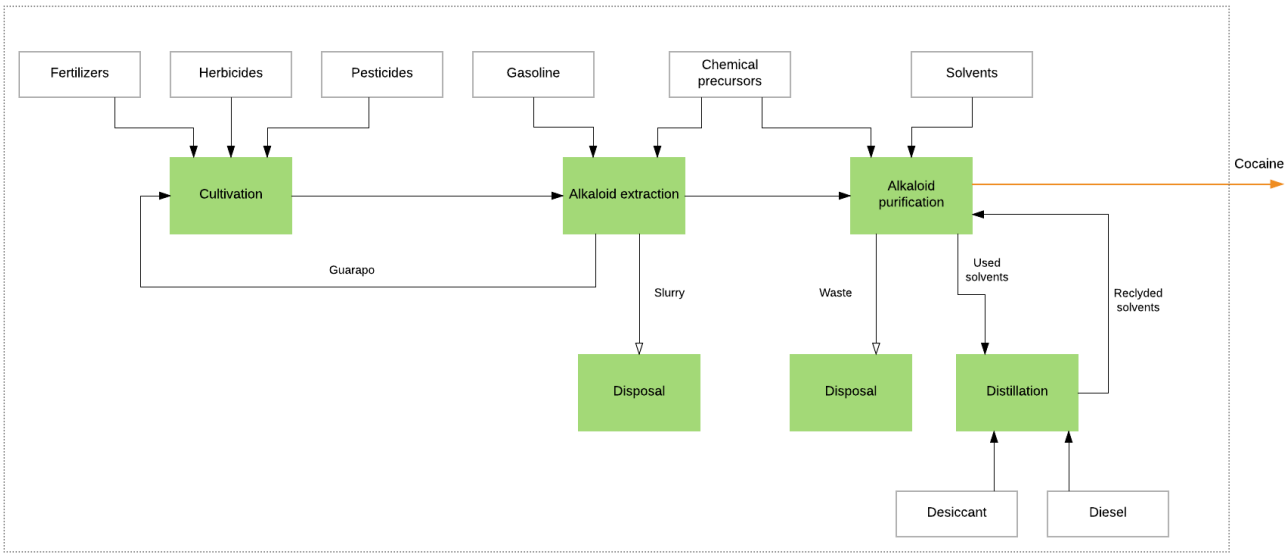


Figure 4-3. Production of Hydrochloride cocaine (Rocha, 2011; UNODC, 2010a)

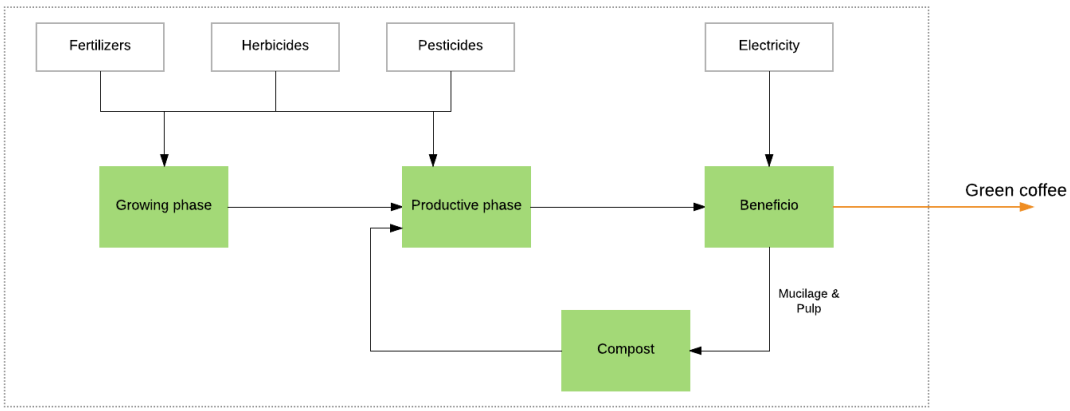


Figure 4-4. Coffee beans production (Coltro, Mourad, Oliveira, Baddini, & Kletecke, 2006; Salinas, 2008)

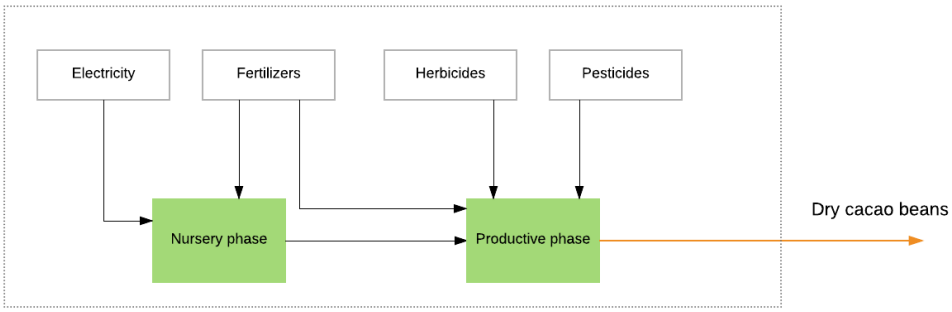


Figure 4-5. Cacao production (Ntiamoah & Afrane, 2008; Ortiz, Gallardo Villamizar, & Rangel, 2014; Perez Neira, 2016)

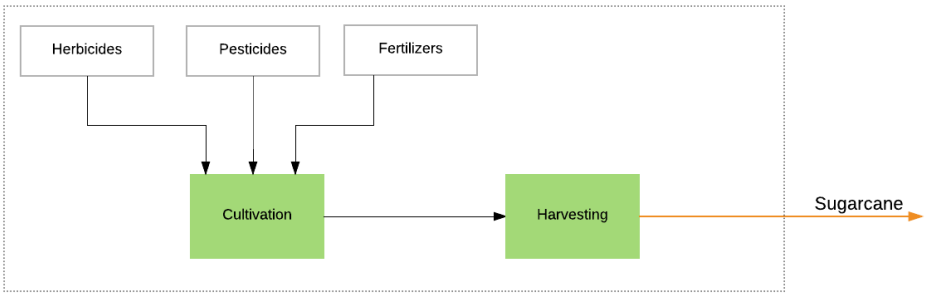
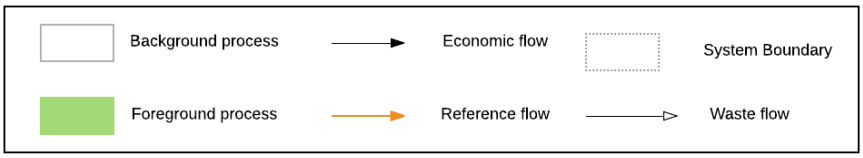


Figure 4-6. Sugarcane process (Renouf & Wegener, 2007; Roberto Ometto, Zwicky Hauschild, & Lopes Roma, 2009; Tsiropoulos et al., 2014)



4.2.2.3. Data collection and unit processes

In agricultural production, the primary nutrients needed by the crops are nitrogen (N), phosphorus (P) and potassium (K), so fertilizers providing those elements are considered for this study. The total amount of N, P and K are derived from fertilization schemes reported by agricultural associations of Colombia allowing a high level of detail and accuracy. Regarding chemical pesticides, used for controlling pest and phytosanitary problems of the crops, quantities, and type of pesticides/herbicides are considered and adjusted to local conditions. For coffee cultivation and processing data reported by the National Federation of Coffee Growers of Colombia is used (Arcila Pulgarín, Rendón Sáenz, & Montoya Restrepo, 2008; Rodríguez Valencia, Sanz Uribe, Oliveros Tascon, & Ramirez Gomez, 2015; Sadeghian Khalajabadi, 2008). The data for cacao cultivation presented by Borrero (2009), Ortiz et al. (2014), and Valenzuela et al. (2012) is considered. Osorio Cadavid (2007) and Tarazona (2011) take into consideration Colombian conditions for the sugarcane cultivation, for that reason the information presented by them is taken for this study.

Coca cultivation can vary from region to region, depending on the availability of the products in the illicit market. However, for this research, it is assumed that the type of agrochemicals (fertilizers, pesticides, and herbicides) is the same for both regions. Agricultural practices for the coca cultivation differ in both regions, fertilizers and herbicides are used in a greater amount in the Catatumbo region, leading into higher coca leaves yield. This issue explains possible differences on the outcome of environmental assessment for the cocaine production in both regions.

The cocaine production method can be modified, depending on which inputs the farmers and drug traffickers can buy in the illegal markets or obtain using the smuggling routes. The raw materials can also change from one batch to the other. The national authorities control some of these chemicals precursors in those regions. For the sake of this study, the raw materials that are taken into consideration for the calculation are the ones published by UNODC.

The emissions of all the substitution crops and the cocaine process are calculated using models reported in the literature (IPCC, 2006; Koch & Salou, 2016; Nemecek & Kagi, 2007; Nemecek & Schnetzer, 2012)

For all the alternatives *Ecoinvent v2.2* database is used as a source for the background information. The systems are modeled using CMLCA 5.2 software. A summary of the data for each crop is presented in the next section. The calculations, assumptions, and proxies are reported and further explained in Appendix 1 and 2.

- Cocaine production

Coca cultivation

Quantities and types of agrochemicals are retrieved from UNODC reports. Agrochemical consumption was available for the year 2005 and 2010, showing a decreasing tendency. This trend was extrapolated to calculate the quantities used per hectare for the Catatumbo and Putumayo-Caquetá region for 2015 (Table 4-2).

Table 4-2. Inputs for the coca cultivation (ha/year)

Agrochemicals	Type	Catatumbo	Putumayo-Caquetá
Fertilizers (kg/ha. year)	Nitrogen	86.7	60
	Phosphorus	35.52	24.34
	Potassium chloride	35.52	24.34
Herbicides (kg/ha. year)	Paraquat	0.86	0.59
	Mancozeb	4.3	2.95
Pesticides (kg/ha. year)	Chlorpyrifos	0.17	0.11
	Methamidophos	0.68	0.47

The first harvest of coca leaves are collected in the third month after the sowing. The coca plant has 3 to 5 harvest per year and life expectancy of 18 years (Healy, 1985), depending on the climate, agricultural practices, variety and also eradication practices from the governmental side. In 2015 the average harvest per year registered was 4.4 in the Catatumbo region and 4.1 in the Putumayo-Caquetá region (UNODC, 2016a).

Alkaloid extraction

Once harvested, the coca leaves are chopped to increase the surface area and facilitate the extraction of the alkaloid. The leaves are moistened with water, then cement and urea are added. The resulting slurry is taken to drums and combined with gasoline or kerosene. This mixture is stirred to extract the cocaine alkaloid from the leaves (vegetable matter) (Addiction Resource, 2017; DEA, 1993; Rocha, 2011; UNODC, 2016a). The mixture is filtered to separate the vegetable matter, which is sun-dried to evaporate the water and the solvent (gasoline or kerosene), then dumped into the environment or used as fertilizer on the coca fields.

Diluted sulfuric acid is added to the gasoline mixture creating two phases. The aqueous phase contains the alkaloid as salt. The organic phase is separated, and approximately 70% of the gasoline is reused. The aqueous phase is mixed with ammonia or sodium carbonate to precipitate the alkaloid. The precipitate which is known as "coca paste" is filtered and dried. Finally, the aqueous phase is drained off and discarded to the environment without any treatment. Approximately 1.66 kg coca paste is obtained per metric ton of fresh coca leaves (UNODC, 2016a)

The inputs for the alkaloid extraction can be modified depending on the availability of the substances used. For this study quantities and types of chemical precursors were taken from UNODC and Rocha, 2011 (Table 4-3).

Table 4-3. Inputs for alkaloid extraction

Chemical precursors	Catatumbo	Putumayo-Caquetá	Unit
Cement	448	307	Kg/ ha of coca leaves harvested
Urea	98	67	Kg/ ha of coca leaves harvested
Gasoline or kerosene	515	353	Kg/ ha of coca leaves harvested
Other liquid precursors (ammonia, sulfuric acid)	35	24	l/ ha of coca leaves harvested

Alkaloid purification

Coca paste is dissolved with a sulfuric acid solution, while potassium permanganate is separately diluted with water. Then the two solutions are combined and stirred, to remove impurities from the coca paste. The mixture is allowed to repose for the impurities to settle down; then the solution is filtered. The liquid drained from the solution is considered a waste, so it is discarded to the environment. The precipitate formed is neutralized by adding ammonia or sodium hydroxide and filtered again to obtain what is called cocaine base.

Cocaine base is mixed with a solvent like acetone or ether. On a side, a solution of hydrochloric acid, acetates, and alcohol is prepared and added to the cocaine base solution. To mix this two solutions causes the cocaine hydrochloride to crystallize. Cocaine hydrochloride is filtered and then dried.

The remaining mixture of solvents is almost always reused, and the cocaine hydrochloride is shaped into a brick and dried under microwave radiation. The yield of hydrochloride cocaine is 1.41 kg per metric ton of coca fresh leaves.

Information about the inputs needed for obtaining the hydrochloride cocaine is retrieved from UNODC reports and Rocha, (2011)(Table 4-4). All the chemicals precursors can be changed depending on their availability since the government controls most of these substances.

Table 4-4. Inputs for alkaloid purification per ha of coca leaves harvested

Chemical precursors	Catatumbo	Putumayo-Caquetá	Unit
Liquid (sulfuric acid, solvents, alcohol, Hydrochloric acid)	21	11	l
Solid (Potassium permanganate, Sodium hydroxide, acetate)	16	15	kg
Energy	0.58	0.39	Mj

- Coffee cultivation

The growth phase of coffee seedlings takes approximately 18 months. At this time coffee trees start producing the cherry beans. The productive life of the coffee trees lasts about 25 years. The fertilizers scheme for the growth and the productive phase is based on reports of the National Federation of Coffee Growers of Colombia (Sadeghian Khalajabadi, 2008), using average values (Table 4-5). For managing the pest, quantities of herbicides are retrieved from the Agri-BALYSE data base, which reports conditions from Brazilian coffee plantations.

Plant density was assumed 6000 coffee trees per hectare, producing 11058 kg of cherry beans (Arcila Pulgarín et al., 2008). Cherries are manually harvested, then are processed at the wet mill (known in Colombia as *beneficio*) within 24h of being picked (Adams & Ghaly, 2007). In Colombia, the wet method is used for processing the cherry beans. The pulp and the mucilage represent 60% of the weight of the cherry beans, which is removed either mechanically or through a fermentation process (Adams & Ghaly, 2007; Rodríguez Valencia & Zambrano Franco, 2010). This organic residue is assumed to be composted and used as fertilizer. After the *beneficio* the green coffee beans are washed, sun dried.

The electricity requirements for the beneficio are taken from Adams & Ghaly, 2007. For the modeling, the Brazilian electricity mix used was since it comes mainly from hydropower generation as it is in Colombia.

Table 4-5. Inputs for the production of green coffee beans

Agrochemicals	Type	Phase	
		Growth	Productive
Fertilizers (kg/ha. year)	Limestone	36	0
	Nitrogen	16	280
	Phosphorus	4.5	30
	Potassium	3	200
	Magnesium sulfate	3	30
Pesticides (kg/ha. year)	cyclic N-compound	0.2	4.32
	pyrethroid-compound	0.075	1.5

- Sugarcane cultivation

Average values for the fertilization requirements for the sugarcane plantation are taken from the Colombian Agricultural Institute (Tarazona, 2011). The consumption of the herbicides and pesticides is reported by Tsiropoulos et al. (2014), who present data for Brazil. The sugarcane is harvested once per year in a 7-year cycle. The yield fluctuates depending on the type of the sugarcane planted. For this study, an average value of 100 tons per hectare is assumed (Tarazona, 2011). A summary of agricultural inputs is presented in the following table.

Table 4-6. Inputs for the production of sugarcane

Agrochemicals	Type	Quantity (kg/ha. year)
Fertilizers	Calcium carbonate	26
	Nitrogen	82.5
	Phosphorus	67.5
	Potassium	112.5
Pesticides	Triazine-compounds	0.42
	Phenoxy -compound	0.07
	Diuron	0.35
	Glyphosate	0.14
	Pesticide unspecified	1

- Cacao cultivation

Agricultural inputs and electricity needed for the irrigation during the nursery phase are taken from the Agri-BALYSE database. After six months of growth, the cocoa plants are field planted, starting the productive phase between the second and third year and lasting about 25 years. The cocoa pods are harvested and opened to extract the beans manually. The beans are fermented for 5 to 7 days then sun dried. The husks are disposed in the soil for returning nutrients and decreasing the use of agrochemicals (Borrero, 2009; Furcal Beriguete, 2016).

Fertilizers for the productive stage are calculated considering the average of values reported by Loli Figueroa & Cavero Rojas (2011), Fedecacao (2006) and Barón Urquijo (2016). Complementary information for this stage about pesticides consumption and packing material for the dry cacao are retrieved from Agri-BALYSE database. The average production of dry cacao for the Colombian conditions comes from Barón Urquijo (2016).

Table 4-7. Inputs for the production of dry cacao beans (hectare/year)

Agrochemicals	Type	Phase	
		Nursery	Productive
Fertilizers (kg/ha. year)	Dolomite	12	70.75
	Nitrogen	0	100
	Phosphorus	1.44	90
	Potassium	0	116
Pesticides (kg/ha. year)	Glyphosate	0	0.43
	Pyrethroid-compound	0	5.25E-03
Other inputs (kg/ha. year)	Polyethylene	15.4	0
	Electricity	54	0
	Jute	0	5.31

- Calculation of emissions

The IPCC (2006) tier 1 and 2 methodologies are used to calculate direct and indirect emissions caused by the use of N-fertilizers. Nitrous oxide emissions are estimated taking into account emissions generated by the deposition of ammonia (NH_3) and nitrogen oxides (NOx) and lixiviation of Nitrate (IPCC, 2006). Ammonia (NH_3) emissions caused by N-fertilizers and compost are calculated using emission factor for temperate climate (Hutchings, Webb, & Amon, 2016). Calculation of phosphate (PO_4) is based on the models presented by Nemecek & Schnetzer (2012). Carbon dioxide emissions caused liming process is calculated as using Tier 1. Emissions resulting from the use of pesticides were assumed to be emitted to the soil and were calculated according to Nemecek & Kagi (2007).

Additional emissions caused by the production of hydrochloride cocaine are calculated taking into consideration the parameters presented in Table 4-8. To calculate the Chemical Oxygen Demand (COD), equation 2 was applied. Further details and amounts are given in the supplementary information (Appendix 2).

$$\mathrm{COD} = \mathrm{a} * \mathrm{TOD} \quad \text{(Equation 2)}$$

Where

a= empirical constant (95-100%)

TOD= Theoretical Oxygen Demand

Table 4-8. Emissions from coca leaves processing.

Substance	Emission	Quantity	Model
Gasoline (mg/L)	Benzene	6140	Chin & Batterman, 2012
	Toluene	15400	
	Ethylbenzene	3080	
	n-Heptane	12800	
	n-Octane	2870	
	Cyclohexane	9830	
Butyl acetate g/g	TOD	2.21	Baker, Milke, & Mihelcic, 1999; Ellis, 2011
Methyl Ethyl Ketone	ThOD	2.44	
Butyl acetate	COD	2.10	
Methyl Ethyl Ketone	COD	2.32	

4.2.3. Life Cycle Impact Assessment

The purpose of impact assessment phase is to convert the data of the inventory table into impact categories.

4.2.3.1. Classification and characterization

The environmental flows gathered in the inventory analysis are assigned to the corresponding impact categories. This procedure is done by applying characterization factors, to convert the Inventory table results' into the common units of the impact category. This study uses the CML 2001 impact assessment method. Table 4-9 presents the environmental impact categories considered in this study with their corresponding characterization factor.

Table 4-9. Impact categories and characterization factors (Guinée et al., 2002).

Impact Category	Characterization factor	Unit	Model
Land use, competition (LU)	1 for all types of land use (dimensionless)	m^2a	
Eutrophication (EU)	Eutrophication potential (EP)	kg PO_4-Eq	[1]
Depletion of abiotic resources (RD)	Abiotic depletion potential (ADP)	kg antimony-Eq	[2]
Acidification (AC)	Acidification potential (AP)	kg SO_2-Eq	RAINS10
Photochemical oxidation (PO)	Photochemical oxidation creation potential (POCP)	kg ethylene-Eq	UNECE
Climate change (CC)	Global warming potential 100-year time horizon (GWP100)	kg CO_2-Eq	IPCC
Terrestrial ecotoxicity (TE)	Terrestrial ecotoxicity potential (TETP) for	kg 1,4-DCB-Eq	USES 2.0
Freshwater aquatic ecotoxicity (FAE)	Freshwater aquatic ecotoxicity potential (FAETP)	kg 1,4-DCB-Eq	USES 2.0
Stratospheric ozone depletion (OD)	Ozone depletion potential in the steady state (ODP steady state)	kg CFC-11-Eq	World Meteorological Organisation
Human toxicity (HT)	Human-toxicity potential (HTP)	kg 1,4-DCB-Eq	USES 2.0

[1] The stoichiometric procedure, which identifies the equivalence between N and P for both terrestrial and aquatic systems deposition/N/P equivalents in biomass

[2] Concentration-based reserves and rate of de-accumulation approach

The inventory table of the evaluated alternatives includes in total 743 elementary flows. The following chart presents the number of environmental interventions corresponding to each of the impact categories.

Table 4-10. Classification of the environmental flows.

Impact Category	Number of environmental flows per impact category			
	Coffee	Cocoa	Cocaine processing	Sugarcane
Land use (LU)	17	18	17	17
Eutrophication (EU)	44	44	44	44
Resources depletion (RD)	100	100	100	100
Acidification (AC)	11	11	11	11
Photochemical oxidation (PO)	111	111	112	111
Climate change (CC)	52	52	52	52
Terrestrial ecotoxicity (TE)	324	325	324	324
Freshwater aquatic ecotoxicity (FAE)	324	325	324	324
Stratospheric ozone depletion (OD)	20	20	20	20
Human toxicity (HT)	348	349	348	348

4.2.3.2. Interventions lacking characterization factors

The absence of characterization factors for environmental interventions is one of the constraints of the impact assessment. That implies that the contribution of certain interventions to the impact categories is not being accounted. For including the uncharacterized interventions, the factors must be calculated, estimated or extrapolated (Guinée et al., 2002). For the alternatives under study, the CML2001 Baseline method does not give characterization factor for 743 environmental interventions. It is not within the scope of this research estimate those characterization factors. However, the influence and relevance of those flows are further assessed and discussed in the sensitivity analysis.

4.2.4. Interpretation

In this stage of the LCA, data, assumptions and methodological choices are analyzed regarding robustness and soundness. For this study, contribution and perturbation analysis are presented to evaluate the quality of the data and find out environmental flows that could be targeted to reduce the impacts of the alternatives considered in this study.

4.2.4.1. Contribution

The aim of this analysis is to determine the contribution of the environmental interventions or processes to a certain environmental score. The contribution analysis serves to identify environmental hot spots of the alternatives that are being evaluated, providing guidance about the flows that should be targeted to decrease the environmental burden.

This study evaluates the contribution of each of the stages of the cocaine hydrochloride production: the agricultural phase, alkaloid extraction and purification. For the substitution crops, this study calculates the contribution of the elementary flows to the total environmental impacts.

4.2.4.2. Perturbation analysis

Perturbation analysis examines the effect of changes in the input parameters on the LCA results. Indicating robustness of the results and opportunities for improving the study. For this research perturbation analysis is performed for the foreground process on all the impact categories.

4.2.4.3. Sensitivity analysis

The objective of the sensitivity analysis is to assess the robustness and soundness of the results concerning certain assumptions. In this study is investigated the effect of the environmental interventions linked with the use of pesticides and herbicides lacking characterization. Also, the influence of the proportion of gasoline recycled in the alkaloid extraction process is evaluated.

4.3. SOCIOECONOMIC ANALYSIS

In 2015, 74,500 families were involved in the coca cultivation, which is translated in almost 300,000 Colombians farmers participating in the illegal business chain (UNODC, 2016a). Virtually no presence of governmental institutions, social inequality, unemployment, precarious transport routes, and infrastructure have favored the consolidation and expansion of the coca industry in the country. Although coca cultivation and processing has not improved the living standard of farmers significantly and is related to high levels of violence, in regions such as Catatumbo and Putumayo-Caquetá, it has become the only agricultural product with a guaranteed market representing a secure income source. Moreover, the weight-to-price ratio of coca leaves and its derivate is relatively high compared to most legal crops (Robledo, 2015), which represent an advantage for handling and transportation. The durability of the coca paste and leaves and the quick returns obtained are factors that make the illegal business more attractive.

Profit generated by the substitution crops must be comparable with the illicit crops to be attractive for the coca growers to adopt the substitution policy (Álvarez, 2001). Building the infrastructure contemplated in the peace treaty is crucial. It is calculated that 69% of the national road network corresponds to tertiary roads, of which 25% are in good condition (DNP, 2017). Improving and building the road network will reduce the production cost of the agricultural products, connecting the rural side with their potential markets and also help to alleviate poverty.

The socioeconomic performance of the implementation of the substitution policy is evaluated using four indicators: net income of farmers, jornales, income for jornaleros and market value. Prices for the agricultural commodities in Colombia are volatile, influenced by the US dollar, petroleum price and international market. In this study, average prices for 2015 are considered. Where prices were not available for the year 2015 (set as the year for the study), data is extrapolated by applying the present value formula. The inflation of the country is considered equivalent to the annual interest rate. Results are reported in Colombian pesos.

4.3.1. Net Income of farmers

For assessing the economic retribution of the substitution crops in comparison with the coca cultivation and processing, the net income is calculated (Equation 1). The profit earned will affect the willingness of the coca farmers to join the policy.

$$Net\ income\ \left(\frac{COP_{2015}}{year}\right) = \text{Gross income} - \sum \text{expenses} \quad \text{(Equation 1)}$$

- Coca cultivation and processing

Income received by farmers comes from the sale of coca leaves and extraction of the cocaine alkaloid (coca paste). Disparities related to prices respond to the different dynamics of drug trafficking in each region. The guerrilla movements and organized crime groups regulate the price of coca leaves, coca paste, and trading conditions.

For calculating the gross income, prices of coca leaves and coca paste reported by UNODC (2016) are used (Table 4-11). The calculation of the expenses (agrochemicals, jornales, and transportation) was extrapolation from the year 2010.

Table 4-11. Economic data for coca plantation

Parameter	Catatumbo region	Putumayo-Caquetá region
Coca leaf yield (kg/ha)	5400	3700
Price of coca leaf on production site (COP2015/kg)	$4150	$1700
Coca cultivation expenses (COP2015/ha)	$15,014,700	$2,507,479
Yield of coca paste (kg/ha of coca leaves harvested)	8.96	6.14
Price of Coca paste (COP_{2015}/kg)	$2,184,800	$1,725,300
Coca Paste Expenses	$9,425,300	$6,544,518

- Substitution crops

Table 4-12 presents the data for calculating the profit of the legal crops. For coffee and sugarcane, the most up to date data were found for the year 2010; extrapolation is performed using the present value formula. The wage of *jornaleros* working on coffee and sugarcane plantations is set as the minimum legal wage in the country. Expenses can be underestimated since the cost for water access is not being considered.

Table 4-12 Economic data for substitution crops cultivation. (Barón Urquijo, 2016; Fedecacao, 2015; SIA & CCI, 2010a, 2010b)

Parameter	Cacao	Coffee	Sugarcane
Production (kg. ha/year)	2000	2100	100000
Price of good (COP_{2015}/kg)	7,000	6,028	58.58
Jornales (COP_{2015}/kg)	2,978,000	5,238,462	2,757,775
Agro supplies (COP_{2015}/kg)	1,473,667	1,296,892	1,409,375
Maintenance and tools (COP_{2015}/kg)	285,167	237,182	169,012
Administration (COP_{2015}/kg)	218,013	338,626	101,407
Additional tasks (COP_{2015}/kg)	0	230,623	0

4.3.2. Jornales

It is important to analyze how the implementation of the policy will affect the labor requirement. The cultivation practices of the coca crops, such as sowing, application of fertilizers, and collection of the leaves are exclusively manual. A mobile population, known as *raspachines* or *jornaleros,* comes to the coca field mostly during the harvest time. Table 4-13 presents the manual labor yearly required by the coca plantation. Table 4-14 shows quantity of *Jornales* needed by substitution crops per activity

Table 4-13. Jornales per ha per year for coca cultivation

Activity	Catatumbo region	Putumayo-Caquetá region
Preparation of the land	6	4
Sowing	6	4
Maintenance	40	24
Harvest	42	26
Total	94	58

Table 4-14. Jornales per ha per year for substitution crops. (Barón Urquijo, 2016; Fedecacao, 2015; SIA & CCI, 2010a, 2010b)

Activity	Cacao	Coffee	Sugarcane
Land management	5.7	0	25
Sowing	0	0	19
Fertilization	3.5	15	10
Manual control of weeds	15.0	41	26
Pest and disease control	14.0	20	26
Pruning and plucking	5.2	0	0
Harvesting	44.6	128	22.4
Technical assistance	4	4	0
Beneficio	0.0	25	0
Total	92	233	129

4.3.3. Income for jornaleros

This indicator analyzes the dynamics of the income earned by *jornaleros* working on the coca cultivation and substitution crops. Chica Jiménez (2016); Ibañez & Vasquez (2013) and Salgar Antolínez (2016) pointed out that *jornaleros* are aware of the legal risks of working in the coca fields. However, higher remuneration compared to the legal crops and lack of opportunities drive Colombians to participate in the cultivation and processing of coca. For calculating the income per *jornal* in 2015 earned on the illicit activities, the share distribution is extrapolated from the UNODC (2010) report (Table 4-15). The remuneration for *jornaleros* working on the coffee and sugarcane plantations is assumed as the legal minimum daily wage for 2015 ($21,478). The salary earned working on cacao plantation reported by Fedecacao (2015) is COP $32,393.

Table 4-15 Income per Jornal per activity for coca cultivation

Activity	Catatumbo region (COP_{2015})	Putumayo-Caquetá region (COP_{2015})
Preparation of the land	55,461	22,483
Sowing	55,461	22,483
Maintenance	66,554	29,977
Harvest	91,511	39,950
Income per Jornal (Weighted sum)	76,289	33,414

4.3.4. Market value

Market value reflects the price at which the agricultural commodities can be sold or traded in a given market. The results of this indicator will emphasize the influence of economic flows derived from the cultivation and transformation of illicit crops and substitution crops on the Putumayo-Caquetá and Catatumbo economy. For this study average prices for 2015 reported by IndexMundi (2017) for coffee and cacao beans and sugar are considered (Table 4-16). The cocaine value in the Catatumbo and Putumayo-Caquetá regions is retrieved from UNODC (2016).

Table 4-16. Market value

Commodity	Price $COP/kg
Cacao dry beans	$8,631.64
Coffee beans	$9,641.36
Sugarcane	$798.04
Cocaine CT region	$4,865,100
Cocaine PC region	$3,977,500

5. RESULTS

5.1. LIFE CYCLE ASSESSMENT

LCA has been widely used in different countries for quantifying, comparing and determining the environmental impacts associated with agricultural products. For instance, coffee (Humbert et al, 2009; Salinas, 2008) cacao (Ntiamoah & Afrane, 2008; Perez Neira, 2016) and sugarcane (Renouf & Wegener, 2007; Tsiropoulos et al., 2014). Those are the alternatives considered in this study as the substitution crops. However, there is no evidence that the environmental impacts of the coca cultivation and its derivates have been quantified. The following section presents the results of the environmental assessment for both illicit and substitution crops.

5.1.1. Impact assessment

The elementary flows from the inventory table are characterized into the selected impact categories (Table 4-9). The environmental impacts for each region are reported in Table 5-1.

Table 5-1. Characterized Impact Results (per hectare/year)

Impact category	Coffee	Cocoa	Cocaine CT region	Cocaine PC region	Sugarcane	Unit
Land use	1.01E+04	1.00E+04	1.00E+04	1.00E+04	1.00E+04	m2a
Eutrophication	52.60	27.50	28.70	21.00	14.80	kg PO4-Eq
Resources depletion	20.90	9.56	28.50	19.50	12.00	kg antimony-Eq
Acidification	203	77.7	78.8	56.20	55.60	kg SO2-Eq
Photochemical oxidation	0.473	0.461	13	8.94	0.21	kg ethylene-Eq
Climate change	6.70E+03	2.59E+03	4.54E+03	3.11E+03	2.91E+03	kg CO2-Eq
Terrestrial ecotoxicity	20.9	8.6	13.6	9.3	1700	kg 1,4-DCB-Eq
Freshwater aquatic ecotoxicity	438	249	447	305	881	kg 1,4-DCB-Eq
Stratospheric ozone depletion	3.88E-04	1.48E-04	5.13E-04	3.51E-04	2.16E-04	kg CFC-11-Eq
Human toxicity	1.74E+03	8.42E+02	1.04E+04	7.08E+03	1.94E+04	kg 1,4-DCB-Eq

Figure 5-1 shows the environmental impact results for the three alternatives evaluated in the Catatumbo region. The results are adjusted for the largest impact in each category, which is set as 1. Cacao represents the alternative with the lowest environmental impact per hectare in the Catatumbo region. For acidification, climate change, terrestrial ecotoxicity, and eutrophication, values associated with coffee are almost double in relation with the results obtained for cacao and coca processing. However, in categories as photochemical oxidation and human toxicity, cocaine has the highest values, being nearly nine times greater than those presented by the substitution crops. For the freshwater aquatic ecotoxicity, there are no differences between the results from coffee and coca processing.

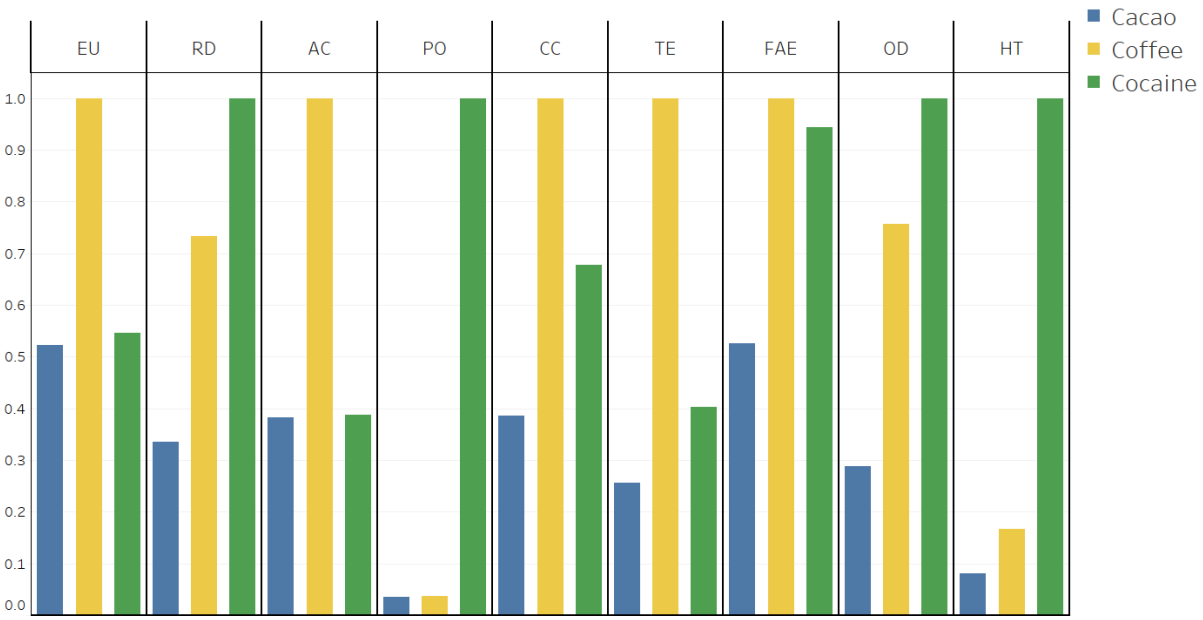


Figure 5-1. Crops evaluated in the Catatumbo region. EU eutrophication, RD abiotic resource depletion, AC acidification, PO photochemical oxidation, CC climate change, TE terrestrial ecotoxicity, FAE Freshwater aquatic ecotoxicity, OD ozone depletion, HT human toxicity.

For the Putumayo-Caquetá region, none of the crops perform better in all the environmental impact categories (Figure 5-2). Greatest differences between the crops are presented in the results of the toxicity categories (fresh water, human and terrestrial), being sugarcane the alternative with higher values. Cocaine production has higher values for ozone depletion, photochemical oxidation (almost nine times compared to the results of the sugarcane and cacao) and abiotic resource depletion impact categories. Additionally, regarding climate change, there is not a significant variation in the results for the three alternatives.

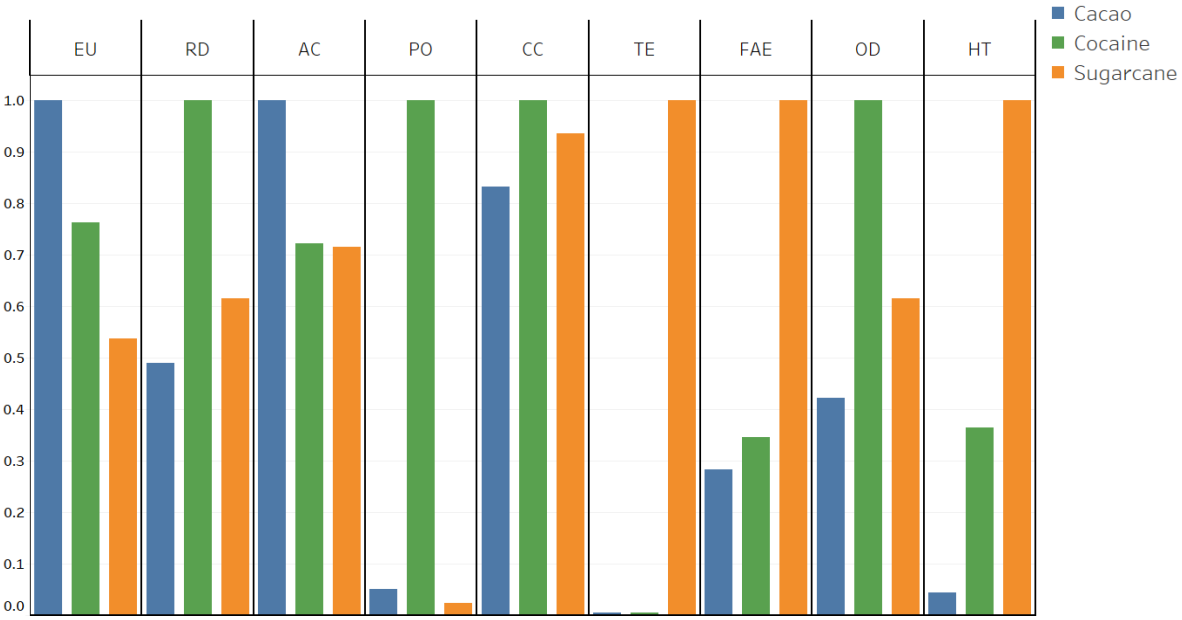


Figure 5-2. Crops evaluated in the Putumayo-Caquetá region. EU eutrophication, RD abiotic resource depletion, AC acidification, PO photochemical oxidation, CC climate change, TE terrestrial ecotoxicity, FAE Freshwater aquatic ecotoxicity, OD ozone depletion, HT human toxicity.

5.1.1.1. *Interventions lacking characterization factors*

Lack of characterization factor leads to underestimation of the environmental impacts of illicit and substitution crops. In this research, interventions caused by the use of some herbicides and pesticides are not accounted, those can contribute to the toxicity impact categories. Elementary flows associated with utilization and disposal of gasoline and solvents in the coca processing (TOC, DOC, BOD_5), are missing of characterization factors. Those can increase the eutrophication and acidification impacts. Appendix 3 presents a complete list of the environmental flows without characterization factor.

The impact of water consumption for irrigation of cacao, sugarcane, and as well for coffee and coca processing is not being considered. Substitution crops required almost ten times more water than the coca plantation (Table 5-2), which can contribute to water stress.

The impact caused by deforestation and the transformation of rainforest for the coca cultivation by clear-cutting is also not taken into consideration, which can increase the climate change emissions related and among others biodiversity loss.

Table 5-2.Interventions lacking characterization factors

Environmental interventions	Coffee	Cacao	Cocaine CT region	Cocaine PC region	Sugarcane	Unit
Water (river source)	86.4	60.3	5.14	3.51	552[3]	m^3/ha
BOD_5	2.65	1.83	21.81	15.30	1.46	kg/ha
DOC	0.79	0.33	2.75	1.89	0.44	kg/ha
TOC	0.80	0.34	2.77	1.89	0.44	kg/ha
Mancozeb	2.19E-06	1.76E-05	4.3	2.95	1.12E-06	kg/ha
Paraquat	0	0	0.86	0.59	0	kg/ha
Epoxiconazole	1.32	0	0	0	0	kg/ha
Flumioxazin	3.21	0	0	0	0	kg/ha
Hydrocarbons, aliphatic, alkanes	7.95E-03	3.25E-03	11.9	8.14	4.42E-03	kg/ha

5.1.2. *Interpretation*

Human interventions as land use, resource extraction and emissions are responsible for the environmental impacts (Guinée et al., 2002). In this section, the impacts quantified for the use of agrochemicals and other inputs for the illicit and substitution crops are analyzed.

5.1.2.1. *Contribution analysis*

Use of fertilizers during the productive phase of the substitution crops is the major cause of environmental impacts (Appendix 3). Climate change, eutrophication, and acidification are mainly due to the leakage of nutrients from the use Nitrogen-fertilizer (urea). The production of raw materials for ammonium phosphate also contributes to eutrophication. Energy generation for the manufacture of the fertilizers is the main contributor regarding abiotic resource depletion.

Processing of raw materials for Nitrogen-fertilizer (urea) and the electricity distribution network, in the coffee and cacao cultivation, represents the highest environmental burden for the toxicity categories. However, for sugarcane, those impacts can be attributed mainly to the use of pesticides. Consumption of energy in the manufacturing process of the fertilizers is the main contributor to the ozone layer

[3] Includes processing of the sugarcane

depletion. Phosphates emitted in the production of phosphorus- fertilizers are the cause of the photochemical oxidation.

Analyzing the cocaine production can be observed that cultivation and waste disposal are the stages that account for almost 80% of the total impacts (Figure 5-3). Alkaloid purification has little influence in most categories, accounting for less than 10% of the results concerning eutrophication, freshwater aquatic ecotoxicity and resources depletion (Figure 5-3). The emissions caused by the disposal of the gasoline dominates the contribution to human toxicity and photochemical oxidation. Coca cultivation is the main contributor to climate change, freshwater aquatic and terrestrial ecotoxicity, related to the use of fertilizers and its production process. Acidification is attributed to the use of N-fertilizers on coca plantation and the disposal of the leaves after the extraction of the alkaloid. Alkaloid extraction and cultivation stage represent almost 95% impact on the depletion of abiotic resources, which is linked to the generation of energy for agrochemicals and chemical precursors manufacturing used.

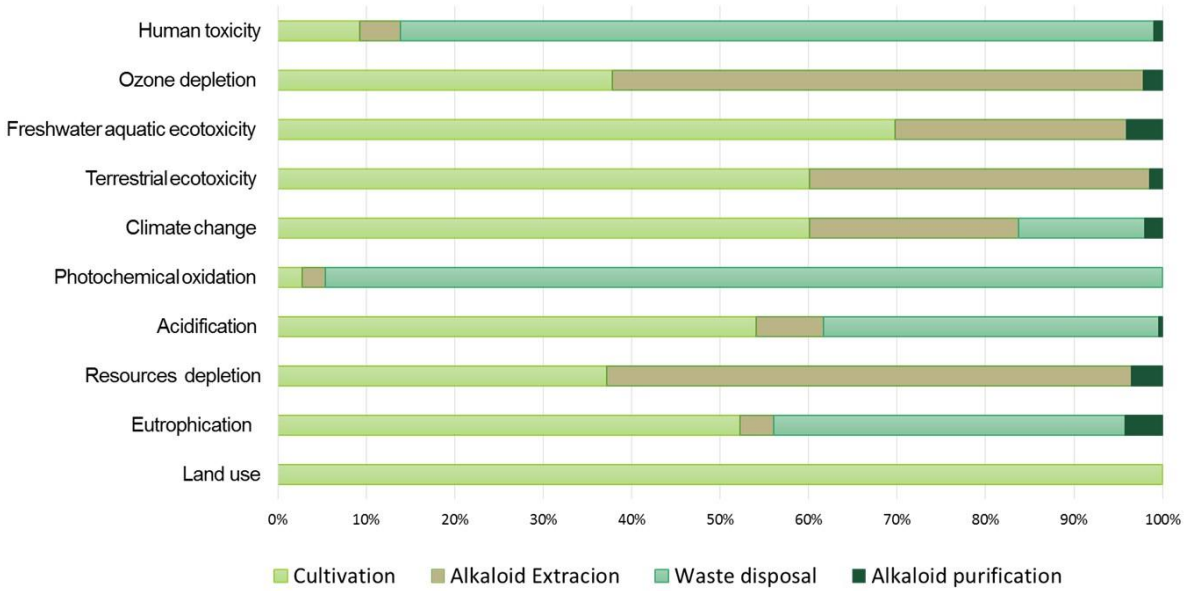


Figure 5-3 Contribution analysis for the production stages of the cocaine.

5.1.2.2. Perturbation analysis

In this analysis, a multiplication factor is applied to the economic flows to estimate the rate of change of the environmental impacts. Results show that the yield of substitution and illegal crops has the major effect on all the impacts. This fact is taken as the basis for the refinement of the data. The results for this analysis are presented in the appendix 3.

For the coffee cultivation, the perturbation analysis reveals that improving the processing of green coffee beans can reduce the impact in all the environmental categories evaluated. The ratio is one to one, meaning improving the yield in 1% of the coffee processing, decreases in the same proportion the value of the environmental impact. Moreover, increasing the consumption of Nitrogen-fertilizer (urea) for the coffee plantation during the productive phase increments the overall result of almost all the categories, except for eutrophication and acidification. The proportion, in this case, is not linear, increasing 1% the quantity of urea will lead into 0.25 and 0.8 increments, depending on the impact category.

For sugarcane and cacao, the analysis indicates a similar behavior. Increasing the yield on the productive phase will reduce the environmental pressure. In this case, linear factors are observed between the

outputs (sugarcane and cacao beans) and the score of the ten evaluated impacts. Increasing the quantity of urea, and in less extension, diammonium phosphate will lead into higher value on the toxicity categories, resource and ozone depletion and photochemical oxidation.

The alkaloid purification presents an inversely proportional relation to the overall score of the ten environmental impacts evaluated. Increasing by 1% the coca paste obtained will reduce between 0.95% and 0.98% the results of the impact categories evaluated.

5.1.2.3. Sensitivity analysis

Pesticides can affect non-target species, as well animal and plant biodiversity (Mahmood, Imadi, Shazadi, & Gul, 2016). In this study, impacts caused by the use of pesticides on coca and coffee fields are underestimated because of the lack of characterization factors. To investigate the pesticides' potential toxicity impact proxies with characterization factors were used (Table 5-3). Proxies were chosen base on the function they fulfill which is prolonged weed control.

Table 5-3. Proxies used in the sensitivity analysis.

Crop	Environmental intervention	Proxy	Quantity kg/ha	
			CT region	PC region
Coca	Paraquat	Atrazine	0.86	0.59
	Mancozeb	Carbendazim	4.3	2.95
Coffee	Epoxiconazole	Mecoprop	1.32	NA
	Flumioxazin	DNOC	3.21	NA

After assessing the effect of the use of pesticides, it is observed that those increase the environmental burden of the toxicity impact categories. Previous results for the Catatumbo region pointed out that coffee was the alternative causing the largest impact on terrestrial ecosystems (Figure 5-1). However, results of the sensitivity analysis showed that the toxicity impacts of cocaine production are almost eight times higher compared to the substitution crops (Figure 5-4). The outcome of the sensitivity analysis for the Putumayo-Caquetá region (Figure 5-5) reveals that for the freshwater ecotoxicity the impact of cocaine production is almost 80% higher compared with sugarcane cultivation. For both Human toxicity impact category increases less than 5%, after using the proxies.

Catatumbo region

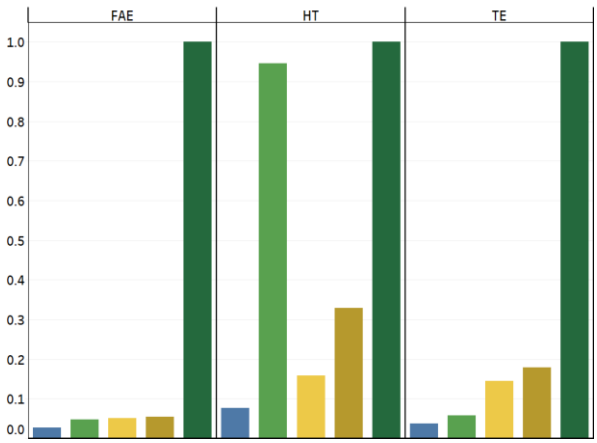


Figure 5-4. Sensitivity analysis Catatumbo region

Putumayo- Caquetá region

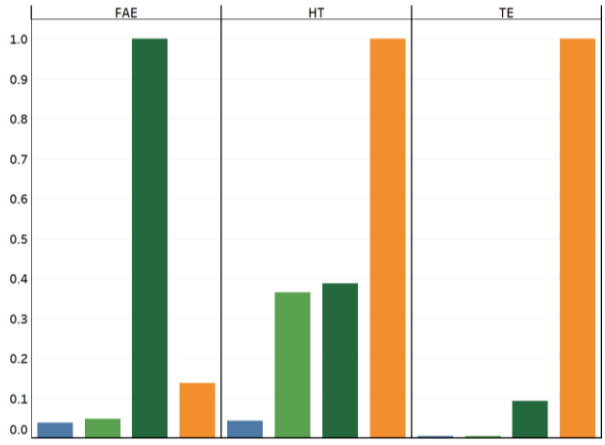


Figure 5-5. Sensitivity analysis Putumayo-Caquetá region

The quantity of gasoline recycled has a direct influence in almost all the environmental categories. Decreasing the percentage of gasoline reused will increase the environmental burden of the cocaine production (Figure 5-6). When 20% of the gasoline is recycled the environmental burden of the human toxicity, and photochemical oxidation is twice in comparison to 70% recycling rate. The depletion of abiotic resources and the ozone layer is also affected, diminishing the recycling quantity will almost double the result of those impacts.

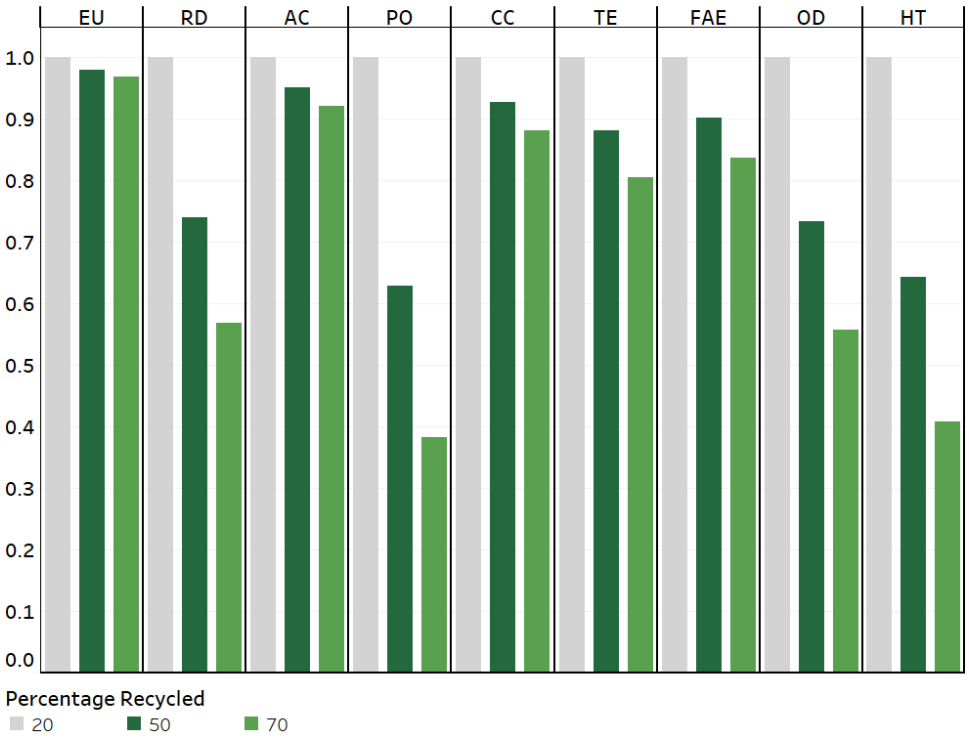


Figure 5-6. Influence of the percentage of gasoline recycled in cocaine production

5.2. SOCIOECONOMIC ANALYSIS

This section presents an overview (hectare base) of the social and economic indicators selected for the analysis (Figure 5-7 and Figure 5-8. Socioeconomic results for the Putumayo- Caquetá region). UNODC has calculated that a family that lives from growing and processing coca leaves could earn in average COP $9.154.000/year (UNODC, 2016a). In this research, in average, the yearly profit of COP $8.363.274/hectare is calculated. The result presented by UNODC is an average value of the eight regions with illicit crops in the country, while this study considers only Putumayo-Caquetá and Catatumbo region. This fact can explain the difference between calculations presented here and UNODC reports.

Comparing the salary of *jornaleros* in the Catatumbo region, it is observed that salary for working on coca plantations is almost two times the income earned on coffee and cacao plantations. The market value presents the same trend, the profit gain for one hectare of coca leaves processed into cocaine is almost double compared with coffee and cacao beans. However, coffee demands almost six times more *jornales* than cacao and coca. For farmers, the difference in the profitability between cacao and coca is less than 20%, while coffee decreases the profit by nearly 50%.

In the Putumayo-Caquetá region, the income for *jornaleros* is nearly the same harvesting cacao or coca. Although sugarcane demands more *jornales* per hectare, it has the lowest revenue for farmers and

jornaleros. In economic terms for farmers of this region cacao is the most profitable option, the income is around 50 % more compared to the illicit crops. Moreover, it is evident that cocaine has the higher market value among all the options evaluated in this region.

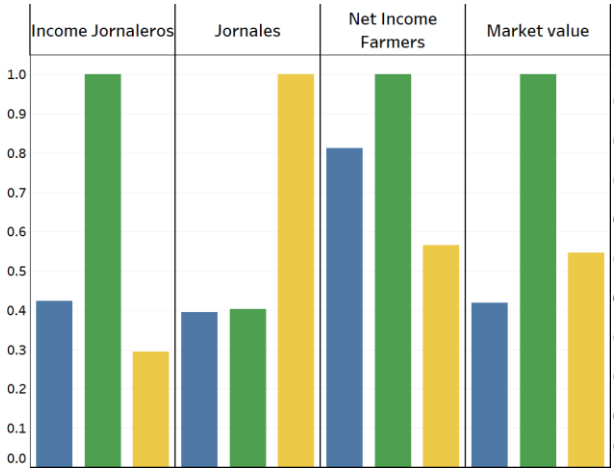


Figure 5-7. Socioeconomic results for the Catatumbo region

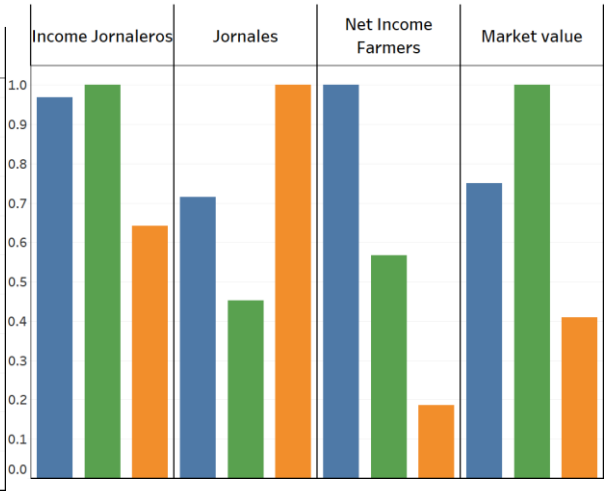


Figure 5-8. Socioeconomic results for the Putumayo-Caquetá region

5.3. Scenarios Results

This section presents the outcome of the environmental and socioeconomic assessment for BAU, PS, CO and BE scenarios.

5.3.1. Environmental assessment

Table 5-4 shows the characterized impact results for the four scenarios in the Catatumbo Region. The Balloon Effect scenario (BE) has the highest values in almost all the categories except in acidification, photochemical oxidation, and human toxicity categories.

Table 5-4 Characterized Impact Results for the alternatives evaluated, for the Catatumbo Region

Impact category	BAU	PS	CO	BE	Unit
Land use	1.08E+08	1.08E+08	1.08E+08	1.57E+08	m2a
Eutrophication	3.09E+05	4.32E+05	3.27E+05	4.44E+05	kg PO4-Eq
Resources depletion	3.07E+05	1.64E+05	1.77E+05	3.26E+05	kg antimony-Eq
Acidification	8.49E+05	1.51E+06	9.76E+05	1.23E+06	kg SO2-Eq
Photochemical oxidation	1.40E+05	5.03E+03	4.55E+04	1.23E+05	kg ethylene-Eq
Climate change	4.89E+07	5.01E+07	3.87E+07	5.88E+07	kg CO2-Eq
Terrestrial ecotoxicity	1.47E+05	2.28E+05	1.36E+05	1.82E+05	kg 1,4-DCB-Eq
Freshwater aquatic ecotoxicity	4.82E+06	3.90E+06	3.57E+06	5.75E+06	kg 1,4-DCB-Eq
Stratospheric ozone depletion	5.53E+00	2.89E+00	3.03E+00	5.71E+00	kg CFC-11-Eq
Human toxicity	1.12E+08	1.39E+07	4.10E+07	1.02E+08	kg 1,4-DCB-Eq

Figure 5-9 shows the comparison of the environmental impact results from the scenarios evaluated in the Catatumbo region. Not surprisingly, BE scenario has the higher impact in almost all the impact

categories. In this scenario, coca cultivation is displaced (more land is taken) requiring additional amounts of agrochemicals. Looking at the other three scenarios is interesting that PS and BAU have almost the same score for climate change, which means that the substitution of illicit crops in this region will not reduce the emissions causing it. The CO scenario performs slightly better than the PS scenario for the climate change, terrestrial and fresh water ecotoxicity impact categories. In the Conservative Scenario (CO) coca processing and substitution crops are presented in different ratios.

The success of the implementation of the policy (PS scenario) will diminish considerably (almost 90%) photochemical oxidation and human toxicity impacts when compared to the current situation (BAU scenario). In the BAU scenario, the score of those impacts is mainly attributed to the use and disposal of gasoline. The depletion of abiotic resources and ozone layer depletion is also ameliorated in the PS scenario. However, in this scenario acidification and eutrophication show an increasing tendency, which can cause an over-enrichment on aquatic and terrestrial ecosystems, attributed to leaching of nutrients from the use of fertilizers. In the PS scenario, coffee and cacao are planted in equal proportion. Nonetheless coffee contributes in a higher percentage of all the impact categories.

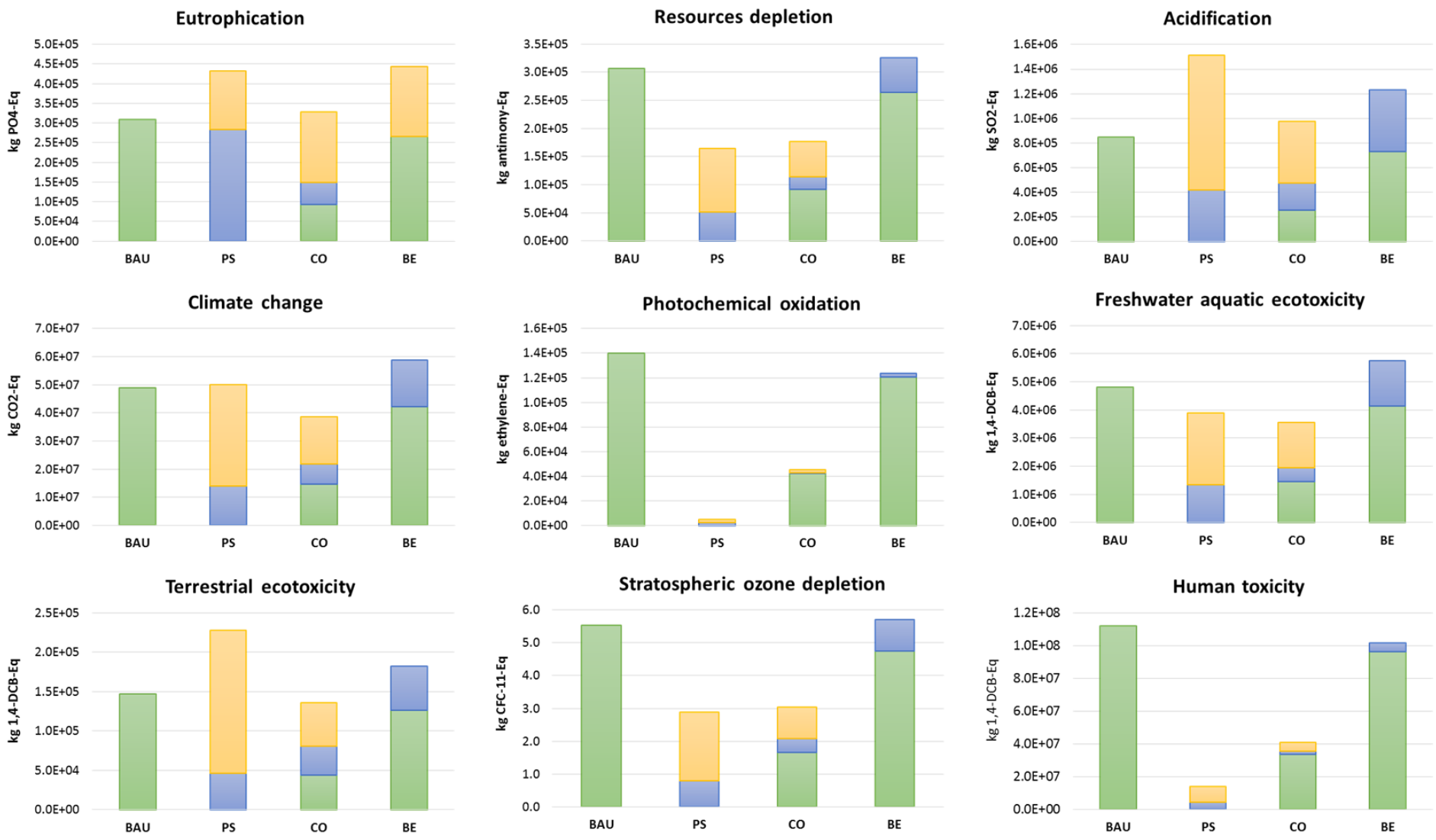


Figure 5-9. Environmental profile for the scenarios of the Catatumbo Region.

Figure 5-10 and Table 5-5 present the characterized impact results per scenario for the Putumayo-Caquetá region.

Table 5-5. Characterized Impact Results for the alternatives evaluated, for the Putumayo-Caquetá Region

Impact category	BAU	PS	CO	BE	Unit
Land use	2.71E+08	2.71E+08	2.71E+08	3.41E+08	m2a
Eutrophication	5.69E+05	5.73E+05	5.21E+05	6.16E+05	kg PO4-Eq
Resources depletion	5.28E+05	2.92E+05	3.49E+05	5.44E+05	kg antimony-Eq
Acidification	1.52E+06	1.81E+06	1.66E+06	1.91E+06	kg SO2-Eq
Photochemical oxidation	2.42E+05	9.13E+03	5.47E+04	1.63E+05	kg ethylene-Eq
Climate change	8.42E+07	7.45E+07	7.77E+07	1.03E+08	kg CO2-Eq
Terrestrial ecotoxicity	2.52E+05	2.31E+07	2.54E+07	2.78E+07	kg 1,4-DCB-Eq
Freshwater aquatic ecotoxicity	8.26E+06	1.53E+07	1.65E+07	1.98E+07	kg 1,4-DCB-Eq
Stratospheric ozone depletion	9.51E+00	4.93E+00	6.12E+00	9.79E+00	kg CFC-11-Eq
Human toxicity	1.92E+08	2.74E+08	3.33E+08	4.42E+08	kg 1,4-DCB-Eq

For the Putumayo-Caquetá region Balloon Effect scenario (BE) has the highest values in all the environmental categories except in photochemical oxidation, on which BAU has the higher score. Analyzing the behavior of the PS and CO scenarios, it can be seen that sugarcane contributes with the greater percentage of the toxicity impact categories.

In this region, the establishment of the policy (PS) will slightly reduce the CO_2 emissions compared to the current situation (BAU scenario). PS scenario presents the lowest values for the depletion of abiotic resources and ozone and photochemical oxidation impact categories. In contrast, acidification may worsen with the substitution of all the illegal crops (PS scenario). The results for eutrophication show almost no difference between the BAU and PS scenario. It is also interesting to observe that the consolidation of a Conservative scenario, where all the crops are present has an environmental performance similar to the success of the implementation of the substitution policy.

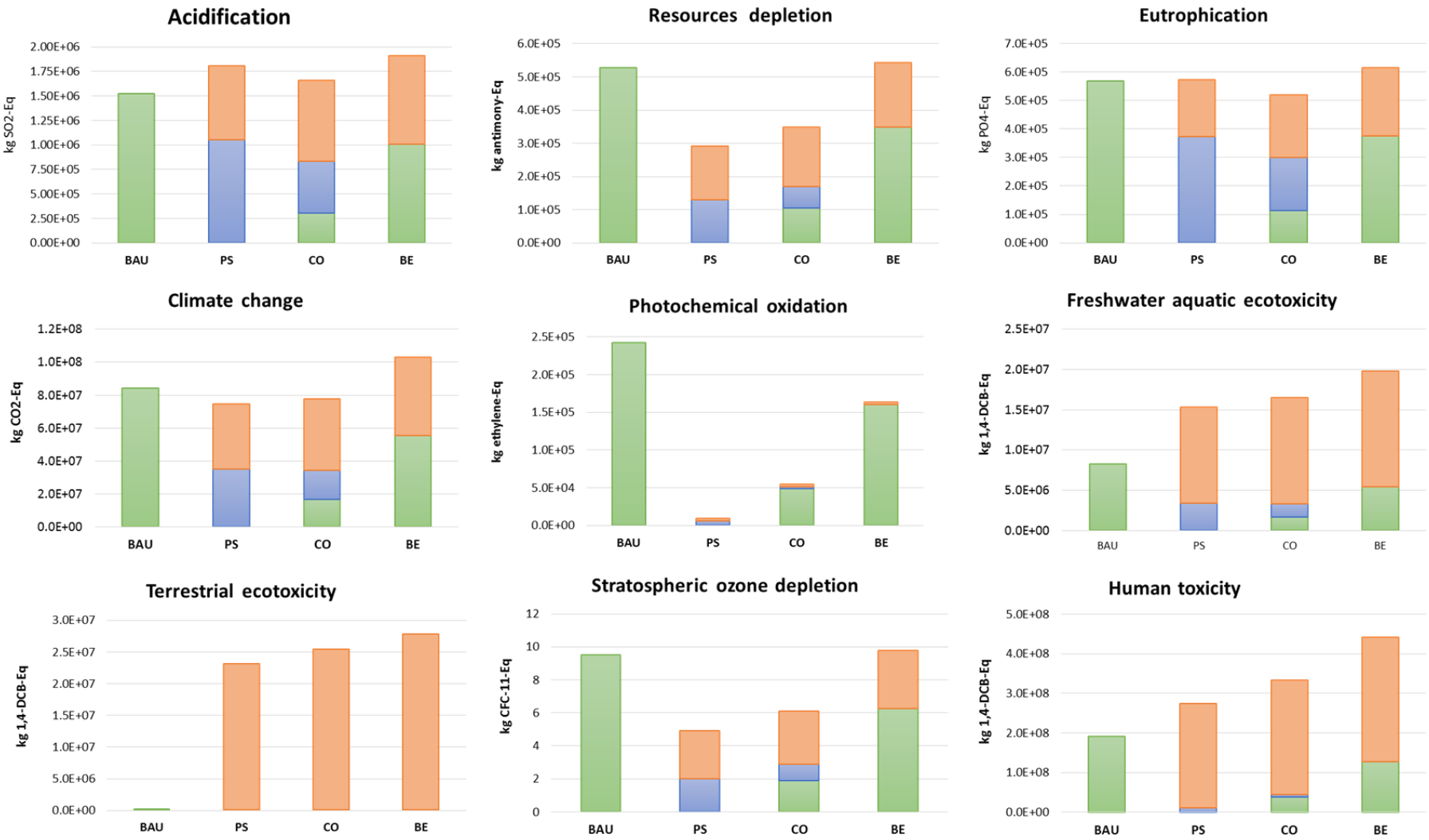


Figure 5-10. Environmental profile for the scenarios of the Putumayo-Caquetá Region

5.3.2. Socioeconomic assessment

In the Catatumbo region, replacing the coca crops by cacao and coffee (PS) will reduce almost by 30% the total income of farmers (Figure 5-11). To a greater extent, the implementation of the policy will affect *jornaleros*, for whom in average salary will be reduced by half (Figure 5-15). That is related to the fact that coffee generates less profit per hectare compared to illicit crops for farmers and the salary per jornal is also lower. However, if the whole area affected by illicit crops is sowed with coffee and cacao, the workforce demand increases by nearly 40% (Figure 5-13)

Implementing the policy (PS) means a socioeconomic benefit for the Putumayo-Caquetá region communities. Profitability for *jornaleros* and farmers will increase, along with the workforce needed. Figure 5-12 shows that even though in the PS scenario the area with sugarcane and cacao is equal, cacao contributes in greater percentage to increase the income of farmers. On the other hand, sugarcane drives the need for the workforce (Figure 5-14).

Weak presence of the state and failure of ADP on reaching all the farmers and provide them a livelihood have helped to the appearance of scenarios similar to the CO and BE, contemplated in this study. In the Catatumbo region those scenarios, will not imply major changes in the income of farmers and the number of jornales compared to the BAU scenario. In contrast, *jornaleros* would be affected, because their total salary could be cut by nearly 35% (Figure 5-15). In the Putumayo-Caquetá region, the displacement of coca crops (BE scenario) will be reflected in a reduction of the total income for the farmers. However, since sugarcane represents half of the crops planted, workforce will increase compared to the current situation (Figure 5-16).

The market value of the BAU scenario is between 40 to 50% greater in relation to the economic benefit generated by the successful implementation of the substitution policy in both regions (Figure 5-17 and Figure 5-18). However, profit from the cocaine trading has been used by guerrillas and organized crime groups to finance the war in Colombia, while marketing cacao, coffee and sugarcane likely will boost the regional and national economy and help on the consolidation of peace and progress in rural areas of the country. The fluctuation of market prices of legal crops is reflected in the graphs 5-17 and 5-18 on the PS, CO and BE scenarios, which is between 15 and 20%.

Socioeconomic indicators are calculated in COP for the year 2015. The results here presented can vary depending on the share of each of the crops per scenario. Coffee and sugarcane are the crops that require more *jornales* per hectare. However, the economic retribution for the *jornaleros* is less compared to cacao and coca. It is important to take into account that for this research the wage per *jornal* was set as the minimum legal wage, which in some cases is greater than the payment received.

Catatumbo Region

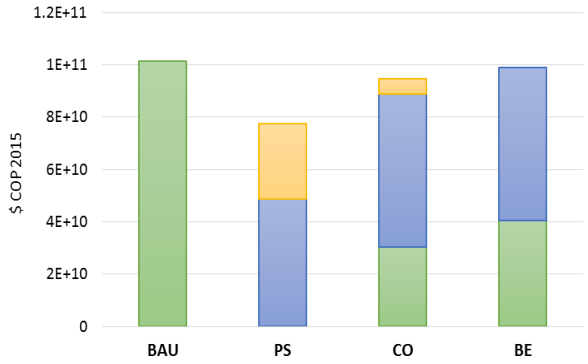


Figure 5-11.Net income per year of farmers.

Putumayo Caquetá Region

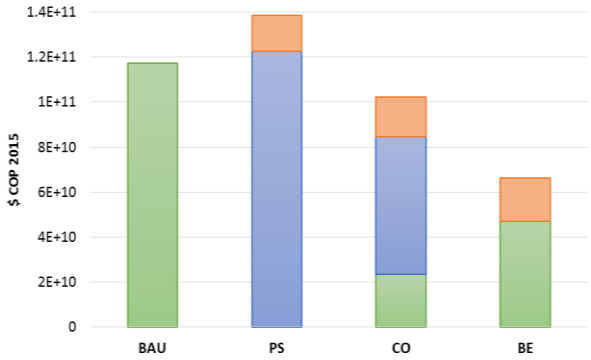


Figure 5-12.Net income per year of farmers.

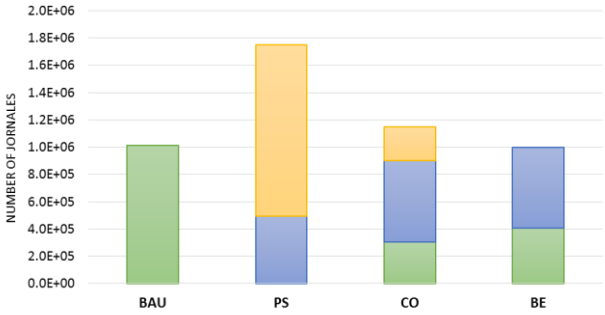


Figure 5-13. Total Jornales per year

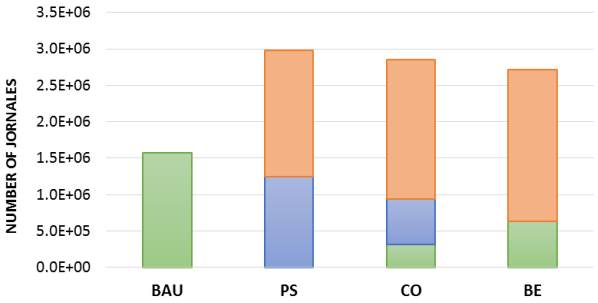


Figure 5-14. Total Jornales per year

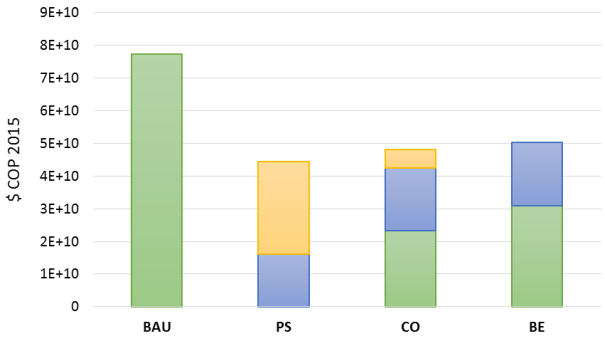


Figure 5-15. Total Income per year of the Jornaleros

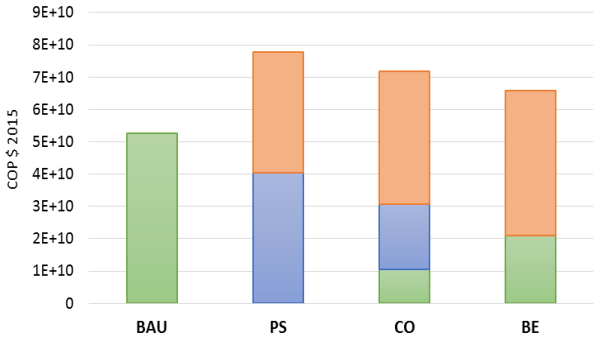


Figure 5-16. Total Income per year of the Jornaleros

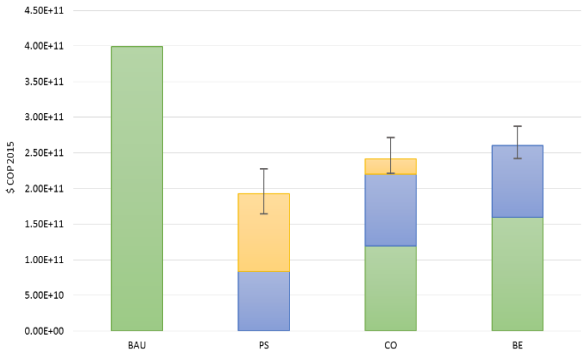


Figure 5-17. Market value

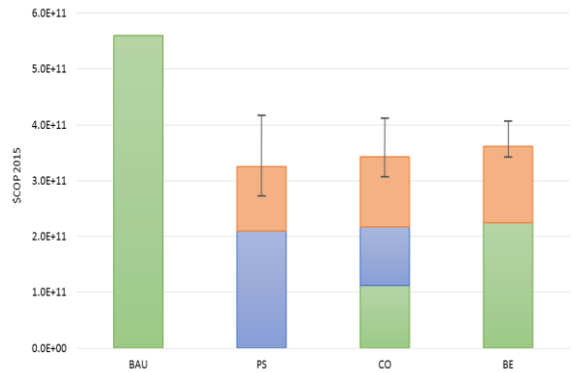


Figure 5-18. Market value

6. DISCUSSION

The substitution crops contemplated in this research, have been previously implemented in APD (Cacao for peace, The Forest-Warden Families) and have as a common feature the potential for being absorbed in national and international markets. Colombian coffee is internationally recognized and is one of the most important agricultural commodities for the country. Moreover, cacao has a steadily growing demand, is expected that the worldwide demand will increase 30% by the year 2020. Analyzing the national market, in 2015, 5,391 tons of cacao were imported while 13,744 tons were exported (Portafolio.com, 2017). Sugarcane has the potential for sugar or national bioethanol production. However, local environmental issues, characteristics of the soil, land suitability and water availability need to be considered when choosing the crops for implementing the substitution policy in each region.

The environmental and socioeconomic assessment per hectare of the substitution crops, as well as the illicit production chain, reveal an interesting dynamic for the regions analyzed. The behavior is not the same in both regions since environmental and socioeconomic results differ one from the other. The discrepancy between the results is linked to agricultural practices and percentage of farmers who sell coca leaves or coca paste. Additionally, geographical location plays a major role in the acquisition of chemical precursors, fertilizers, and pesticides.

Results per hectare for the Catatumbo region shows that cacao has a lower impact in all the environmental categories. Coffee reduces the photochemical oxidation, depletion of abiotic resources and the ozone layer compared to the cocaine production. Its results for climate change, eutrophication and acidification are higher than those produced by illicit drugs processing. Environmental performance of the coffee is affected by the relatively large use of N-fertilizer compared to the other crops, the production and use of this fertilizer account for over 40% of the contribution to the total impact results in most categories. In the Putumayo-Caquetá region, the environmental assessment per hectare shows that neither cacao nor sugarcane achieves the reduction of all the impacts categories. For climate change, substitution crops present similar results, reducing the impact on nearly 5%. When analyzing the toxicity categories (terrestrial and human) sugarcane has a higher impact, almost five times more than coca and cacao. These impacts are attributed to the type of pesticides required by this crop. The present study considers the average use of fertilizers and pesticides for the substitution crops. Nonetheless, farming practices are dependent on the type of soil, climate conditions and need to be adapted to each region. Replace chemical fertilizers by organic ones (manure, compost) and in general sustainable agriculture practices can reduce the environmental impacts (FAO, 2017).

In both regions, coca processing shows higher impact per hectare on photochemical oxidation and abiotic resource and ozone layer depletion. However, the environmental implications of the cocaine production were underestimated because of the missing characterization factors. That effect was investigated using proxies for the interventions caused by the use of pesticides on the coca cultivation. Results for the Catatumbo region indicated that the freshwater aquatic and terrestrial ecotoxicity impacts of the coca cultivation are at least nine times higher compared to the substitution crops. For the Putumayo region, the score of the freshwater ecotoxicity impact category was increased by 90%. Moreover, effects generated by the discharge of substances used for alkaloid extraction and purification are not entirely reflected in the results. BOD5, COD, and TOC are listed as interventions without characterization factor, having values between two and ten times higher compared to the legal crops. That fact needs to be addressed since regions like Catatumbo and Putumayo-Caquetá have a great variety of ecosystems and those environmental interventions can increase the eutrophication and acidification.

Emissions of the substitution crops and coca cultivation and processing were calculated applying models reported in the literature which allow the same level of detail for all the alternatives. However, the use of self-reported information and not including the emissions of secondary nutrients (Sulfur (S), Magnesium (Mg), Calcium (Ca)) can lead to underestimation of the environmental impacts. Also, the results can be affected by the use of background information, *Ecoinvent 2.2* reports data for European conditions.

From the economic perspective, cacao is the best option for farmers to replace coca plantation. However, it takes at least three years to reach the productive phase, while coca gives the first harvest at seven months after being planted. Establishing food security projects and monthly subsidy contemplated on the substitution policy are essential to support the communities and provide them a livelihood while the substitution crops start providing economic returns. It is also important to mention that freight rate for the substitution crops was not included in this study. In 2005, the cost of the transport in Colombia was approximately 10% of the final value of agricultural products (El Tiempo.com, 2005).

It has been proven that in average, the products of one hectare of coca plantation are between 5% and 50% more profitable for farmers and *jornaleros* in the Catatumbo region compared to legal crops. The outcome is consistent with the work presented by Ibañez (2013), who conclude that coca is three to five times more profitable than the legal crops. Results for the Putumayo-Caquetá highlight that profit for farmers per hectare of cacao is 50% higher compared to illicit cultivation, while the salary for *jornaleros* is almost equal. Differences in the economic results can be explained first by the fact that prices of chemical precursors used for transforming coca leaves into coca paste represent 30% of the expenses in the Putumayo Caquetá region and only 15% in the Catatumbo region. In addition, the price per kilogram of coca leaves and coca paste in the Catatumbo region is almost twice than in the Putumayo-Caquetá region.

In the Catatumbo region, coffee will demand more *jornales* per hectare than the other crops, but with a lower payment. Same occurs with sugarcane in the Putumayo-Caquetá region, even though the number *jornales* per hectare is higher the salary is the lowest for the crops evaluated in that region.

The comparison between the four scenarios in the two areas showed BE has in overall the largest environmental impacts associated. The fact is explained by the displacement of the illegal crops, which requires more land, fertilizers and chemical precursors for processing the coca leaves. Exploration of the BAU scenario in both regions showed higher environmental impacts on photochemical oxidation, and ozone and abiotic resources depletion, compare to the satisfactory implementation of the policy. The behavior of the PS, CO and BE scenarios is determined by the percentage of each crop assumed.

Compared to the BAU scenario, the PS scenario reduces less than 13% emissions associated to climate change in both region. Nevertheless, carbon dioxide emissions in the current situation (BAU scenario) are underestimated in this research. Contribution from deforestation is not taken into account. In the last ten years in the Catatumbo region the loss of 2,205 hectares are directly attributed to illicit crops, while in the Putumayo-Caquetá 9,198 hectares have been deforested (REDD+ Colombia, 2017). Also, the slash and burn techniques used by farmers to clear the land can damage the vegetative matter that protects the soil (UNODC, 2015). Moreover, environmental interventions caused by transportation of coca leaves and paste are left out of the boundaries of this research, alkaloid purification can take place in another region, or even in another country. Information is not available due to the illegal nature of the activity.

Colombia is the second most biodiverse country, being the home to 10% of the world flora and fauna (Pinzón & Sotelo, 2010) of which about 18% of the animal species and 30% of the plants are endemic. The Humbolt Institute (2014) indicates that the expansion of illicit crops in the country has been partly responsible for biodiversity loss. Achieving a PS scenario could eventually reduce the impact on biodiversity linked to illicit crops by reducing the deforestation rate and applying agro-silvoforestry approach, which combines agriculture, animal production, and forestry. This method is already being implemented in Colombia in coffee and sugarcane plantations, using shade trees that protect bird and pollinator diversity (Baptiste et al., 2017).

During the peace treaty and the substitution policy implementation timeline, the government and national institutions focus on overcoming socio-political instability, peacekeeping and poverty alleviation (Suarez et al., 2017). Also on attracting foreign and domestic investment to the underdeveloped areas. Investment is necessary to consolidate the PS scenario, generating employment and reactivating the local economy on growing coca communities. However, Colombia is at high risk from climate change impacts (Cote, Martin, Gonzales, & Cardona, 2010). Water shortages and floods, land instability, the decline in the agricultural productivity are some of the events that the country can face. For that reason, calculating the total potential emissions associated with climate change of the implementation of the peace treaty is vital. Also, land use planning and management of natural resources need to be also a priority to avoid the intensification of pressure on the environment. It has been observed that in countries going through a post-conflict phase; there is a detriment of natural resources due to infrastructure development (roads, schools, and sanitation systems), economic exploitation, internal migration and lack of embedding the environmental dimension into the national policy framework (Suarez et al., 2017).

BAU scenario has the highest market value and is more profitable for farmers and *jornaleros* of the Catatumbo region. However, coca growers experience unfair/hazardous working conditions (Hernandez Mora, 2017). Often farmers and *jornaleros* handle herbicides and pesticides without protective clothing, are exposed to chemicals and excessive working hours. The places where coca leaves are processed do not comply with security measures. Also, in this scenario participation of children (people under 9) on coca plantation and processing is common in both regions (Catatumbo region 23 % and Putumayo-Caquetá 15%). They contribute to increasing the household income, usually collecting coca leaves. The absence of formal education and infrastructure has helped to spread this issue.

In general, social investment is an essential ingredient of the peace treaty and specifically of the substitution policy. That is expected to account for closing the existent social gaps and as an effective measure to control and reduce the illicit crops. Davalos (2016) shows that by allocating USD 5.5/per inhabitant to human capital and infrastructure, can prevent the plantation of one hectare of coca. That is one of the reasons why development of road infrastructure plays a central role in the success of the substitution policy (PS scenario). Since it will facilitate farmers to reach markets with the agricultural products, revitalize the local economy (Davalos, 2016), and provide access to health and education centers. Likewise, will help to restore the confidence of farmers in governmental programs and state institutions and increment the chances of the solidification of the PS scenario. Also, integration of stakeholders and establishment of productive alliances and cooperatives is necessary to eradicate coca plantations (PS scenario). The Government has the responsibility to accomplish the substitution agreements and the peace treaty. Farmers and *jornaleros* commit not to replant coca. There is also a third important partner, private sector, agricultural associations, and industry. They can help to enhance markets for agricultural products, ensuring a minimum purchase price (Ibañez, 2013) and for mobilizing more investment for the transition towards a legal economy.

The land reform is a priority to boost the willingness of farmers to participate in the substitution policy. Colombia registers one of the highest inequitable land distribution, recording a Gini coefficient of 0.85 (with 1 representing maximum inequality) (Morales, 2017). Lack of land titles has prevented farmers from planting crops such as cacao, which required long-term commitment before getting financial returns (Mejía, 2016; UNODC, 2015). Furthermore, dependency on international financing for the implementation increases the vulnerability of the substitution policy. Those issues can increase the chances for the consolidation of a Conservative scenario. In this scenario between 20 to 30% of farmers and *jornaleros* return to grow coca because the lack of continuity of the program or because the means to reach local markets are missing (DNP, 2017).

On the PS scenario, the number of *jornales* increased 40% for both regions, which can contribute to generate employment not only for coca-*jornalero*s but also for FARC ex-combatant. The infrastructure that will be built in this scenario will also require workforce. Calculations showed that paving 1km will require approximately three people (Ávila, 2016). Assuming that half of the tertiary roads of each region are improved, this work would generate 16.000 new jobs. Additionally, the peace treaty is opening the opportunity for the creation of sustainable tourism programs and ecosystem services. Estimates show that bird tourism alone could generate revenue of $ US 46m a year, and create at least 7,500 new jobs (The Economist, 2017). Ecotourism can boost rural economies and support the consolidation of the PS scenario. While the substitution crops reach their productive phase farmers can have an economic support for working on the tourism sector.

The peace process and treaty have shown the first environmental advantages, since the number of attacks on oil facilities perpetrated by the FARC guerrilla began to decline in 2014 (Ramirez Prado, 2015), ceasing entirely this year. In the BAU scenario, FARC attacks on oil facilities, released approximately 757,000 of barrels, affecting ecosystems and water resources in the whole country (Weir, 2016). In contrast, in 2016 the deforestation rose by 44%, the majority of municipalities affected lie in the former FARC territory (Redacción EFEverde, 2017). The FARC guerrilla had controlled the logging by establishing quotas, but their demobilization, the high demand of exotic wood, expansion of the agricultural frontier and the illegal crops are the main causes of the deforestation rate growth (Redacción EFEverde, 2017).

The signing of the peace treaty has already shown social gains since homicide and kidnapping rate have been significantly reduced. Colombia has gone from witnessing 66 murders (per 100,000 people) and 3570 kidnappings in the year 2000 to 25 homicides and 210 abductions in the year 2015 (Alseman, 2016; UNODC, 2017). However, the Colombian government is failing to provide robust local institutional structures on isolated and coca growing areas (Dennis, 2017). Guerrilla movements (ELN, EPL) and BACRIM had started to dispute the control of FARC's drug trafficking routes and strategic resources. In Nariño and Catatumbo social leaders, their families and farmers negotiating the substitution of illicit crops with the government have been threatened by ELN, EPL and BACRIM (Flórez, 2017; Semana.com, 2017a; Zamudio Palma, 2017). Since the beginning of the peace treaty implementation, selective killings and offensives against civil and rural leaders have increased (Sánchez Garzoli & Londoño, 2017). That reflects the weakness, and lack of planning of the government, which can serve for the consolidation of the BE scenario, where farmers afraid and pressured will continue planting coca and a new wave of violence impedes the construction a lasting peace.

Relocation process of the coca plantations (BE scenario) will increase nearly 20% the climate change associated emissions when compared to the current situation in both regions. Deforestation and biodiversity loss on vulnerable areas are likely to raise in this scenario, because of the diffusion and increment of the coca crops. Furthermore, in the BE scenario income for farmers in the Putumayo

region will be reduced almost by half, while for farmers in the Catatumbo region will not experience significant changes compared to the current situation.

Colombia is the world's main cocaine producer, 20% is consumed domestically (Crisp, 2013). Reports show that large percentage of the cocaine ends up in foreign markets, as the United States and the European Union. Chemicals precursors and agricultural products for cultivating and processing coca leaves come from Venezuela and Ecuador. Those issues demonstrate the relevance of sharing the responsibility to tackle the drug trafficking problem. Global policies are needed, since the illicit drug is a lucrative business, and given the fact that while demand exists someone will supply it (Navarrete Frías, 2004). Prioritizing policies for the reduction of cocaine demand in the United States and the European Union will help the consolidation of the substitution policy and reduce the possibility of the BE and CO scenarios.

7. CONCLUSIONS

This research highlights the environmental and socioeconomic interactions of the substitution policy in the Catatumbo and the Putumayo-Caquetá region, considering sugarcane, cacao, and coffee as substitution crops. To illustrate the outcome of the implementation of the policy a series of scenarios were proposed. Results for the scenarios are dependent on the share of the crops.

LCA serves to identify the environmental tradeoffs of the substitution crops in contrast with coca plantation and processing. Taking agricultural practices and cocaine production technique reported by Colombian agricultural associations and UNODC, environmental results indicate that for both regions cacao is the substitution crop with lower environmental impact and higher economic benefits. Nevertheless, cacao reaches its productive phase at the third year, so alongside the substitution alternatives, short term crops need to be considered for guarantying an income for the farmers and cut the economic dependence on the illicit crops.

The effect of lacking characterization factors for environmental interventions and quantity of gasoline used are addressed in this research. Using interventions for which characterization factors were available, it is observed that toxicity impacts of the coca processing were between two to nine times higher. The quantity of gasoline used and discharged during the alkaloid extraction has a direct impact on the results of the almost all the impact categories. Decreasing by 20% the amount of gasoline reused implies an increment of the environmental burden of the cocaine production.

The BAU scenario was constructed to assess the implications of the implementation of the substitution policy. In this way, benefits are highlighted as well as undesirable effects. This scenario provides quantitative information about the environmental impacts of the production of cocaine in Catatumbo and the Putumayo-Caquetá regions. Results reveal that cultivation and waste disposal are the stages accounting for almost 80% of the environmental burden, which is attributed to the use of fertilizers and discharge of gasoline. The quantity of CO_2 emitted by the cocaine production is almost 300 times its weight.

The BAU scenario has the higher market value for both regions. Nevertheless, profit from the cocaine production has been used to finance the armed conflict in Colombia that has left a significant number of civilian victims.

The growing and processing coca have left a footprint on ecosystems and rural communities nationwide. For the Catatumbo region implementing the substitution policy as is stated in the peace treaty will bring environmental benefits, ameliorating most of the environmental impact categories evaluated. However, the use of N-fertilizers on coffee plantation increases acidification and eutrophication. Effect of fertilizers can be counteracted by applying agro-silvoforestry practices and also reducing the proportion of coffee on the PS scenario. On the Putumayo-Caquetá region shifting from illegal drug production to cacao and sugarcane plantation (PS scenario), reduces the depletion of abiotic resources and the ozone layer, photochemical oxidation, and climate change. Nevertheless, toxicity impacts (human and terrestrial) can worsen as result of the pesticides used for sugarcane cultivation. Reducing the quantity and modifying the type of pesticides used, can mitigate the environmental burden of the sugarcane.

The socioeconomic analysis shows that *jornaleros* and farmers of the Catatumbo region are negatively affected by the successful implementation of the substitution policy, since their income can diminish by nearly 35% compare to the revenue generated by coca growing and processing. The opposite case is observed in the Putumayo-Caquetá region, where migrating from coca growing to cacao and

sugarcane provides economic gains for *jornaleros* and farmers because of the increase of its revenue. However, the land reform, social programs, expansion public services coverage and development of infrastructure considered on the peace treaty, can generate social welfare in the coca growing areas and create the means to reach local markets, compensating the reduction of the income for *jornaleros* and farmers of the Catatumbo region. Moreover, the successful implementation of the substitution policy will increase the workforce needed it because legal crops require more *jornales* than coca plantation.

On the other hand, signing the peace treaty has reduced the victims of the FARC armed conflict, as proven by the fact that the number of kidnappings and the homicides have dropped drastically. However, integrating and put in place security strategies on regions affected by the conflict and illicit crops, to protect the integrity of the social leaders and farmers promoting the substitution policy remains a challenge for the government. The lack of security can conduce to the failure of the substitution policy.

A partial implementation of the substitution policy (CO scenario) will not present significant differences compared to the total replacement of the illicit crops on environmental terms. From the socioeconomic perspective in the CO scenario, total profit for *jornaleros* will remain the almost same as in the successful implementation of the policy. In contrast, the revenue farmers can be reduced by 20% in the Putumayo-Caquetá region and increased by the same proportion in the Catatumbo region.

Geographical displacement of coca plantation (BE scenario) caused by the substitution policy will increase environmental pressure on both regions. In the BE scenario *jornaleros* in the Catatumbo region will be affected, since the need of workforce will decrease. The income for farmers on the Putumayo-Caquetá region will also be reduced. In addition, a rise in the deforestation rate is likely to take place, as well a wave of violence caused by the disputes to exert the control of drug trafficking routes and strategic resources.

To implement the substitution policy along the country is important to look the dynamics of drug trafficking chain in each region. The policy needs to be flexible to adjust to changing circumstances throughout the negotiations with farmers and communities involved in coca plantation and processing. This study analyzes two of the eight regions affected by coca plantations. There is not a legal crop that performs better in all the variables evaluated (social, economic, and environmental); it is best to select a mix of legal crops adapted to local circumstances.

8. RECOMMENDATIONS

The implementation of the peace treaty must entail long-term solutions for the coca-growing and areas hardly hit by the conflict. This means creating local institutional structure and bringing rule of law in those areas, providing access to public goods and infrastructure and profitable livelihood for farmers and *jornaleros*. In summary, the substitution policy and the peace treaty need to address all the causes of illicit crop growing: state abandonment, lack of infrastructure and unsatisfied basic needs. The State needs to maintain the control to prevent the dissemination of the coca crops and the consolidation of the Balloon Effect scenario presented in this study.

To execute the substitution policy, it is necessary to consider the particularities of each region. The dynamics of the illegal chain vary along the country: the yield of coca plantation, prices of agrochemicals and chemical precursors and the role of farmers. In particular, it is important to study the substitution crops that are economical, socially, and environmentally suitable for the region. This will allow tailoring the substitution policy offering feasible livelihood for Colombians involved in the illicit drug chain. As a result of this research, a series of recommendations are drawn, aiming to contribute to a successful implementation of the policy.

ENVIRONMENTAL RECOMMENDATIONS

To apply LCA or other environmental assessment methodology can guide policy and decision makers to avoid burden shifting and identify potential impacts on the peacebuilding process in Colombia. This research presents the environmental tradeoffs of the implementation of the substitution policy in two regions of the country. Results show that replacing 1 hectare of coca by coffee in the Catatumbo region, can mitigate the depletion of the ozone layer and abiotic resources, also photochemical oxidation but at the expense of aggravating the climate change related emissions and the environmental pressure of aquatic and terrestrial ecosystems. The same happens with sugarcane in the Putumayo-Caquetá region; this crop can worsen the impacts related to human and freshwater toxicity. However, cacao will reduce the environmental impact of the indicators evaluated in this study. On the other hand, the results here presented to highlight the agricultural inputs that should be targeted to reduce the environmental burden of the substitution crops and also where data refinement is needed to have more precise results.

Water consumption must be considered when selecting the substitution crops. Calculations show that legal crops can increase up to 10 times the water requirement. To better assess the impact caused by the consumption of freshwater, the approach proposed by Pfister, Koehler, & Hellweg, (2009) can be used. This method takes into consideration local freshwater scarcity.

Potential emissions from substituting illegal crops in other regions need to be further assessed. As was observed in this study, each region has characteristics that influence the environmental performance of a successful implementation of the policy. Biodiversity aspects, and other characteristics of the environment also need to be considered when implementing tourism programs. Responsible and sustainable management of natural resources is required to achieve the goal of the peace treaty.

This research is the first attempt to quantify environmental impacts of the production of cocaine in two regions of Colombia by applying the LCA framework. Results show that agricultural practices on the coca plantation and processing techniques can influence the environmental impact. One hectare planted and processed produce approximately 4,540 kg of CO_2, which is equivalent to the emissions produced by 1,873 gallons of gasoline consumed. Further investigations can assess the impacts caused

by transportation, deforestation and land-use change. Also, the impact of the use of glyphosate for aerial spraying for eradication and as an herbicide on the coca cultivation need to be further studied; the substance is classified as potentially carcinogenic by Office of Environmental Health Hazard Assessment of California (Deutsche Welle, 2017).

Special attention must the granted to Carbon dioxide emissions if the Paris Agreement goals are to be achieved. Substitution and post-conflict policies need to be aligned with the climate change adaptation and mitigation strategies of the country. As is highlighted in this document, substitution crops can affect the climate change burden negatively.

The information of this study can support campaigns targeting consumers and community, to raise the awareness of farmers and *jornaleros* about the environmental and socioeconomic consequences of coca cultivation. Ibañez & Vasquez (2013) points out that informing the community about the impacts could increase the willingness to participate in substitution programs and reduce the disposition to invest on coca plantation. Additionally, this study allows countries affected by illicit drug cultivation and processing to understand its environmental impacts better, helping to incorporate environmental dimension tangentially on the local substitution policies.

SOCIOECONOMIC RECOMMENDATIONS

One of the most important steps for the government to foster the implementation and sustainability of the substitution policy is to develop security strategies. These strategies need to be in place as fastest as possible to limit the expansion of the BACRIM, EPL, and ELN. They are also instrumental in avoiding those groups to take control of the coca plantations, and intimidate the community to preventing them from joining the substitution policy.

Establishing synergies among farmers, communities and companies and the state is vital to the success of the substitution policy. Farmers could rely on having an accessible market for their agricultural products. Companies besides helping to the peace building process in the country can reduce dependency on supply importations. Fixing the minimum price will contribute to reduce uncertainty for both parties. For instance, the Montebravo organization, which is integrated by 1202 families who replace illicit drugs by cacao, have established a marketing agreement with the National Chocolate Company and the Austrian chocolate company Zotter to commercialize over 770 tons of dry cocoa (Embajada de Colombia en Austria, 2014; UNODC & Government of Colombia, 2015). The government can also foster this type of cooperation relationships by establishing tax reduction schemes.

Provision of technical and administrative assistance for farmers migrating from illicit to legal economies is essential during all the phases of the substitution process. This will help the communities to manage their development and build local governance. The Colombian government must develop and strengthen strategic partnerships for supporting these activities. For instance, the UNODC has a vast experience in the implementation, monitoring, and evaluation of ADP. Agricultural associations as CORPOICA, Fedecacao, Federation of Coffee Growers of Colombia, national and International education institutions can help for boosting the legal agricultural products. Farmers, jornaleros and the community need to have access to education centers to learn sustainable agricultural practices and develop innovative strategies to respond and adapt to the market. The figure below shows some of the support activities that can be considered throughout the implementation of the policy.

Figure 8-1. Support activities for farmers on the implementation of the policy

Both the Government and the communities involved in the substitution policy should be aware that success in eradicating coca crops depends on long-term commitment, monetary resources and the ability to adapt to changing circumstances. Also, the integration of demobilized ex-combatants is necessary help them maintain their separation from armed groups and allow them to connect with peer groups within their community.

The peace treaty also contemplates an environmental zoning plan that seeks to delimit the agricultural frontier and protect areas of special environmental interest. Environmental and social implications of this plan should be assessed in future investigations, paying special attention on how its implementation would affect the production and agricultural markets in the country.

Natural parks can support the diversification of a region's and the country's economy with biodiversity-based, environmentally friendly products. Further research is also needed to assess impacts caused by the illicit crops and identify the opportunities that those areas represent for Colombia for the peace building process.

REFERENCES

Acosta, L. J., & Murphy, H. (2017, January 27). Colombia and FARC rebels to wage joint fight against coca cultivation | Reuters. Retrieved from http://www.reuters.com/article/us-colombia-peace-idUSKBN15B28O

Acuerdo final para la terminación del conflicto y la construcción de una paz estable y duradera. (2016). La Habana.

Adams, M., & Ghaly, A. E. (2007). Maximizing sustainability of the Costa Rican coffee industry, *15*, 1716–1729. http://doi.org/10.1016/j.jclepro.2006.08.013

Addiction Resource. (2017). How is Cocaine Made? A Comprehensive Guide to Cocaine Production. Retrieved May 8, 2017, from https://addictionresource.com/drugs/cocaine-and-crack/how-is-cocaine-made/

Alseman, A. (2016). Kidnapping in Colombia down 27%. Retrieved August 2, 2017, from https://colombiareports.com/kidnapping-in-colombia-down-27/

Álvarez, M. D. (2001). Could peace be worse than war for Colombia's forests?

Álvarez Vanegas, E. (2017). Siete regiones sin la presencia de las Farc, ¿siete problemas más? | La Silla Vacía. Retrieved May 14, 2017, from http://lasillavacia.com/silla-llena/red-de-la-paz/historia/siete-regiones-sin-la-presencia-de-las-farc-siete-problemas-mas

Arcila Pulgarín, J., Rendón Sáenz, J. R., & Montoya Restrepo, E. C. (2008). Estimación de la producción de café con base en los registros de floración, *59*(3), 238–259.

Arenas Usme, G. (2016, June). Los Urabeños se disputan dominio del Putumayo - Las2orillas. *Las 2 Orillas*. Retrieved from https://www.las2orillas.co/los-urabenos-se-disputan-dominio-territorial-en-el-putumayo/

Argüello, F. (2010). Las FARC intimidan a los agricultores: "O siembran coca de nuevo o se mueren." Retrieved August 17, 2017, from http://www.elmundo.es/america/2010/11/30/colombia/1291140510.html

Ávila, A. (2016). Vías terciarías y el desarrollo local. Retrieved May 14, 2017, from http://www.pares.com.co/paz-y-posconflicto/vias-terciarias-y-el-desarrollo-local/

Baker, J. R., Milke, M. W., & Mihelcic, J. R. (1999). Relationship between chemical and theoretical oxygen demand for specific classes of organic chemicals. *Water Research*, *33*(2), 327–334. http://doi.org/10.1016/S0043-1354(98)00231-0

Baptiste, B., Pinedo-vasquez, M., Gutierrez-velez, V. H., Andrade, G. I., Vieira, P., Estupiñán-suárez, L. M., … Lee, T. M. (2017). Greening peace in Colombia, (March). http://doi.org/10.1038/s41559-017-0102

Barón Urquijo, J. D. (2016). *EL CULTIVO DEL CACAO; UN NEGOCIO RENTABLE, COMPETITIVO Y AMBIENTALMENTE SOSTENIBLE EN COLOMBIA*.

Biondich, A. S., & Joslin, J. D. (2016). Coca: The History and Medical Significance of an Ancient Andean Tradition. *Emergency Medicine International*, *2016*, 1–5. http://doi.org/10.1155/2016/4048764

Borrero, C. A. (2009). Fertilizacion del cultivo de cacao en sitio definitivo, 2009.

Brunner, E., & Grande, R. (2017). Colombia hereda una guerra por la coca en los antiguos territorios FARC. Retrieved August 17, 2017, from

http://www.elespanol.com/mundo/america/20170728/234727158_0.html

Chica Jiménez, F. (2016, June). Una semana como raspachín (I). Retrieved from https://www.traslacoladelarata.com/2016/06/02/una-semana-raspachin-i/

Chin, J.-Y., & Batterman, S. (2012). VOC composition of current motor vehicle fuels and vapors, and collinearity analyses for receptor modeling. *Chemosphere*, *86*(9), 951–958. http://doi.org/http://doi.org/10.1016/j.chemosphere.2011.11.017

CND Blog. (2017). Special Event: The Post-Conflict Stage in Colombia and the Strategies to Address Illicit Crops – CND Blog. Retrieved June 3, 2017, from http://cndblog.org/2017/03/special-event-the-post-conflict-stage-in-colombia-and-the-strategies-to-address-illicit-crops/

Coltro, L., Mourad, A., Oliveira, P., Baddini, J., & Kletecke, R. (2006). Environmental profile of brazilian coffee. *The International Journal of Life Cycle Assessment*. http://doi.org/10.1065/lca2006.01.230

Cote, M., Martin, P., Gonzales, J., & Cardona, A. (2010). Mainstreaming Climate Change in Colombia: Screening for risks and opportunity, 1–8. Retrieved from http://www.undp.org/content/dam/aplaws/publication/en/publications/environment-energy/www-ee-library/climate-change/mainstreaming-climate-change-in-colombia/CC risk Mainstreaming Climate Change in Colombia-EN.pdf

Count the cost. (2012). The War on Drugs: Causing Deforestation and Pollution, 1–12.

Crisp, J. (2013). 20% of Colombia cocaine consumed domestically: Report. Retrieved July 20, 2017, from https://colombiareports.com/20-of-colombias-cocaine-consumed-domestically/

DANE. (2016). *Encuesta Calidad de vida (ECV)*. Retrieved from https://www.dane.gov.co/index.php/estadisticas-por-tema/pobreza-y-condiciones-de-vida/calidad-de-vida-ecv

Davalos, E. (2016). New answers to an old problem: Social investment and coca crops in Colombia. *International Journal of Drug Policy*, *31*, 121–130. http://doi.org/10.1016/j.drugpo.2016.02.002

Dávalos, L. M., Bejarano, A. C., Hall, M., Correa, H. L., Corthals, A., & Espejo, O. J. (2011). Forests and drugs: coca-driven deforestation in global biodiversity hotspots. *Environmental Science Technology*, *45*(17), 1219–1227. http://doi.org/10.1021/es102373d

DEA. (1993). Coca Cultivation and Cocaine Processing: An Overview -. Retrieved May 4, 2017, from https://erowid.org/archive/rhodium/chemistry/coca2cocaine.html

Dennis, C. (2017, July). Colombia's New Crop Substitution Plan Facing Old Obstacles: Report. *InSight Crime*, 13. Retrieved from http://www.insightcrime.org/news-analysis/colombia-new-crop-substitution-plan-facing-old-obstacles-report

DeShazo, P., McLean, P., & Forman Mendelson, J. (2008). Colombia's Plan de Consolidación Integral de la Macarena. *CENTER FOR STRATEGIC & INTERNATIONAL STUDIES*, (June), 1–19. Retrieved from www.accionsocial.gov.co

Deutsche Welle. (2017). California: el glifosato entra en lista de potenciales cancerígenos. Retrieved July 7, 2017, from http://www.dw.com/es/california-el-glifosato-entra-en-lista-de-potenciales-cancerígenos/a-39432270

DNP. (2016). Conpes 3857 LINEAMIENTOS DE POLÍTICA PARA LA GESTIÓN DE LA RED TERCIARIA.

DNP. (2017). *Marco de Implementación Acuerdo Final*.

Durán Núñez, D. C. (2015, January 25). Los socios que las Farc encontraron en Putumayo. *El Espectador*.

Retrieved from http://www.elespectador.com/noticias/investigacion/los-socios-farc-encontraron-putumayo-articulo-539969

El Tiempo.com. (2005). COLOMBIA NO TIENE CAPACIDAD PARA MOVER LA CARGA DEL TLC. Retrieved from http://www.eltiempo.com/archivo/documento/MAM-1684431

El Tiempo.com. (2016, September 28). Número de guerrilleros de las Farc en sus filas. Retrieved from http://www.eltiempo.com/politica/proceso-de-paz/numero-de-guerrilleros-de-las-farc-en-sus-filas-33484

Ellis, T. (2011). *Appendix 1 . Theoretical Oxygen Demand (TOD) Values of Organic Compounds*.

Embajada de Colombia en Austria. (2014). Cacao colombiano conquista los mercados de Austria. Retrieved July 7, 2017, from http://austria.embajada.gov.co/newsroom/news/2014-12-18/5146

Escobar, M. (2017, May 23). Trump quiere recortar el presupuesto para Colombia. *El Espectador*. Retrieved from http://www.elcolombiano.com/internacional/eeuu/trump-quiere-recortar-el-presupuesto-para-colombia-CK6590602

European Commission. (2015). Life Cycle Analysis. Retrieved June 18, 2017, from http://ec.europa.eu/smart-regulation/guidelines/tool_58_en.htm

FAO. (2017). Organic Agriculture: What are the environmental benefits of organic agriculture? Retrieved July 3, 2017, from http://www.fao.org/organicag/oa-faq/oa-faq6/en/

Fedecacao. (2006). Validación y transferencia del paquete tecnológico del cultivo del cacao para el departamento del Casanare, 1--28.

Fedecacao. (2015). *Costos 2015 promedio nacional*.

Federación Nacional de Cafeteros de Colombia. (2013). Comportamiento de la Industria Cafetera Colombiana 2012, 60.

FIP, USAID, & OIM. (2015). Conflicto armado en {Caquetá} y {Putumayo} y su impacto humanitario. *FIP - Ideas Para La Paz*, 1–70. Retrieved from http://www.ideaspaz.org/publications/posts/1012

Flórez, M. (2017). “Los Pelusos”: esta es la banda criminal que amenaza al Catatumbo | Pacifista. Retrieved July 6, 2017, from http://pacifista.co/los-pelusos-esta-es-la-banda-criminal-que-amenaza-al-catatumbo/

Fukumi, D. S. (2013). *Cocaine Trafficking in Latin America: EU and US Policy Responses*. Retrieved from https://books.google.com/books?id=foSCMuVrPpEC&pgis=1

Fundación Paz y Reconciliación. (2016, May 25). Comenzó la guerra por los territorios de las Farc. *El Espectador*. Retrieved from http://www.elespectador.com/noticias/politica/comenzo-guerra-los-territorios-de-farc-articulo-634211

Furcal Beriguete, P. (2016). Extracción de nutrientes por los frutos de cacao en dos localidades en Costa Rica. *Agronomía Mesoamericana*, *28*(1), 113. http://doi.org/10.15517/am.v28i1.23236

Gillin, J. (2014). Colombia’s peace deals in depth: Illicit drugs. Retrieved June 3, 2017, from https://colombiareports.com/colombia-illicit-crops-voluntary-substitution/

Gobierno de Colombia. (2015). Los 6 frentes del Plan Integral de Sustitución de Cultivos.

Guinée, J. B., Gorrée, M., Heijungs, R., Huppes, G., Kleijn, R., Koning, A. de, … Huijbregts, M. A. J. (2002). *Handbook on life cycle assessment. Operational Guide to the ISO Standards. Eco-Efficiency in Industry and Science* (Vol. 7). http://doi.org/10.1007/0-306-48055-7

Healy, K. (1985). The Cocaine Industry in Bolivia - Its Impact on the Peasantry | Cultural Survival. Retrieved July 2, 2017, from https://www.culturalsurvival.org/publications/cultural-survival-quarterly/cocaine-industry-bolivia-its-impact-peasantry

Hernandez Mora, S. (2017, February 28). Esto es lo que te metes con una raya de coca. *El Mundo*. Retrieved from http://www.elmundo.es/sociedad/2017/02/28/58b41634e2704e2c178b4575.html

Humbert, S., Loerincik, Y., Rossi, V., Margni, M., & Jolliet, O. (2009). Life cycle assessment of spray dried soluble coffee and comparison with alternatives (drip filter and capsule espresso). *Journal of Cleaner Production*, *17*(15), 1351–1358. http://doi.org/10.1016/j.jclepro.2009.04.011

Hutchings, N., Webb, J., & Amon, B. (2016). *3.D Crop production and agricultural soils Contents*.

Ibañez, M. (2013). *Is the war on drugs working? Examining the Colombian case using micro data*.

Ibañez, M., & Vasquez, J. (2013). *Can we fight drugs using communication campaigns ?*

IndexMundi. (2017). Cacao en grano - Precio Mensual (Peso colombiano por Tonelada) - Precios de Materias Primas. Retrieved July 27, 2017, from http://www.indexmundi.com/es/precios-de-mercado/?mercancia=granos-de-cacao&meses=60&moneda=cop

infobae. (2016, September 29). El último censo de las FARC: cuántos miembros tiene la guerrilla hoy - Infobae. Retrieved from http://www.infobae.com/america/america-latina/2016/09/29/el-ultimo-censo-de-las-farc-cuantos-miembros-tiene-la-guerrilla-hoy/

Instituto Humbolt. (2014). BIODIVERSIDAD EN COLOMBIA: Las cifras hablan por sí solas. Retrieved July 3, 2017, from http://www.humanumcolombia.org/biodiversidad-en-colombia-las-cifras-hablan-por-si-solas/

IPCC. (2006). 2006 IPCC Guidelines for National Greenhouse Gas Inventories Volume 4: Agriculture, Forestry and Other Land Use, 11.1-11.54. Retrieved from http://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/4_Volume4/V4_11_Ch11_N2O&CO2.pdf

Jelsma, M. (2001). *Viscuous Circle: The Chemical and Biological " War on Drugs ."*

Koch, P., & Salou, T. (2016). *AGRIBALYSE ® : METHODOLOGY Version 1.3*. Angers. France.

Kraul, C. (2006, August 4). Coca Is Difficult to Root Out in Colombia - latimes. *Los Angeles Times*. Retrieved from http://articles.latimes.com/2006/aug/04/world/fg-coca4

Leech Garry. (2012). The Shifting Contours of Colombia's Armed Conflict | NACLA. Retrieved May 22, 2017, from http://nacla.org/news/2012/2/10/shifting-contours-colombia's-armed-conflict

Letonturier, P. (2014). Panorama de la educación 2014. *Nota Pais*, 571–572. Retrieved from https://www.oecd.org/edu/Colombia_EAG2014_CountryNote_ESP.pdf

Loli Figueroa, O., & Cavero Rojas, J. (2011). Taller Fertilización Y Post Cosecha de Cacao.

Mahmood, I., Imadi, S. R., Shazadi, K., & Gul, A. (2016). Effects of Pesticides on Environment, (December). http://doi.org/10.1007/978-3-319-29573-2

Matiz Cortes, S. (2016, May 5). Las Farc se consolidan como el mayor cartel de narcotráfico del país. Retrieved from http://www.elespectador.com/noticias/judicial/farc-se-consolidan-el-mayor-cartel-de-narcotrafico-del-articulo-630659

Mejía, D. (2016). Plan Colombia: An Analysis of Effectiveness and Costs. *Brookings Institution Information Paper*, 1–17. Retrieved from http://www.globalinitiative.net/download/drugs/south-america/Mejia Colombia final 2.pdf

MJD. (2015). Proyectos de desarrollo alternativo en Colombia han impedido la producción de 4.500 millones de dosis de cocaína - Ministerio de Justicia y del Derecho. Retrieved June 16, 2017, from http://www.minjusticia.gov.co/Noticias/TabId/157/ArtMID/1271/ArticleID/885/Proyectos-de-desarrollo-alternativo-en-Colombia-han-impedido-la-producción-de-4500-millones-de-dosis-de-cocaína.aspx

Morales, L. (2017). LA PAZ Y LA PROTECCIÓN AMBIENTAL EN COLOMBIA : Propuestas para un desarrollo rural sostenible.

Navarrete Frías, C. (2004). *El impacto de la cooperación internacional, en materia de financiación y asistencia técnica, en la erradicación de cultivos ilícitos y su sustitución en el Putumayo, caso Palmito de Chontaduro*.

Nemecek, T., & Kagi, T. (2007). Life cycle inventories of Agricultural Production Systems, ecoinvent report No. 15, (15), 1–360. Retrieved from http://www.upe.poli.br/~cardim/PEC/Ecoinvent LCA/ecoinventReports/15_Agriculture.pdf

Nemecek, T., & Schnetzer, J. (2012). Methods of assessment of direct field emissions for LCIs of agricultural production systems. *Agroscope Reckenholz-Tanikon Research Station*, *0*(15), 34.

Ntiamoah, A., & Afrane, G. (2008). Environmental impacts of cocoa production and processing in Ghana: life cycle assessment approach. *Journal of Cleaner Production*, *16*(16), 1735–1740. http://doi.org/10.1016/j.jclepro.2007.11.004

Oficina del Alto Comisionado para la Paz. (2016). *COLOMBIA'S AGREEMENT to End Conflict and Build Peace*.

Ortiz, O. O., Gallardo Villamizar, A. R., & Rangel, J. M. (2014). Applying life cycle management of colombian cocoa production, *34*(1), 62–68.

Osorio Cadavid, G. (2007). *Manual: Buenas Prácticas Agrícolas -BPA- y Buenas Prácticas de Manufactura -BPM-en la Producción de Caña y Panela*.

Otis, J. (2014). The FARC and Colombia's Illegal Drug Trade. *Wilson Center*. Retrieved from http://www.wilsoncenter.org/sites/default/files/Otis_FARCDrugTrade2014.pdf

Perez Neira, D. (2016). Energy sustainability of Ecuadorian cacao export and its contribution to climate change. A case study through product life cycle assessment. *Journal of Cleaner Production*, *112*, 2560–2568. http://doi.org/10.1016/j.jclepro.2015.11.003

Pfister, S., Koehler, A., & Hellweg, S. (2009). Assessing the Environmental Impact of Freshwater Consumption in Life Cycle Assessment. *Environmental Science & Technology*, *43*(11), 4098–4104. http://doi.org/10.1021/es802423e

Pinzón, L. F., & Sotelo, H. (2010). Efectos de los cultivos ilícitos sobre el medio natural en Colombia, 11.

Policía Nacional. (2014). *COCA: Deforestación, contaminación y pobreza*. Retrieved from http://www.odc.gov.co/Portals/1/publicaciones/pdf/oferta/estudios/OF5022014-coca-deforestacion-contaminacion-pobreza.pdf

Ramirez Prado, J. (2015). Reducción de la violencia en 40% atraería más inversión extranjera. Retrieved July 30, 2017, from https://www.larepublica.co/asuntos-legales/actualidad/reduccion-de-la-violencia-en-40-atraeria-mas-inversion-extranjera-2228136

Ramsey, G. (2012, October 24). FARC "Earns $2.4 to $3.5 Billion" From Drugs: Govt. Retrieved from http://www.insightcrime.org/news-briefs/farc-earns-24-to-35-billion-drugs

Rebitzer, G., Ekvall, T., Frischknecht, R., Hunkeler, D., Norris, G., Rydberg, T., … Pennington, D. W. (2004).

Life Cycle Assessment: Framework, goal and scope definition, inventory analysis, and applications. *Environment International*, *30*(5), 701–720. http://doi.org/http://dx.doi.org/10.1016/j.envint.2003.11.005

Redacción EFEverde. (2017). La deforestación en Colombia aumentó en un 44 % en 2016. Retrieved July 30, 2017, from http://www.efeverde.com/noticias/la-deforestacion-en-colombia-aumento-en-un-44-en-2016-segun-estudio/

Redacción Política. (2017, January 27). Arranca plan de sustitución de cultivos ilícitos | ELESPECTADOR.COM. Retrieved from http://www.elespectador.com/noticias/politica/arranca-plan-de-sustitucion-de-cultivos-ilicitos-articulo-676917

REDD+ Colombia. (2017). *COCA Y DEFORESTACIÓN: Mensajes de acción para la planeación del desarrollo*.

Reed, D. (2012). Life-Cycle Assessment in Government Policy in the United States. *Doctoral Dissertations*. Retrieved from http://trace.tennessee.edu/utk_graddiss/1394

Renouf, M. A., & Wegener, M. (2007). Environmental life cycle assessment (LCA) of sugarcane production and processing in Australia. *29th Conference of the Australian Society of Sugar Cane Technologists*, *29*(December), 385–400. http://doi.org/10.1007/s13398-014-0173-7.2

Reyes, L. C. (2014). Estimating the Causal Effect of Forced Eradication on Coca Cultivation in Colombian Municipalities. *World Development*, *61*, 70–84. http://doi.org/10.1016/j.worlddev.2014.03.024

Rincon-Ruiz, A., Correa, H. L., Leon, D. O., & Williams, S. (2016). Coca cultivation and crop eradication in Colombia: The challenges of integrating rural reality into effective anti-drug policy. *International Journal of Drug Policy*, *33*, 56–65. http://doi.org/10.1016/j.drugpo.2016.06.011

Roberto Ometto, A., Zwicky Hauschild, M., & Lopes Roma, W. N. (2009). Lifecycle assessment of fuel ethanol from sugarcane in Brazil. *International Journal of Life Cycle Assessment*, *14*(3), 236–247. http://doi.org/10.1007/s11367-009-0065-9

Robledo, J. (2015). *Economic Analysis of Eradication and Alternative Crop Policies for Controlling Coca Supply in Colombia*. University of Nebraska.

Rocha, R. (2011). *Las nuevas dimensiones del Narcotrafico en Colombia*.

Rodríguez Valencia, N., Sanz Uribe, J. R., Oliveros Tascon, C. E., & Ramirez Gomez, C. A. (2015). *Beneficio del Cafe en Colombia*.

Rodríguez Valencia, N., & Zambrano Franco, D. (2010). Los subproductos del café: fuente de energía renovable. *Avances Técnicos Cenicafé*, (3), 8. http://doi.org/ISSN-0120-0178

Sadeghian Khalajabadi, S. (2008). *Fertilizad del suelo y nutricion del cafe en Colombia*. Chinchiná.

Sala, S., Reale, F., Cristobal Garcia, J., Marrelli, L., & Pant, R. (2016). *Life cycle assessment for the impact assessment of policies*.

Salgar Antolínez, D. (2016, July 5). “Estas manos deberían tener un cuaderno”: raspachines de Tumaco | Colombia 2020. Retrieved from http://colombia2020.elespectador.com/territorio/estas-manos-deberian-tener-un-cuaderno-raspachines-de-tumaco

Salinas, B. (2008). Life Cycle Assessment of Coffee Production. -, 6.

Sánchez Garzoli, G., & Londoño, S. (2017). The Activists Key to Consolidating Colombia’s Peace Are Facing Increased Attacks. Retrieved July 19, 2017, from http://colombiapeace.org/page/2/

Santamaría, M. (2015). *El Desarrollo Territorial Sostenible en el Posconflicto, de la economía ilícita a la*

economía lícita: Análisis de tres Regiones en Colombia.

Semana.com. (2017a). La pelea de los ilegales por los vacíos que dejaron las FARC.

Semana.com. (2017b, January 27). Gobierno y Farc ponen en marcha plan de sustitución de cultivos ilícitos. Retrieved from http://www.semana.com/nacion/articulo/gobierno-lanza-programa-nacional-integral-de-sustitucion-de-cuiltivos-de-uso-ilicito/513403

Semana.com. (2017c, January 27). Gobierno y Farc ponen en marcha plan de sustitución de cultivos ilícitos. Retrieved from http://www.semana.com/nacion/articulo/gobierno-lanza-programa-nacional-integral-de-sustitucion-de-cuiltivos-de-uso-ilicito/513403

Sheate, W. R., Partidário, M. R. Do, Byron, H., Bina, O., & Dagg, S. (2008). Sustainability assessment of future scenarios: Methodology and application to mountain areas of Europe. *Environmental Management*, *41*(2), 282–299. http://doi.org/10.1007/s00267-007-9051-9

SIA, S. de I. A., & CCI, C. C. I. (2010a). Costos de producccion por hectarea. Caña Panelera, *68*(2).

SIA, & CCI. (2010b). Costos de produccion por hectarea. Cafe tradicional, *0*(2), 8–10.

Suarez, A., Árias-Arévalo, P. A., & Martínez-Mera, E. (2017). Environmental sustainability in post-conflict countries: insights for rural Colombia. *Environment, Development and Sustainability*. http://doi.org/10.1007/s10668-017-9925-9

Tarazona, G. (2011). *Manejo fitosanitario del cultivo de la caña panelera. Medidas para la temporada invernal.*

teleSUR. (2017). A Social Leader Is Killed Every 4 Days In Colombia. Retrieved July 20, 2017, from http://www.telesurtv.net/english/news/A-Social-Leader-Is-Killed-Every-4-Days-In-Colombia-Report-20170719-0022.html

The Economist. (2017, July 6). Colombia's future involves fewer terrorists and more ecotourists. Retrieved from https://www.economist.com/news/americas/21724845-bird-watching-farcland-colombias-future-involves-fewer-terrorists-and-more-ecotourists?fsrc=rss%7Came

The Guardian. (2008, May 21). The ecological impact of Colombia's cocaine trade | Environment | The Guardian. Retrieved from https://www.theguardian.com/environment/gallery/2008/may/21/endangeredhabitats.forests

Tsiropoulos, I., Faaij, A., Seabra, J. E. A., Lundquist, L., Schenker, U., Briois, J. F., & Patel, M. K. (2014). Life cycle assessment of sugarcane ethanol production in India in comparison to Brazil. *International Journal of Life Cycle Assessment*, *19*(5), 1049–1067. http://doi.org/10.1007/s11367-014-0714-5

UNEP. (2007). *The Future Today*. *United Nations Environment Programme, Global Environment Outlook GEO 4 Environment for Development (Section E - The Outlook - Towards 2015 and Beyond, Chapter 9)*. http://doi.org/10.2307/2807995

UNODC. (2010a). *CARACTERÍSTICAS AGROCULTURALES DE LOS CULTIVOS DE COCA EN COLOMBIA 2005 - 2010*.

UNODC. (2010b). The global cocaine market. *World Drug Report 2010*, 65–94.

UNODC. (2015). *World drug report 2015*. Retrieved from http://www.unodc.org/documents/wdr2015/World_Drug_Report_2015.pdf

UNODC. (2016a). Colombia: Monitoreo de territorios afectados por cultivos ilícitos 2015, 146.

UNODC. (2016b). Monitoreo de Territorios Afectados por Cultivos Ilíticos 2015.

UNODC. (2017). Intentional homicides (per 100,000 people) | Data. Retrieved August 2, 2017, from http://data.worldbank.org/indicator/VC.IHR.PSRC.P5?locations=CO

UNODC, & Goverment of Colombia. (2015). Colombia. Coca cultivation survey 2014.

UNODC, & Ministerio de Justicia y del Derecho. (2015a). Caracterización Regional de la problemática asociada a las drogas ilícitas en el departamento de Caquetá, 146.

UNODC, & Ministerio de Justicia y del Derecho. (2015b). Caracterización Regional de la problemática asociada a las drogas ilícitas en el departamento de Putumayo.

UNODC, & Ministerio de Justicia y del Derecho. (2016). *Caracterización Regional de la problemática asociada a las drogas ilícitas en el departamento de Norte de Santader*.

Valenzuela, J. F., Fernández, J. A., Restrepo, A. P., & Aristizábal, R. M. (2012). El cultivo de cacao, 12.

Wills Pedraza, S. (2015). Colombian National Army's Vulcan Task Force Provides Security in Catatumbo Region. Retrieved May 22, 2017, from https://dialogo-americas.com/en/articles/colombian-national-armys-vulcan-task-force-provides-security-catatumbo-region

WOLA. (2016a). Colombia's 52-Year-Old Conflict with the FARC Comes to an End - WOLA. Retrieved February 24, 2017, from https://www.wola.org/2016/08/colombias-52-year-old-conflict-farc-comes-end/

WOLA. (2016b). Social Leaders Face a Wave of Attacks in Colombia. The Peace Accord's Credibility Hinges on Immediate Action to Stop It. Retrieved July 20, 2017, from http://colombiapeace.org/2016/12/05/social-leaders-face-a-wave-of-attacks-in-colombia-the-peace-accords-credibility-hinges-on-immediate-action-to-stop-it/

Woody, C. (2016). Colombia FARC peace plan drug production and trafficking problems. Retrieved July 20, 2017, from http://www.businessinsider.com/colombia-farc-peace-plan-drug-production-and-trafficking-problems-2016-8?international=true&r=US&IR=T

Zamudio Palma, M. (2017). Las "autodefensas" están llenando de grafitis las paredes en Cauca y Nariño | Pacifista. Retrieved July 6, 2017, from http://pacifista.co/las-autodefensas-estan-llenando-de-grafitis-las-paredes-en-cauca-y-narino/

APPENDIX

Supplementary information is provided as an attachment Appendix JBR Thesis.zip along with the CMLCA file. The Appendix contains the following files

1. Inventory table substitution crops
2. Inventory table Cocaine
3. Inventory results
4. Socio economic indicators.