Mémoire de Mission Professionnelle

présenté pour l'obtention du diplôme de Mastère Spécialisé®
Innovations et politiques pour une alimentation durable

Assessing the carbon footprint and climate risk of most consumed food products in Cali, Colombia: Methodological development of a decision support tool

Par Lisa Gerbal

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Année de soutenance : 2019

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Résumé

Titre : Évaluation de l'empreinte carbone et du risque climatique des aliments les plus consommés dans la ville de Cali, Colombie : Développement méthodologique d'un outil d'aide à la décision

Les villes s'étendent, et avec elles augmentent leurs impacts environnementaux, par l' approvisionnement de la population urbaine en nourriture, en eau et en énergie. Le changement climatique menace également nos systèmes alimentaires : la production même, et la capacité des personnes a s'alimenter. Dans ce contexte, cette étude vise à développer une approche méthodologique pour mieux évaluer et utiliser l'information sur la durabilité environnementale d'un système alimentaire. La proposition consiste à évaluer l'empreinte carbone à l'aide d'une méthodologie d'analyse du cycle de vie (ACV) et à la compléter par la méthodologie Ecocrop qui permet de prédire les changements en terme « d'adéquation climatique» de cultures spécifiques dans l'espace et dans le temps, dans le but d' évaluer à la fois les impacts du régime alimentaire d'une ville sur l'environnement, ainsi que les impacts potentiels du changement climatique sur ce régime. L'étude de cas porte sur la ville de Cali, département de Valle del Cauca, Colombie, et se concentre sur les cinq produits alimentaires les plus consommés (par jour) à Cali, déterminés comme le "caleño typical plate". Les résultats ont montré que « le plat caleño » émet 431,5 grammes d'équivalent CO2. La portion de viande (volaille) a l'empreinte carbone la plus élevée par kg (2,04 kg CO2eq/kg), suivie du riz (1,46 kg CO2eq/kg), du plantain (0,28 04 kg CO2eq/kg), de la pomme de terre (0,23 04 kg CO2eq/kg) et de la tomate (0,09 04 kg CO2eq/kg). Le modèle Ecocrop a montré que le changement climatique pourrait ouvrir de nouvelles zones de culture pour le plantain (68% de la région sera plus apte à sa culture), alors que la pomme de terre et surtout le riz auront moins de zones adaptées à leur culture régions (perte de 60% de zones cultivables pour le riz au niveau national). Cette méthodologie permet de lier d'un côté la consommation et ses impacts sur l'environnement, ainsi que la production, qui sera elle-même impactée. Cette proposition peut être un outil important pour les décideurs, en particulier pour notre étude de cas à Cali, où une bonne partie des produits est produite dans la Valle del Cauca ou en Colombie.

Mots clés : Analyse du cycle de vie, Systèmes alimentaires, changement climatique, méthodologie d'évaluation, régimes alimentaires durables

Abstract

Title : *Assessing carbon footprint and climate risk of most consumed food products in Cali, Colombia: Methodological development of a decision support tool*

Cities are spreading, and with it, the impacts of a growing urban population on the environment through the provisioning of food, water, and energy. Changing climate is also threatening our food systems: the kinds of foods that can be produced, and peoples' ability to buy them. In this context, this study aims at developing a methodological approach to better assess, understand, and use information on environmental sustainability and resilience of highly consumed products in a city. The proposal is to assess carbon footprint using a Life Cycle Analysis (LCA) methodology and complement it with the Ecocrop model that can project potential changes across space and time, of crops suitability under different future scenarios. In this way, we can assess both the impacts of a community's diet on the environment, as well as the potential impacts of climate change on that diet. The case-study of the methodological proposition is the city of Cali, department of Valle del Cauca, Colombia and focus on the five most commonly consumed food products (per day) in Cali, determined as the "caleño typical plate". The results found that the *caleño* plate emits 431.5 grams of CO2eq. The meat portion (poultry) has the highest carbon footprint per kg (2.04 kg CO2eq/kg), followed by rice (1.46 kg CO2eq/kg), plantain (0.28 04 kg CO2eq/kg), potato (0.23 04 kg CO2eq/kg) and tomato (0.09 04 kg CO2eq/kg). The Ecocrop model found that climate change could open new areas of cultivation for plantain (68% of the region will be more suitable to its production), whereas potato and most of all rice will not be suitable for culture in a majority of areas (loss of 60% of the suitable areas at the national level for rice). This proposal can be an important tool for decision makers, especially for our case study in Cali, where a fair portion of the food is produced in Valle del Cauca or else in Colombia. We hope that the results of this study will demonstrate to local policy makers the challenges of food systems, what is at stake, and the key areas for intervention.

Key words : Life Cycle Analysis, Food systems, climate change, assessment methodology, sustainable diets

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Foreword

This project is part of CIAT's contributions to the research theme "Rural-Urban Linkages" (RUL) of the GCIAR research program on Water, Land and Ecosystems (WLE) which combines the resources of FAO, Ruaf and 11 CGIAR centers. WLE focuses on providing evidence and solutions on natural resource management to influence key decision makers, including governments, international development organizations, and financiers. The Rural- Urban Linkages (RUL) Research Theme addresses the interlinked challenges of urbanization (growth, food security, farming system transformation, climate change, among others) from a landscapes and territorial perspective. It assesses the performance of city region food systems and of urban and peri-urban agriculture, analyzes climate vulnerability, sustainability dimensions, resource competition and environmental degradation, while identifying innovative ways to turn challenges into policies, strategies and business opportunities. Within this research theme, CIAT and WLE collaborative work aims at understanding how to improve the resilience of city food systems to feed urban populations in a sustainable way.

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Abbreviations

ENSIN: Encuesta Nacional de la Situación

Nutricional GCM: Global Climate Model

GEIH : *Gran encuesta integrada de hogares*

DANE : *Departamento Administrativo Nacional de Estadística*

RCP : Representative concentration

Pathway GWP : Global Warming

Potential

FAO : Food and Agriculture Organization

IPCC: International Panel on Climate

Chance LCA : Life cycle Analysis

GHG : Green House Gases

AFOLU : Agriculture, Forestry, and Other

Land Use CIAT : *Centro International de*

Agricultura Tropical

CGIAR : Consultative Group for International Agricultural Research

Introduction

IPCC (International Panel on Climate Change) reports these last years have been warning about the threats of climate change, as the later already has caused impacts on natural and human systems on all continents and across the oceans. One of the symptoms of climate change is global warming, caused by the emissions of Greenhouse gases (GHG) from human activities. The AFOLU (Agriculture, forestry and Land Use) sector is responsible for a quarter of the anthropogenic greenhouse gas emissions (between 10 and 12 Giga tons of CO2-eq per year) related to anthropogenic activities mainly due to livestock and soil management (IPCC, 2014). These reports (also see Steinfeild 2006, about the environmental impact of livestock) have led to an increasing consciousness[1] on the environmental burden of our food. On the other hand, they have also highlighted the potential effects that future climate changes might have in all aspects of food security including food access, food use and price stability among others. Urban food systems are at the core of this issue, as they condense food demand.

Food system is a concept that allows to better understand and analyze dynamics around food. It can be defined as "an interdependent network of actors, located in a given geographical area and participating directly or indirectly to the creation of flows of goods and services oriented towards the satisfaction of nutritional needs of one or various consumer groups inside or outside the considered area" (Rastoin, 2010). In the context of its research on Sustainable Food Systems, CIAT (International Center for Tropical Agriculture) had the will to generate new and actionable information and tools to enable local stakeholders and decisions makers from the Cali region to better understand both current and future challenges of its food system in order to foster policy and institutional action. This study builds on the former work done by CIAT on Cali's food system. In the recent years, CIAT has developed projects hand in hand with local actors of the city : the construction of a food and nutritional security policy that was finally adopted by Council in August 2019; the *Cali come Mejor* project in 2015 to produce more knowledge on nutrition issues in Cali; the creation of an academic dialogue platform in 2016 to support and foster projects; analysis on food issues for the urban poor in Cali, supply chains, public policies related to nutrition etc. So far, the notion of sustainability in those projects was more focused on the social dimension. This study integrates the environmental dimension of sustainability, in the conceptual framework of food systems.

[1] In the context of global warming, policies are trying to organize themselves to reduce greenhouse gas (GHG) emissions, hence the establishment of common objectives at the international level, as for example the most

recently objective of carbon neutrality by 2050, adopted by 66 countries at the climate summit in New York on 23 September 2019.

1. Project scope and research questions

1.1 Research questions and hypothesis

In the context of growing concerns about environmental impacts of food and resilience of our systems to climate, CIAT formulated a project to develop and field-test a combined methodology of assessing the sustainability of a community's food patterns, using the city of Cali as a case study. The study seeks to answer to the following **questions**: How to assess the environmental sustainability of food products consumed in a city and put it into the context of a changing climate? What tools and information can be used to assess the environmental sustainability of an consumption of food in a city and how? What is the environmental impact of Cali's food consumption and how could it react and adapt to climate change?

The aim of this work was to combine two methodologies in order to assess on one hand the impact of food production and consumption in the environment (focusing only on carbon footprint and global warming potential) and, on the other hand, the potential impact of future changes in climate on food crops production. For the purpose of the study, the environmental assessment will be focusing only on one environmental impact: GHG emissions and Global Warming Potential (GWP). The focus on carbon footprint is important as it can be used as a baseline to determine the degree of environmental sustainability of the current production system of these crops in order to encourage its key actors along the value chain to improve it. The exploration of potential impact of climate change on production areas that currently sustain *caleños* food habits can provide insight of possible threats to access to food, and the need to develop resilience strategies.

1.2 Study area

Cali is located in the Region Valle del Cauca, in the south east of the country (Figure 1). The city is the capital of the region with a population of slightly more than 2 million inhabitants, surrounded by intermediate cities. A bit more than 80% of the population belongs to low and mid-low social classes. The city has suffered a continuous flow of poor migrants and refugees from the period of violence, as well as an important socio economic crisis in the 90s. Levels of poverty in the country have decreased the last few years: from 26.% in 2010 to 15.4% in 2016 (Cali en cifras, 2016) however, according to the National Survey of the Nutritional Situation

(ENSIN, 2015) 54% of the country's households experience food insecurity. Cali has the highest rates of poverty and extreme poverty (3.2 %) out of the other two big cities of the country Bogota and Medellin (Cali en cifras, 2016).

FIGURE 1: MAP OF COLOMBIA. AUTHOR

The strategies developed to face nutritional and food challenges focus principally on malnutrition and hunger issues. However, at the national level, results show there is a strong increase in obesity and overweight in the country. It has reached in 2010 more than half of the population (Dury, 2015). Cali is the city that has the highest overweight rate of the country, especially for women, despite the fact Cali's inhabitants consume less dairy products and more fruits than the rest of the country (ENSIN 2010). However, consumption of fruits and vegetables remains quite low compared to ideal and recommended healthy diets. Malnutrition schemes and access to food are associated to socio-economic conditions, however the low level of fruits and vegetables consumption is also the consequence of a lack of knowledge on how to prepare and eat these products (Peña, 2017) rather than lack of access. In terms of food environments, the "*tiendas*" (little local shops that sells mostly processed products, grains, oils and a bit a fresh products) are the first place where *caleños* (Inhabitants of Cali) buy their food (Peña, 2017) and thus have a big influence on access to food and quality of diet in the city especially in the vulnerable neighborhoods.

With regard to urban policies, the city lacks a cohesive policy to implement strategies with a long-term vision, as well as a more global perspective of what the food and environmental challenges are. The challenges related to food and health issues have been undertaken with short-term goals and assistance-based approaches such as implementing and funding community kitchens. Concerning food sovereignty, Cali and the department suffers from the intensive agricultural specialization of lands into sugarcane monoculture. The El Valle region is a geographical zone crossed from north to south by two mountain ranges (*Cordilleras*) and a vast valley between the two mountain ranges, following the bed of the Cauca River, has given its name to the region ("Valle" means valley in Spanish). As shown in figure 2, the sugar cane industry (intended for sugar and biogas) has invaded the vast majority of the valley areas, and more diversified crops are entrenched on the mountainside or further North in the region. The region counts with approximately 243 000 hectares of sugarcane fields (Assocaña, 2018). As a consequence, the region produces around 20% of the food needed to feed the region capital (Dury, 2015), and the issues of access to land related to sugarcane monoculture that concentrates land use seems to impede the development of peri-urban agriculture.

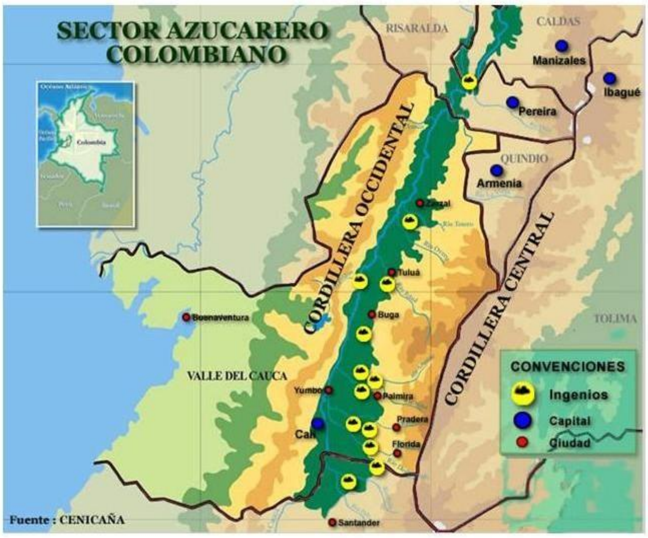

FIGURE 2 : THE SUGARCANE SECTOR IN EL VALLE DEL CAUCA REGION. CENICAÑA

2 Methodology development

To address the research questions and develop the composite methodology, three steps were followed (figure 3) :

- Step 1: The identification of the target food products
- Step 2: Assessment of their Carbon footprint (from production to distribution)
- Step 3 : Modeling of the expected changes in terms of crop-specific climate suitability in the regions currently producing this food.

Step 1 included the **identification of most consumed products**, based on a revision of the existing data on food consumption in Cali and the identification of their geographic production areas and the temporal dynamic of their availability in Cali's main market. Step 1 will be described in 2.1

Step 2 included the **Carbon Footprint assessment** (described in 2.2), based on the PAS 2050: 2011 standard "Specification for the assessment of the life cycle greenhouse gas emissions of goods and services" (British Standards Institution, 2011) which proposes a methodology and specific system boundaries for the analysis of greenhouse gases in the life cycle of goods and services. This standard is based on the Life Cycle Analysis (LCA) methodology. Life cycle assessment is a "cradle-to-grave or cradle-to-cradle analysis technique to assess environmental impacts associated with all the stages of a product's life, which is from raw material extraction through materials processing, manufacture, distribution, and use" (Muralikrishna et Manickam, 2017). In accordance with ISO standards 14040 and 14044, an LCA investigation must be carried out in four steps:

- Definition of the objectives and scope of the study (delimiting with the best transparency what will be the limits of the life cycle we choose to study)
- Life Cycle Inventory (Listing each activity operated in the life cycle and input used, and finding/calculating its emission factor for CO_2, NH_4 or N_2O).
- Life cycle impact assessment (converting the emission factor in carbon equivalent (CO_2eq) and calculating the overall carbon footprint)
- Analysis

Step 3 included using the Ecocrop model (Ramirez-Villegas, Jarvis, et Läderach, 2013 ; Hijmans *et al.*, 2005) to assess the changes in the crop-specific suitability of current producing regions under projected future climate conditions. Climate parameters defining the ideal environment niche for the crop production are defined and integrated to future climate change scenarios using the Ecocrop methodology with Targeting Tools. This step will be described in 2.3.

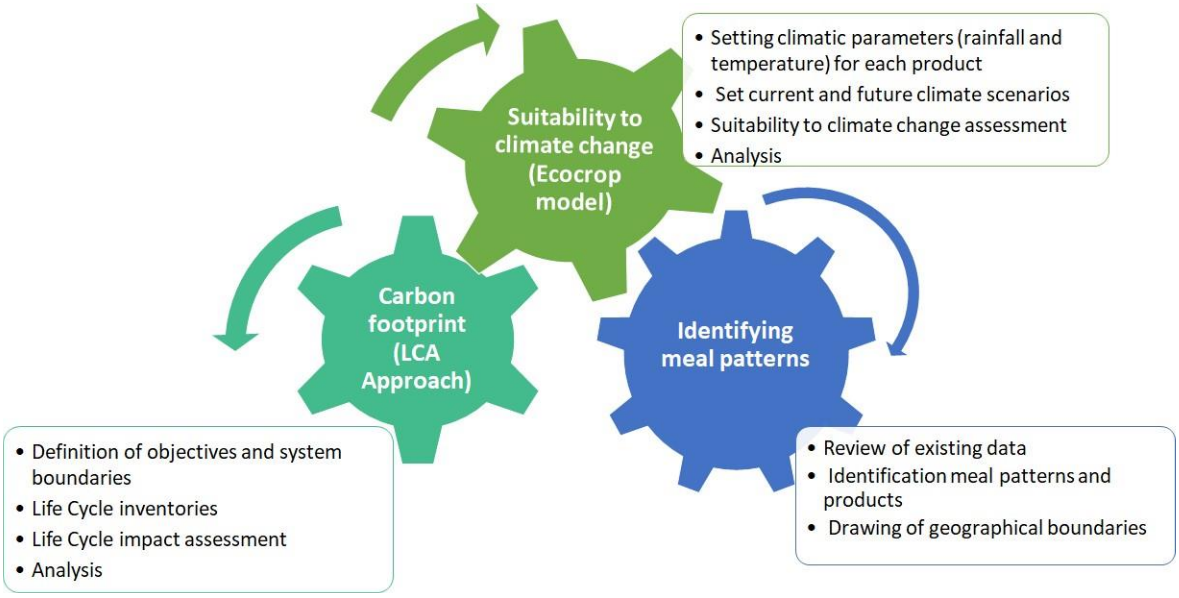

FIGURE 3: THE THREE STEPS METHODOLOGY. AUTHOR.

2.1 Identifying meal patterns

2.1.1 The meal pattern approach

With the growing concern of the environmental impacts of food and the related nutrition driven health concerns, more research is now focusing on identifying what people eat. However, identifying food patterns is not an easy task. A majority of studies of environmental impacts of diets uses the Food Balance Sheets from FAO (Food and Agriculture Organization of the United Nations). They are statistics at the national level that show the availability for human consumption of a food item by adding the total quantity of foodstuffs imported to quantity of foodstuffs produced in the country or the region, and adjusting it to changes in stocks. These statistics give a first glance on food that is available to human consumption in the country. For Colombia, the balance sheets present a national diet mostly composed of a high quantity of carbohydrates, milk and fruits, and a small quantity of vegetables. Results of Food Balance sheets for Colombia (FAO, 2018) can be seen in figure 4.

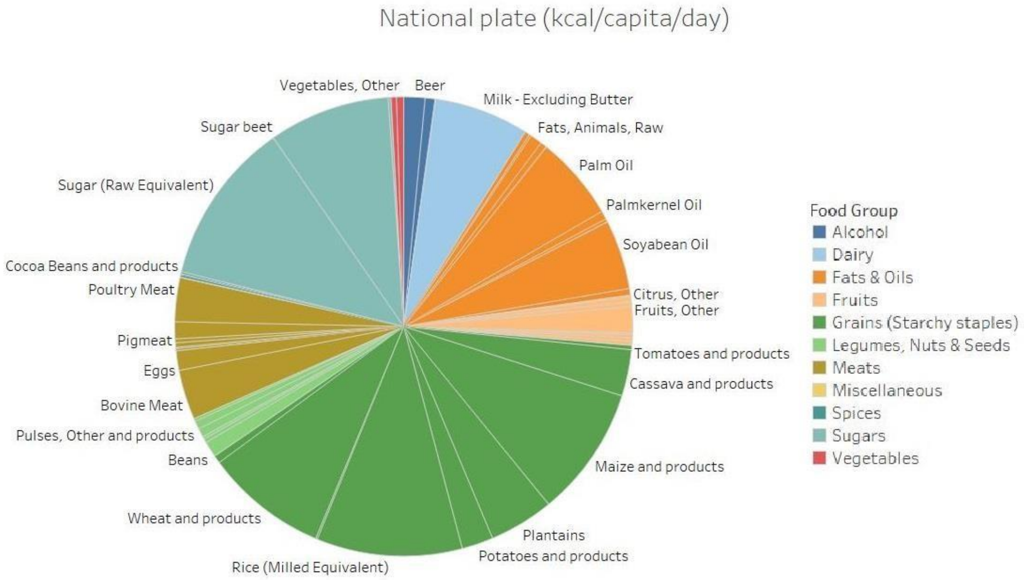

FIGURE 4: COLOMBIAN DIET ACCORDING TO FAO FOOD BALANCE SHEETS. ANNA WHITTON, CIAT.

Nonetheless, the balance sheets give a measure of food consumption from a food supply perspective and does not rely on real food consumption surveys. They can give a good idea of the food available in the country but are not relevant at sub-national level. This study though, needed to rely on the available data on food consumption at the municipality level. According to the available data, we decided to establish the most representative lunch meal, composed by the five most consumed products, rather than the full diet. Eventually, identifying such a thing as a “typical *caleño* lunch meal” solely can be theoretical, as it does not take into consideration the diversity of a city in terms of cultures, migrations, socio-economic conditions. Cali is a diverse city where live together afro communities, indigenous, as well as the recent immigration from Venezuela, producing a diversity in terms of culture and way of living, cooking and eating.

2.1.2 Gathering and reviewing the existing data

In Cali, a good amount of studies and surveys have been conducted about nutritional situation and issues of the city's inhabitants (malnutrition, overweight, hunger, especially of mothers and babies). More information is to be found about social interaction and commensality (Quintero, 2008), dietary habits of adolescent students (Piñeros, 2011), dietary patterns of one-year-old children (Ocampo, 2014) and where food is provided in the city (Castellanos, 2009), and real surveys of food consumption of adult population are lacking. However, the national survey of the nutritional situation (ENSIN)[2] generated important content on food consumption in the country, per regions and per city. The ENSIN 2010 gives information on frequency of consumption per food groups, whose results for Cali are shown in figure 5.

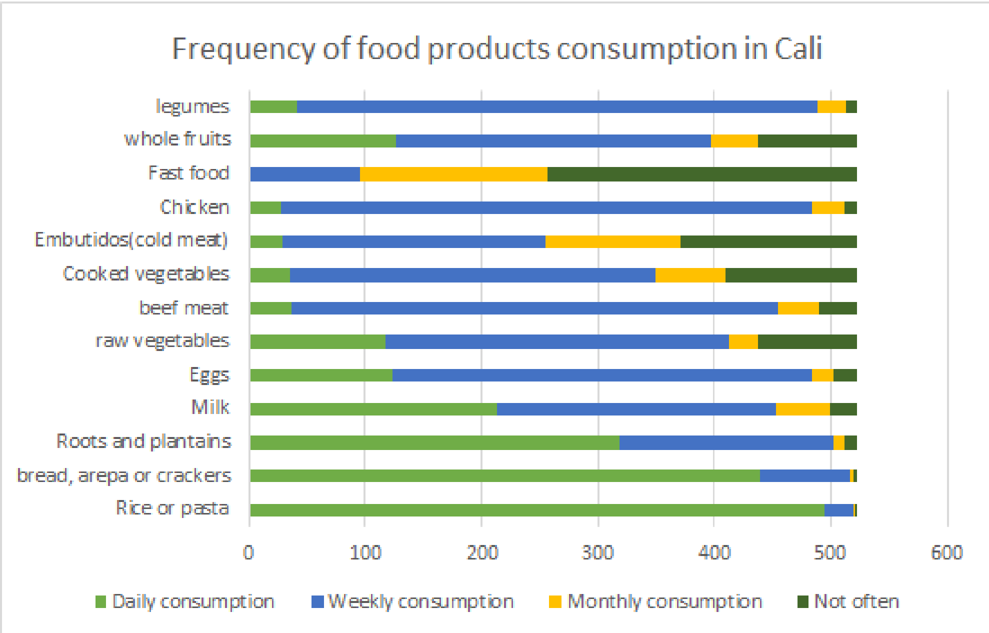

FIGURE 5 : FREQUENCY OF FOOD PRODUCTS CONSUMPTION IN CALI. AUTHOR, BASED ON ENSIN 2010

[2] ENSIN is a wide survey conducted every five years and meant to identify social determinants, indicators and tendencies in the country related to nutrition, made by the National Administrative Department of Statistics (DANE).

The survey covered 536 households and the questions focused on groups of food products and on their frequency of consumption. Responses were classified as follows :

- *Daily consumption – which included all the products from whom the responses were : "once a day, twice a day and two to three times a day answers"*
- *weekly consumption – corresponding to the aggregation of the"once a week, twice a week, more than 5 times a week " responses and,*
- *Monthly consumption – gathering the products where the reported frequency was "once a month, more than twice a month".*

According to ENSIN 2010, *caleños* eat on a daily basis rice or pasta, bread, roots and plantains. Chicken meat, legumes and beef meat are eaten on a weekly basis. Surprisingly, it shows that caleños do not eat fast food that often.

To further identify the specific products within the food groups, a revision of available data was undertaken. Two academic papers (Peña 2017, Dufour 2015) three surveys were selected (ENSIN 2010, Municipalidad de Cali 2009, FAO 2010). General patterns stand out:

- Rice seems to be a very important product in Colombia and Cali, as well as potato and plantain as "the wide variety of preparations of such food products is part of popular gastronomy and embedded in our culture" (translated from *Secretaría de Salud Pública*, 2009).
- Bread and milk are also consumed on a daily basis, which is not the case for meat such as chicken or red meat.
- Vegetables, such as tomato and onion, are frequently consumed however in small amounts.

Details of information from the studied data are listed in Appendices 1. The existing data used date from 2009 to 2017. During this large time rate, it is arduous to detect if food habits have drastically changed in Cali over the last ten years. A research (Dufour, 2015) studying food habits of women in Cali between 1997 and 2008 did not observe critical changes during that time period.

2.1.3 Identification of products and geographical boundaries

Based on the revision of the existing literature described earlier, five products most eaten at lunchtime were identified: Rice, plantain, potato, tomato and chicken meat. For each of the product, a mean of quantity (grams) per person per day was established, based on results from the ENSIN 2005 for the city of Cali (representing the results of 941 inhabitants surveyed). The *"caleño lunch plate"* is presented below (figure 6). During the identification phase, some products were intentionally excluded :

- Imported products were avoided, in order to be able to develop the Ecocrop methodology for crops produced in the country.

- Fruits were excluded. Fruits are a big part of Cali's diet (in form of juices), but it is very difficult to choose one fruit over another because the consumption strongly depends on crop period and can vary a lot.

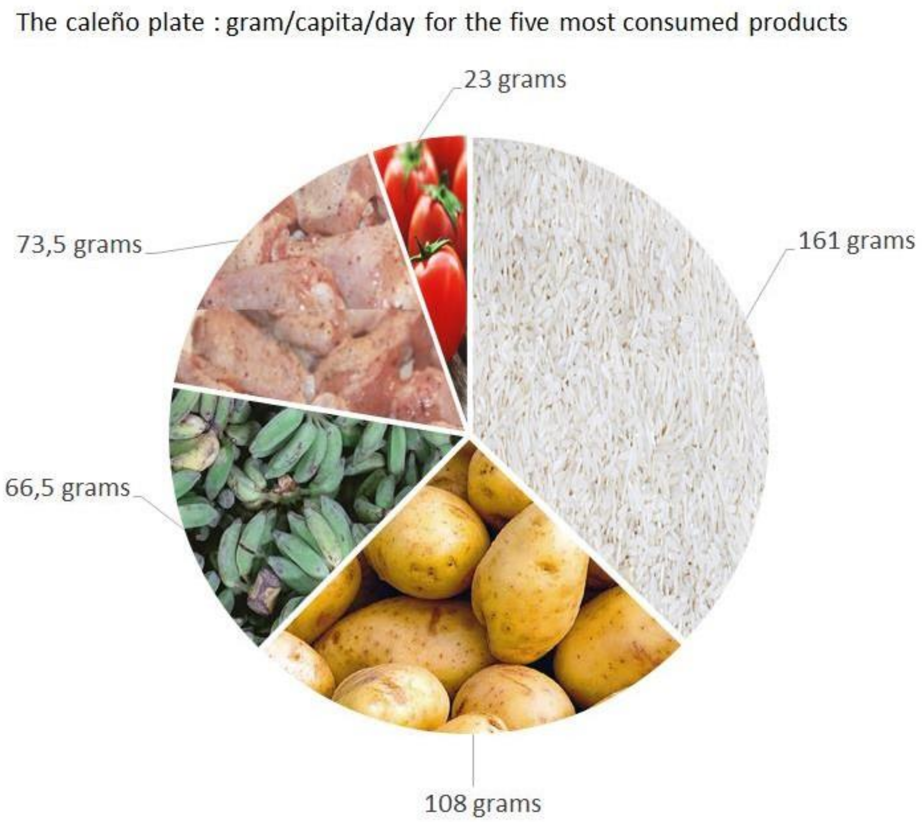

FIGURE 6: THE "*CALEÑO* PLATE. AUTHOR.

Then, geographical boundaries of each product identified were set by identifying origins of production of the five products. Food products in the city are distributed through numerous retailers : local shops (*tiendas*), supermarkets, marketplaces etc. There are two central wholesale markets in Cali : Santa Helena and Cavasa, where food is sold to retailers and then distributed in the city. The Wholesale Market Cavasa participates in 34% of the food exchanges in the city (Universidad del Valle, 2018) with 265 000 tons of food products sold in 2017 (DANE-SIPSA, 2017). The areas of production of the products were established by looking at the origins of products stored in the Cavasa wholesale market for 2018. The corresponding information is provided by DANE statistics (DANE, 2018) which identifies the places of origin, quantities and type of products transported by trucks at the entrance of the market. Production areas are identified in Figure 7.

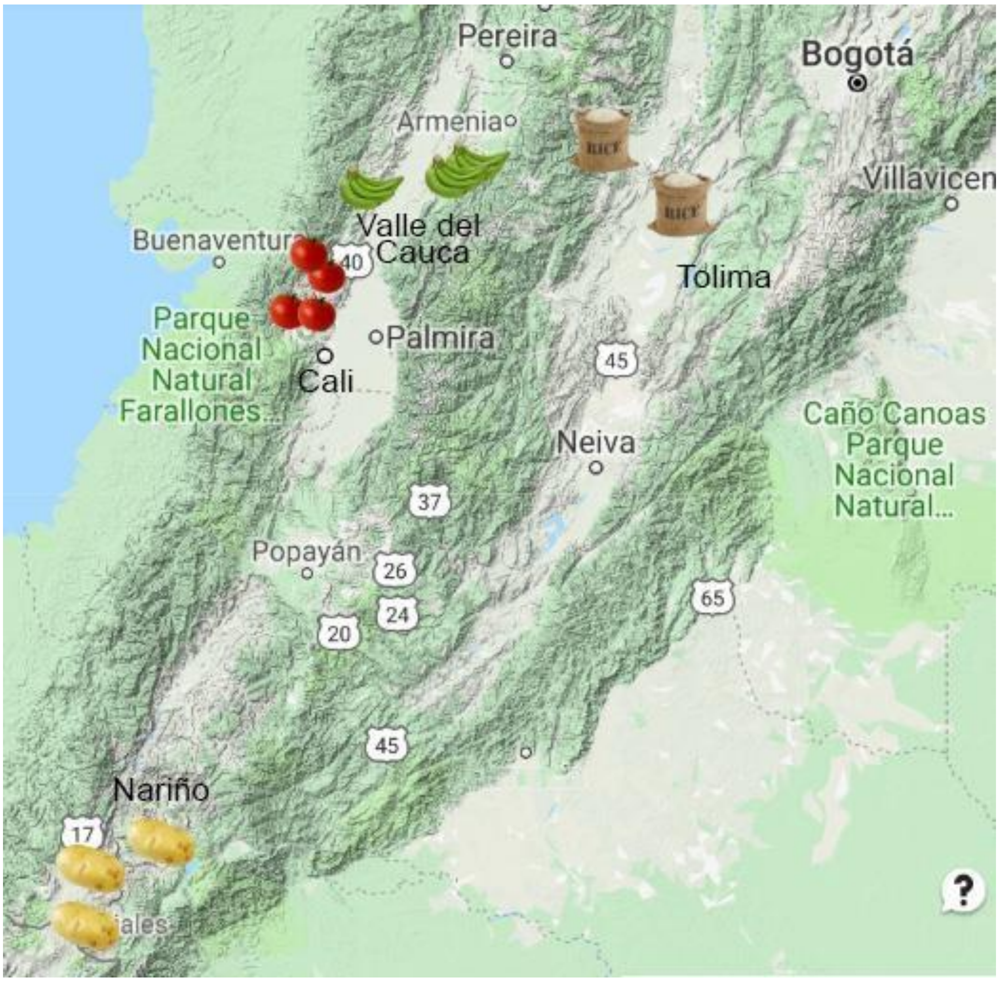

FIGURE 7 : PRODUCTION AREAS OF THE FIVE MOST CONSUMED PRODUCTS IN CALI. AUTHOR, BASED ON DANE, 2018.

2.2 Carbon footprint to assess environmental burden of food

2.2.1 Carbon emissions calculation : norms and emission factors

A carbon footprint corresponds to the total of GHG emissions generated directly and indirectly by a product, a service, an individual during all its life cycle (ADEME, 2015). The first step is to draw the system boundaries of the life cycle of the target products (See 2.2.2) to clearly define what will be included and excluded from the calculation. The second step is to identify each activity and quantify its consumption in energy, inputs, fossils fuels as well as the generated waste (see 2.2.3).

Each activity has a GHG emission factor, a coefficient that converts the activities into emissions of greenhouse gases. A lot of different GHG are generated by human activities or simply present in soils, air and water. This study focuses on three of them: Carbon dioxide (CO2), methane (CH4) and nitric oxide (N2O), as they are the three principal GHG emitted by agricultural and livestock activities and most often studied in carbon footprints of food products. All GHG have different Global warming potential (GWP) that corresponds to how much heat can be captured by a GHG. The IPCC published in 2014 (the AR5 Report, IPCC 2014) a list of different GHG and their respective GWP in relation to a reference gas, here carbon dioxide, as carbon equivalent (**CO2-eq**), allowing to give a common value to all of the GHG emissions estimates. CH4 and N2O has a GWP of 28 and 265 times higher than CO2 respectively.

For every activity GHG are directly and indirectly emitted. The PAS 2050 give guidelines on which direct and indirect emissions should be included in the assessment. The list of emissions included in this study is shown below (Table 1). The majority of indirect emissions factors are found on LCA database such as Ecoinvent 3.3.

Direct emissions	Indirect emissions
- Use of machinery for production and transformation steps, vehicles for transport : emissions from fossil fuels and biomass combustion - Use of fertilizers: direct emissions generated by the application of synthetic and organic fertilizers in the fields - Emissions from field : Methane emitted from rice flooded fields	- Electricity consumption : emissions associated with the generation of electricity consumed - Input manufacturing and transportation: emissions generated by the manufacture and transport of inputs (e. g. fertilizers, fuels, feed), including raw material extraction and transport (fossil combustion) to a nearby point of sale

TABLE 1 : LIST OF DIRECT AND INDIRECT EMISSIONS FOR CARBON FOOTPRINT. AUTHOR

2.2.2 Description of the system under study and system boundaries

As the study cannot encompass the totality and diversity of production processes, one specific scenario was given to each item (presented in Table 2) in order to communicate with the best transparency about what will be assessed in the carbon footprint analysis. Choices of agricultural practices in the scenarios were set by the data that was collected during the time of the study. The carbon footprint that will be undertaken is not representative of the whole production of a product in a Region, but accounts for the scenario described.

SELECTED SCENARIOS PER PRODUCTS

SCENARIO FOR TOMATO	Tomatoes produced in open air in the El Valle region, under conventional practices, transported 97 km from farm to to the Cavasa wholesale market
SCENARIO FOR PLANTAIN	Plantains produced in the El Valle region, under conventional practices, transported through 139 km from farm to to the Cavasa wholesale market
SCENARIO FOR POTATO	Potatoes produced in the Nariño region, under conventional practices, transported through 440 km to the Cavasa wholesale market
SCENARIO FOR RICE	Rice produced in the Tolima region, under traditional conventional practices, transformed in Tolima with conventional mills, transported 295 km to the Cavasa wholesale market
SCENARIO FOR CHICKEN	Chicken broilers grown in the El Valle region, under conventional practices, and processed.

TABLE 2 : SELECTED PRODUCTION SCENARIOS PER PRODUCT. AUTHOR.

The system boundaries define all the processes that are included in the analysis, as well as the geographical and temporal boundaries of the study and the environmental flows taken into account. For the five products identified, the boundaries go from production stage to distribution stage at the Wholesale market Cavasa, and does not include the last mile stage, neither use stage nor end-of-life, due to lack of information and time to cover the whole life cycle. The system boundaries for tomato, plantain and potato are shown in figure 8.

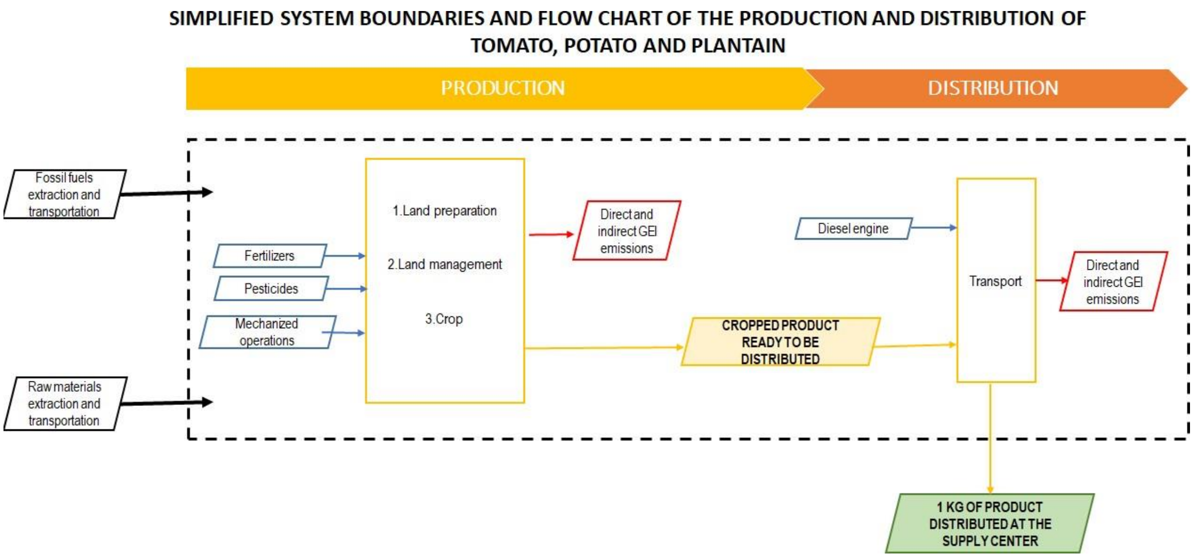

FIGURE 8 : SYSTEM BOUNDARIES OF TOMATO, PLANTAIN, POTATO. AUTHOR.

The analysis is not a cradle to grave study, but the analysis goes a little beyond the cradle to gate, as it includes the transformation stage for rice and chicken, as well as distribution to the wholesale market. Packaging was not included due to lack of data on the packaging process. System boundaries for rice and chicken are shown respectively in figures 9 and 10.

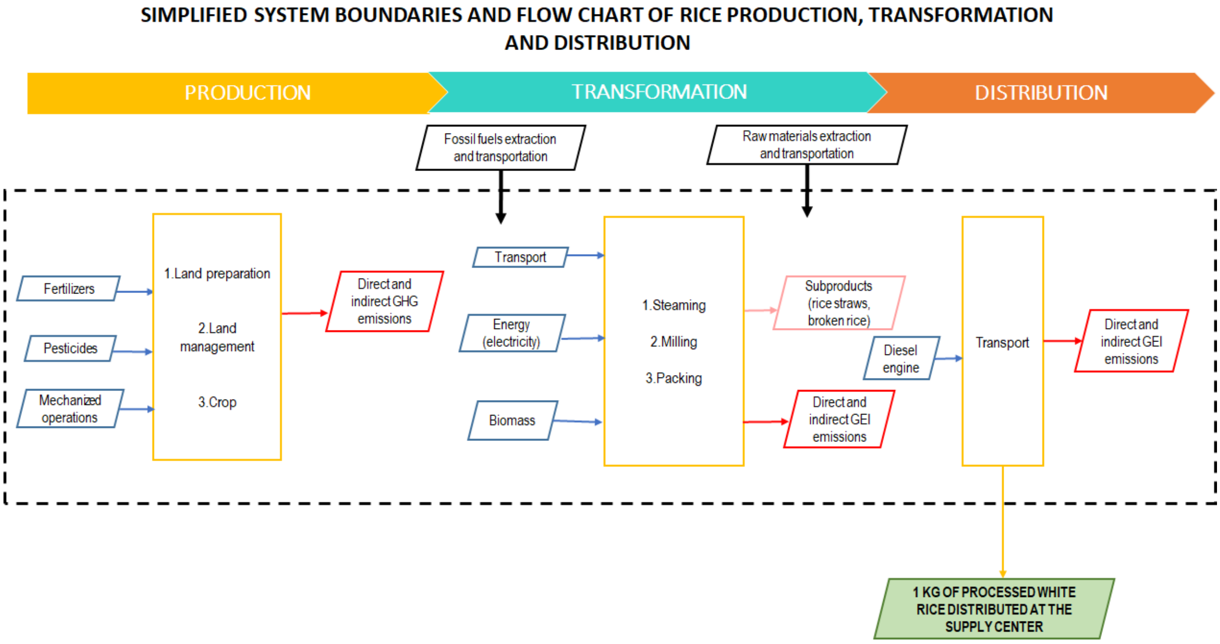

FIGURE 9 : SYSTEM BOUNDARIES OF RICE . AUTHOR.

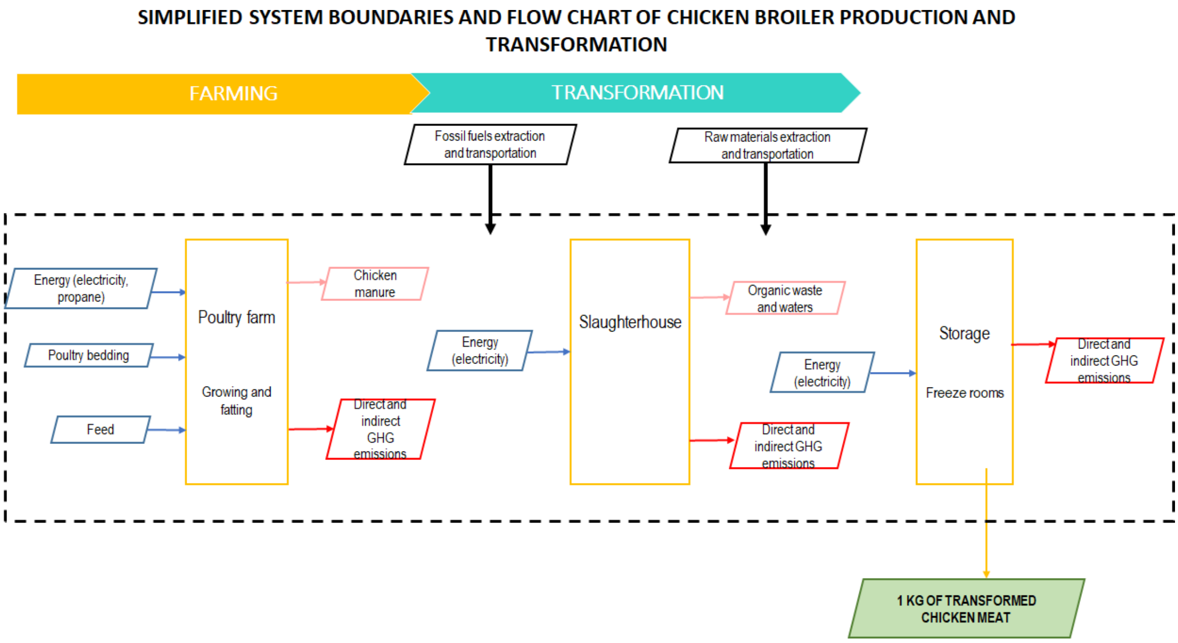

FIGURE 10 : SYSTEM BOUNDARIES FOR CHICKEN BROILER. AUTHOR.

The Functional Unit is the unit of measurement used to evaluate the service provided by the product (ADEME, 2015). The functional unit for each of the product under study will be one **kilogram of transformed product** delivered to Cali.

2.2.3 inventory analysis

The inventory analysis explains how the collected data is used in the LCA model and reveals the assumptions that were made and choices that were taken. For this study, the assessment built on secondary information delivered by institutions and official actors from the sectors, listed in Table 3. The scenarios defined earlier are “theoretical farms” or estimates that were built in order to make this assessment possible.

- **Tomato, plantain, potato and rice**

Mechanical operations and capital goods

Mechanical operations represent all use of machines in the production phase (land preparation, fertilizing, sowing, application of pesticides, crop). The operations are generating emissions from combustion of fuels (gas and diesel), manufacture and transportation of fuels. Information on mechanical operations use were taken from the production cost analysis for each crop (see table 3). Indirect and direct emissions were taken from the Ministry of Mining and Energy (UPME-*Ministerio de Minas y Energía de Colombia,* Fecoc 2016) and from World Resources institute (GHG protocol tool for mobile combustion, 2015). Capital goods were excluded from the life cycle analysis, as suggested by the PAS 2050. Seeds production was not considered, as due to their low mass the impacts might be negligible (Bojacá, Wyckhuys, et Schrevens, 2014).

Use of fertilizers

The application of nitrogenous fertilizers in the field (synthetic mineral fertilizers or organic fertilizers such as manure) causes nitrous oxide emissions, directly to the field after ground application, or indirectly, after transfer of nitrogen to the water as nitrate (leaching) and via the atmosphere as ammonia (volatilization). Direct emissions of N2O (from the field to the atmosphere) are related to soils' microbial functioning through nitrification (oxidation of ammonium to nitrate) and denitrification (reduction of nitrate to nitrogen) processes. For each N-based fertilizer applied to the field, N2O emissions related to nitrification and denitrification, leaching and volatilization processes were calculated. The emission factors were found in the Ecoinvent 3.3 database.

Manufacture of inputs

Production costs analysis of each product provided by official actors were used as a base to define how and how much inputs are used in the fields for each crop. Each fertilizer was

divided into its active ingredient and linked to its CO2eq emission factor found in Ecoinvent 3.3. For pesticides, a generic and unspecified emission factor from Ecoinvent was used for all of the pesticides (10.675 kg Co2eq/kg).

TABLE 1 : INVENTORY OF REFERENCES. AUTHOR

Production	Tomato and plantain : Secretary of Agriculture of El Valle region, production costs analysis for El Valle region
	Potato : National potato producers federation (Fedepapa), production costs analysis for one farm in Nariño (Ipiales)
	Rice : National rice growers federation (Fedearroz), production costs analysis of Tolima Region
	Chicken : National poultry farming federation (FENAVI), production costs analysis of chicken feed of Colombia
Manufacture of inputs	Ecoinvent 3.3
Transformation and storage	Chicken : Pollos el Bucanero S.A, Poultry production and processing Company based in el Valle región
	Rice : Ginsan S.A, Agricultural machinery firm, based in Cali.
Transportation	DANE, National Administrative Department of Statistics

Transportation of inputs

For pesticides and fertilizers, the three mains firms commercializing most products in the country were identified as well as the location of their production site in Colombia. A mean of transportation distances from each production site to the production areas was calculated in order to have a global approximate for transportation of inputs, as detailed information on origins of each input was lacking (see Appendice 2). The transportation of compost used in tomato and plantain field was not included due to lack of data.

Field emissions of rice

Wetland rice fields are identified as a major source of atmospheric methane (Neue, 1993) and are now said to be a major hotspot in the general GHG emissions related to agriculture . Methane emission is the result of a decomposition of organic matter and is due to long submersion times of crops in water. Irrigated rice fields is a common agricultural practice in the center of Colombia and in the Region (Tolima Region) identified in the scenario. To include methane emissions from rice fields in the carbon assessment, a generic NH_4 emission factor was taken from FAOStats (FAOstats, 2017), corresponding to 20.72 grams of CH_4 per square meter of rice field in Colombia for 2017.

Transformation of rice and allocation of by-products

For the transformation process of rice a simplified model was constructed, based on information given by a Colombian agricultural machines vending firm. The transformation process splits into two steps : Drying and milling. It was considered that the drying phase transforms the moisture of rice and temperature from 23 degrees to 13 degrees (from information given by actors involved in the rice sector), and create a subsequent loss of weight of the rice. Electricity (KW/ton of rice) and biomass consumption of the dryer (charcoal, rice husks, firewood) were modeled. The milling phase is divided into different steps (cleaning, hulling, milling, whitening, polishing, sorting) that also require electricity. In our theoretical transformation phase, 1000 kg of paddy rice results in 513 kilos of white milled rice. As the transformation generated byproducts (rice husks, rice bran, broken rice), an allocation method was considered. An allocation method is used to divide the impacts between products and byproducts, and can be done in proportion to the economic value of the products and by- products or in proportion to the mass. The PAS 2050 guidelines encourages the allocation in proportion to the economic value. The allocation economic factor for white rice (85.44%) was found in Rocco Lahr et al, 2015.

Final transportation

Final transportation between farms and Cavasa wholesale market was made by calculating a mean of distances between the different production areas to the wholesale market. Emissions factors from trucks were found in Ecoinvent 3.3 . Refrigerated trucks were not considered as it is not common in the country.

- **Chicken**

Poultry farms and feed

Broiler poultry farms use electricity for light and propane for heating. Approximate consumptions were given by the national poultry federation (FENAVI), as well as the ingredients and quantities of the feed during the whole life of the broiler, which is 40 days approximately. Inputs for poultry bedding were taken into account (rice husks and wood chips). Vaccines were not taken into account due to the lack of data available.

Transformation, packaging and storage

The energy consumption for transforming the live chickens was modeled. It was considered that a 2.2 kilos live chicken weights 2.125 kilos when dead and eviscerated. Packaging was not taking into account due to lack of data on how chicken is distributed to local shops and how local shops pack it to sell it to consumers. Storage in freezers was included in the model, taking into account an inventory rotation of four days in cold chamber.

Transportation

In the geographical context of El Valle region, the main poultry producer is Pollos El Bucanero S A (second producer of broilers at the national level). Bucanero SA owns 171 poultry farms of different sizes in the region, and broilers are transformed in the central slaughterhouse located few kilometers from Cali. Regarding the difficulty in providing a mean of distances between the totality of the farms and the slaughterhouse, transportation between poultry farms and slaughterhouse was excluded from the assessment model.

2.3 Simulation of climate change with Ecocrop

2.3.1 Model description

With the current progression of GHG emissions in the atmosphere, the global warming is changing the seasons and environmental conditions for crops to grow are likely to be altered. The objective of this ultimate step is to show how climate change might affect the crop suitability, or in other words the growing conditions for tomatoes, potatoes, rice and plantain in Colombia in the future.

To that end, a modeling tool that predicts suitability of various crops under different climatic conditions was used. The Ecocrop methodology is based on a database of environmental parameters of a wide range of plants created by FAO called Ecocrop database (FAO, 2010), first modeled in 2001 by Hijmans et al. This model determines geographically and theoretically the areas where climatic parameters are optimal for a specific crop (niches) and focuses on two climatic parameters: rainfall and temperature, using a gridded data of temperature and rainfall (minimum, maximum, and mean monthly temperatures, and total monthly rainfall). The algorithm determines climatic conditions by multiplying both variables at a particular place and gives a suitability score (from 0 to 100%) for a defined crop. Eventually, the Ecocrop module can be used in Python ArcGIS to predict the adjustment of a particular crop in the future by changing the climate variables in the studied area. The methodology then consists in defining climate (current and future) data sets (see 2.4.2) and then defining parameters for each crop (see 2.4.3). The objective is to produce maps at the scale of the regions and to show changes in crops suitability in the future.

2.3.2 Climate datasets

To model the current climate situation, historical climate data that gather means of temperatures and precipitation at the level of the planet were used from WorldClim (worldclim.com). To model future climate situations, Representative Concentration Pathways (RCP) were employed. The RCPs are “scenarios that include time series of emissions and concentrations of the full suite of GHGs and aerosols and chemically active gases, as well as land use/land cover” (Moss *et al.*, 2010). Four RCPs have been developed by an international multi model collaboration (CMIP5) based on a wide number of General Circulation Models (GCM, climate model simulations) built on assumptions about present economic activity, energy sources, evolution of population and political choices. The four scenarios (see figure 11) were used in the Fifth and most recent IPCC Assessment (AR5) as a basis for the climate predictions and projections. To assess the suitability of crops in Colombia’s regions, scenario 4.5 and scenario 8.5 were chosen as 4.5 refers to a low climate change where many mitigation policies are developed and RCP 8.5 represents the highest GHG emissions and the biggest change where few mitigation policies and implemented (also sometimes referred as the worst-case or business-as-usual scenario). The selection of time horizons differs a lot from one climate prediction study to another. Nonetheless, it has been chosen to present a large time horizon, 2020-2080, to be able to show significant changes.

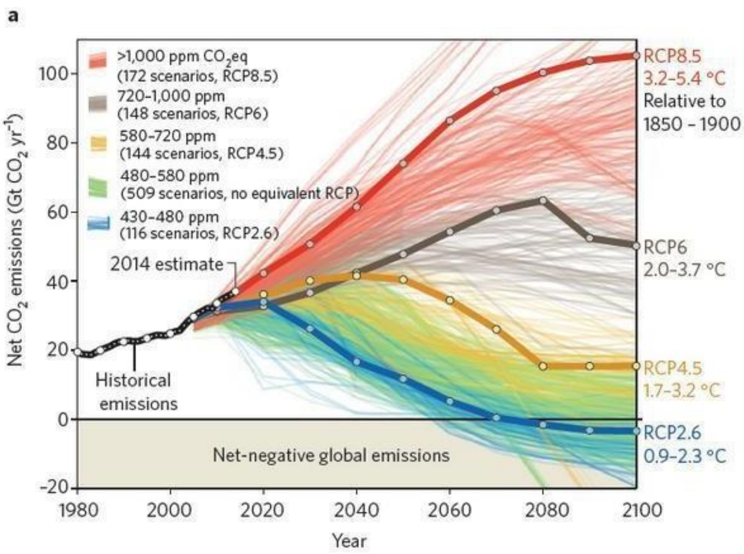

FIGURE 11 : THE FOUR REPRESENTATIVE CONCENTRATION PATHWAYS. ANTHENTHEREPHYSICS.COM

2.3.3 Downscaling and Determination of ecological parameters

A procedure called downscaling was needed to be able to get a higher resolution at the local scale (scale of Colombia), as the GCM give grid cells of more than 100 km a side and would be inappropriate for analyzing suitability of crops at a smallest scale. A downscaling method called Delta method and first developed by (Hijmans *et al.*, 2005) was thus developed (see Jarvis and Ramirez, 2010 for more explanation of the Delta downscaling method).

The ecological parameters for the crops under study then were identified and added to the model. The parameters were taken from the FAO data base Ecocrop and also from local literature and technical guides. Table with parameters per crop is shown in appendices 3. The parameters correspond to an absolute range (minimum and maximum absolute temperatures and rainfall at which the crop can grow) and an optimum range (minimum and maximum optimum temperatures and rainfall). An additional temperature parameter of temperature at which the crop cannot survive the cold was added to illustrate the effect of a season's minimum temperature. There are no suitable conditions when parameters at a specific geographical place are beyond the absolute thresholds. There are suitable conditions (from 1 to 99) when parameters are between the absolute and optimum range of temperature and rainfall. There are highly suitable conditions when parameters are within the optimum range (suitability score at 100%). Results can show suitability levels at a given time (current or 2080) and can show the percentage of suitability changes (no change, gain or decrease) between now and 2080.

3 Results

3.1 Carbon footprint of the typical *caleño* lunch

All of the CO2, NH4 and H2O emissions factors were added and results divided by yield of crops and weight of dead chicken after transformation to present the carbon footprint per functional unit. Results in kg CO2-eq are shown in figure 12 .

The product that has the highest carbon footprint is chicken, with 2.04 kg Co2-eq. The second highest carbon footprint is from rice, with 1.46 kg Co2-eq. Plantain and potato have quite close carbon equivalent emissions (0.28 kg Co2-eq and 0.23 kg Co2-eq respectively) and tomato has a very low carbon footprint of 0.09 kg Co2-eq.

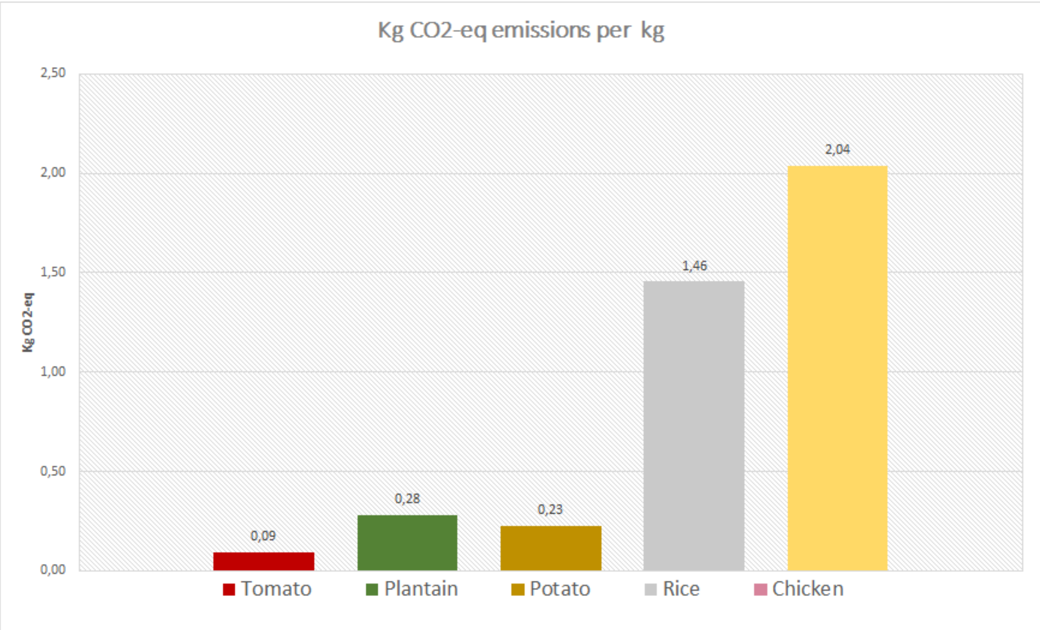

FIGURE 12: CARBON FOOTPRINT (KG CO2EQ PER KG OF PRODUCT) OF FIVE PRODUCTS MOST CONSUMED IN CALI. AUTHOR

To identify the hotspots of GHG emissions, a contribution analysis was conducted and shown in figure 13 and carbon footprint per activity detailed in table 4. Manufacture of inputs is the activity that has the highest contribution for GHG emissions for tomato (60% of contribution), plantain (59%), potato (52%) and chicken (65%). For crop products, manufacture of inputs corresponds to the extraction of raw materials and manufacture of fertilizers and pesticides. Manufacture of input for chicken meat corresponds to the feed of chicken, majorly composed of maize corn, soybean meal and sorghum, produced in the United States and imported to Colombia.

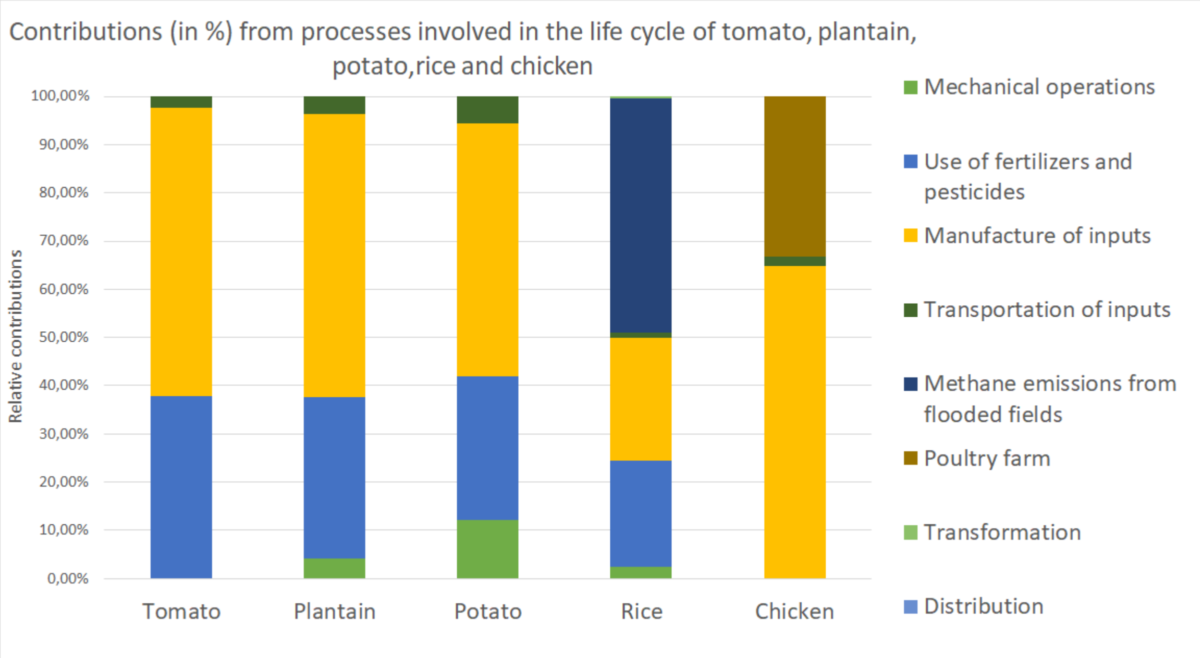

FIGURE 13 : CONTRIBUTION ANALYSIS (% OF CO2EQ EMISSIONS). AUTHOR

Emissions (kg CO2-eq/kg) per activity for tomato, plantain, potato, rice and chicken meat

	Tomato	Plantain	Potato	Rice	Chicken
Mechanical operations	0,00	0,01	0,03	0,04	0,00
Use of Fertilizers and Pesticides	0,035	0,09	0,07	0,37	0,000
Manufacture of inputs	0,055	0,16	0,12	0,43	1,32
Transportation of inputs	0,002	0,01	0,01	0,02	0,04
Emissions from flooded fields				0,83	
Chicken farm					0,68
Transformation				0,01	0,00
Distribution	0,00	0,00	0,02	0,00	0,00

TABLE 2 : EMISSIONS IN KG CO2EQ PER ACTIVITY PER PRODUCT. AUTHOR

Transformation phase is nearly close to no emissions for rice and chicken. One of the explanation could be that the information gathered for rice transformation were given by a firm that sells highly modern and efficient rice mills, thus consumption of energy and biomass required by the machines are probably lower than the average rice mills in Colombia. For chicken transformation, management of water and organic waste was not taken into account due to lack of data, however waste water treatment plants generates methane and nitrous oxide. Direct emissions from use of fertilizers and pesticides are high for rice because of methanogenesis (formation of methane by microbes in the flooded rice fields).

In general, results from carbon footprints greatly differ from one study to another, depending on the context, life-cycle activities, and the chosen system boundaries. A quick review of life cycle analysis studies from different countries reveals the wide range of results : a French LCA database (agribalyse®) calculated a total of 3.3 kgco2eq for imported Thai rice, a LCA of rice production in Italy gave a result of 2.9 kg co2eq, and the Ecoinvent database gives an overall approximation of 1.7 kg co2eq per kg of white milled rice. In Colombia, a Life Cycle analysis has been undertaken on rice production in the Huila region and found a carbon footprint of 998 kg CO2eq/hec of paddy rice, (Andrade, Campo, et Segura, 2015), as another study, also for the Huila region gives 4991 kg co2/ha for paddy rice (Meneses, 2014). Results in hectare of paddy rice are difficult to compare to results for white milled rice. However results from these studies from Colombia seem quite low, and the reason might be that they did not include methane emissions from fields. Tomato production under greenhouses in the Boyaca Region in Colombia has been studied by Bojaca, Wyckuys and Schrevens, 2014, whose result was 0.074 kg co2eq per kilo of tomato and highlighted the environmental burden of polyethylene cover from greenhouses due to its short lifespan and absence of plastic recycling. Tomato in northern countries can have a highest carbon footprint due to controlled climatic conditions (heated greenhouses): from 2.2 to 0.1 kg CO2eq according to the French LCA database Agribalyse for example. Results for potato production vary a lot: 0,09 kgCO2eq for France (Agribalyse®), 0.34 kgCO2eq as global footprint given by Ecoinvent 3.3. Carbon footprint results of broiler meat are comprised between 2 and 5 kg CO2eq: 2.6 kgCO2eq from global LCA database Ecoinvent, 3 kgCO2eq for Tunisia (Ibidhi *et al.*, 2017), 2.5 kgCO2eq for brazil (Prudêncio da Silva *et al.*, 2014), to 5.6 kgCO2eq for UK (Leinonen *et al.*, 2012). Eventually, the diversity in the results highlights the diversity of situations but also the capacity of the LCA approach to manage the complexity of a production system where a numerous of different parameters co-exist (Blengini et Busto, 2009)

3.2 How climate change affects what *caleños* eat?

The Ecocrop model generated maps to predict climate suitability of each of the four crop products. Eventually, results will only show the scenario RCP 8.5 (worst-case scenario) for the period 2020-2080 in order to show the possible impacts of climate change if GHG emissions are still on the rise. Maps are showing the percentage of change in suitability, positive or negative, between 2020 and 2080. In this way, it is possible to quickly locate areas subject to change and which will need to implement resilience strategies to face climate change. The scale of the maps was set per region: El Valle region for tomato and plantain, Nariño region for potato, Tolima region for Rice. Results at the country level as well as tables with quantitative results will be found in the appendices 4 to 7.

Tomato

For tomato production, the model predicts a deterioration of climatic conditions in mountain areas (figure 14), and less so in the valley area, which, as mentioned above, is monopolized by sugar cane cultivation. According to the model, 31% of the area would suffer a sustainability decrease of -1 to -25%, and 57% a medium decrease of -25 to -50% suitability (cf appendices 4).

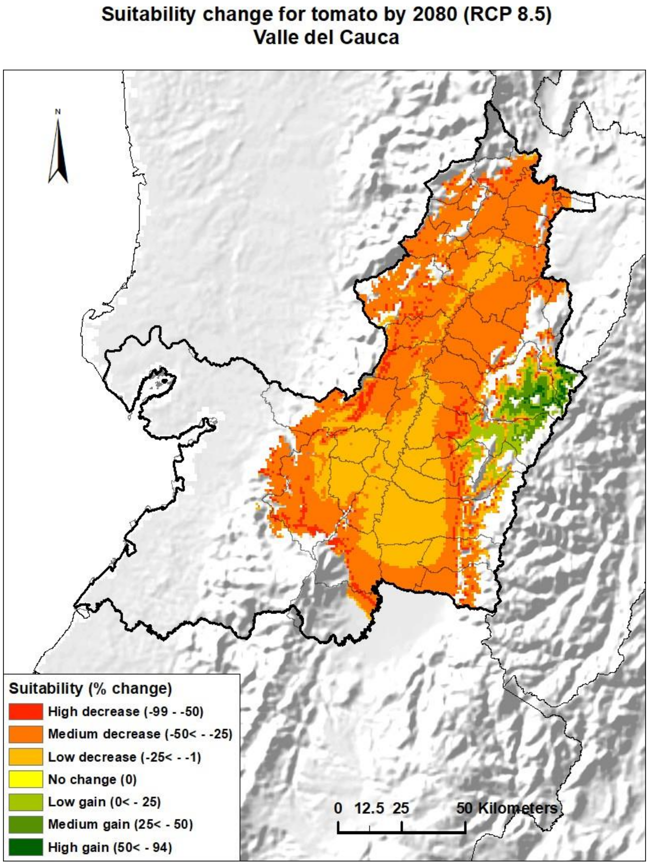

FIGURE 14: SUITABILITY CHANGE (%) BY 2080, RCP 8.5, FOR TOMATO IN THE EL VALLE DEL CAUCA REGION. ANDRES JINES AND AUTHOR.

Plantain

In theory, plantain production seems to benefit more from changes in climatic parameters than suffer from it (figure 15) . If part of the territory seems not to change by 2080, another part would see even more favorable parameters for the cultivation of plantain. The current plantain production areas in the north of the region are located in areas that will see their suitability increase. Depending on the model, 68% of the area will benefit from an increase in suitability, including 37% from an increase between 25% and 30%.

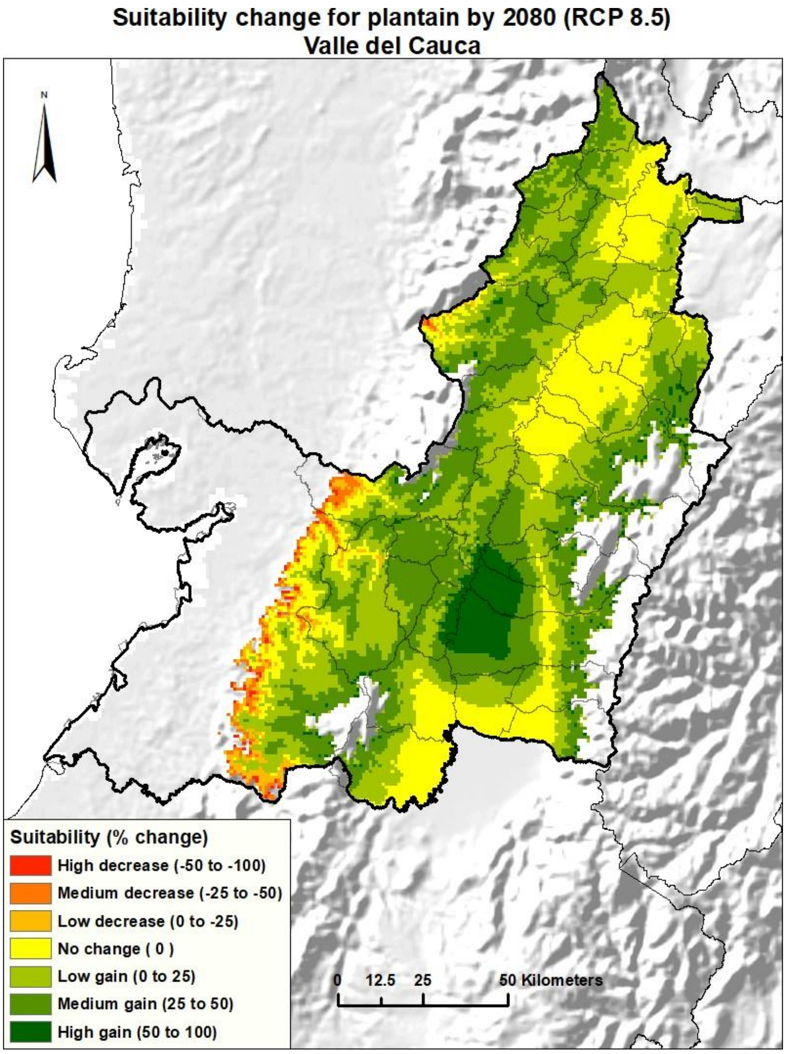

FIGURE 15: SUITABILITY CHANGE (%) BY 2080, RCP 8.5, FOR PLANTAIN IN THE EL VALLE DEL CAUCA REGION. ANDRES JINES AND AUTHOR.

Potato

Figure 16 shows the percentage of change the climate suitability for potato cultivation in the Nariño region. The results are clear: a majority of areas will experience a deterioration in the climatic parameters favorable to potato production, and few areas located in the South of the region (25% of the area depending on the model) have predictions of increased suitability. According to the model, it is predicted that 39% of the area will see its suitability decrease by

-1 to -25%, and 33% by more than -25%. Nariño is a mountainous region (Colombian Andes), where a large part of the rural economy relies on potato production. Nariño is the country's leading potato producing region, generating 21% of the national production in 2018 (Fedepapa, 2018). The potato sector in Nariño, therefore, must prevent future changes by implementing resilience and climate change adaptation strategies

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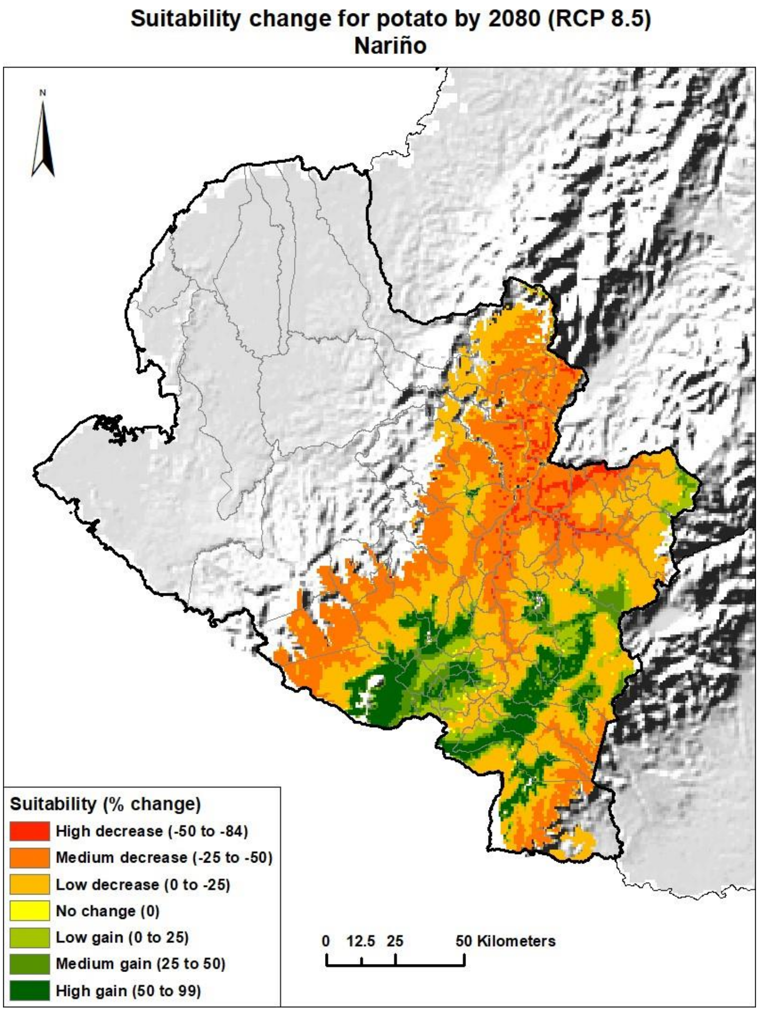

FIGURE 16 : SUITABILITY CHANGE (%) BY 2080, RCP 8.5, FOR POTATO IN THE NARIÑO REGION. ANDRES JINES AND AUTHOR

Rice

Colombia is a major producer of rice, particularly irrigated rice, but the current cultivated areas are below the country's productive potential (Castro-Llanos *et al.*, 2019). Domestic production does not meet domestic demand and the country is forced to import rice from abroad. The central part of the country, which includes the Tolima Region, represents 60% of irrigated rice growing areas (Fedearroz, 2018). The results of the Ecocrop methodology for the Tolima region (figure 17) are moderate: the northern regions seem to be affected (or even strongly affected), while the areas close to the mountains would logically have more favorable conditions for rice cultivation over time. Indeed, the model predicts 52% of areas whose suitability would decrease (20% would decrease from -25 to -50%), and 42% whose suitability would increase. One could therefore imagine that a decrease in yields due to poor climatic parameters in some areas could be offset by an increase in yields in areas where climatic conditions have become optimal. However, CIAT research (Castro, 2018), which has developed a similar methodology for predicting climate suitability and niche based models, integrating environmental variables, real location of crops and maximum entropy for irrigated rice cultivation, has shown that climate change in Colombia could reduce the area that is suitable for rice production by 60%, from 4.4 to 1.8 million hectares, and that the most vulnerable areas would include the upper Magdalena River Valley in the departments of Huila and Tolima.

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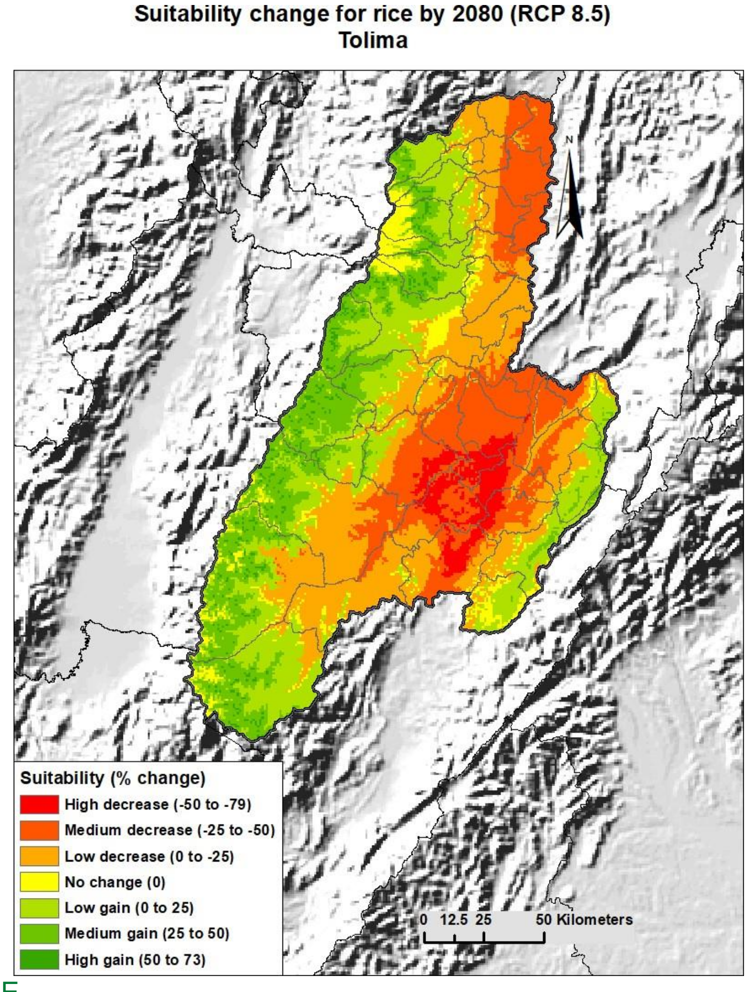

FIGURE 17 : SUITABILITY CHANGE (%) BY 2080, RCP 8.5, FOR RICE IN THE TOLIMA REGION. ANDRES JINES AND AUTHOR

Rice is very important for Colombia's rural economy in general. If the central regions (like Tolima) produce a large amount of irrigated rice, the Northwestern part of the country (Los Llanos), is the major producer of rice (45,3% of cultivated lands according to Andrade et al, 2017, see figure 18). On a national scale, the eastern part of the country will experience a high decrease in sustainability to climate change, only the regions located in the mountains will high their suitability increased. At the national level (figure 19), rice production is predicted to be strongly impacted impacted in a business-as-usual scenario : the model predicts that 25% of the territory will have a decrease in suitability between -1 and -25%, and 45% between -25 and -45%. Only 24% of the territory in the model will have no change or an increased in the suitability.

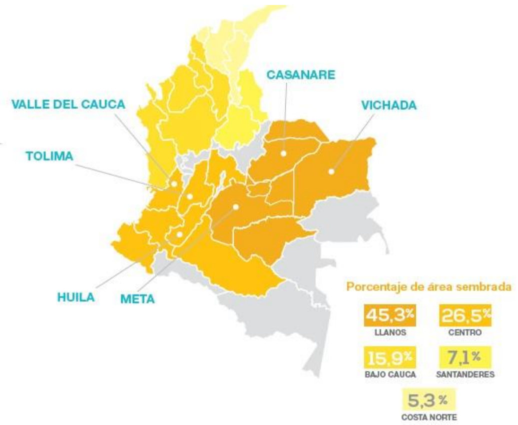

FIGURE 18 : RICE CULTIVATED AREAS IN COLOMBIA. ANDRADE ET AL. (CIAT)

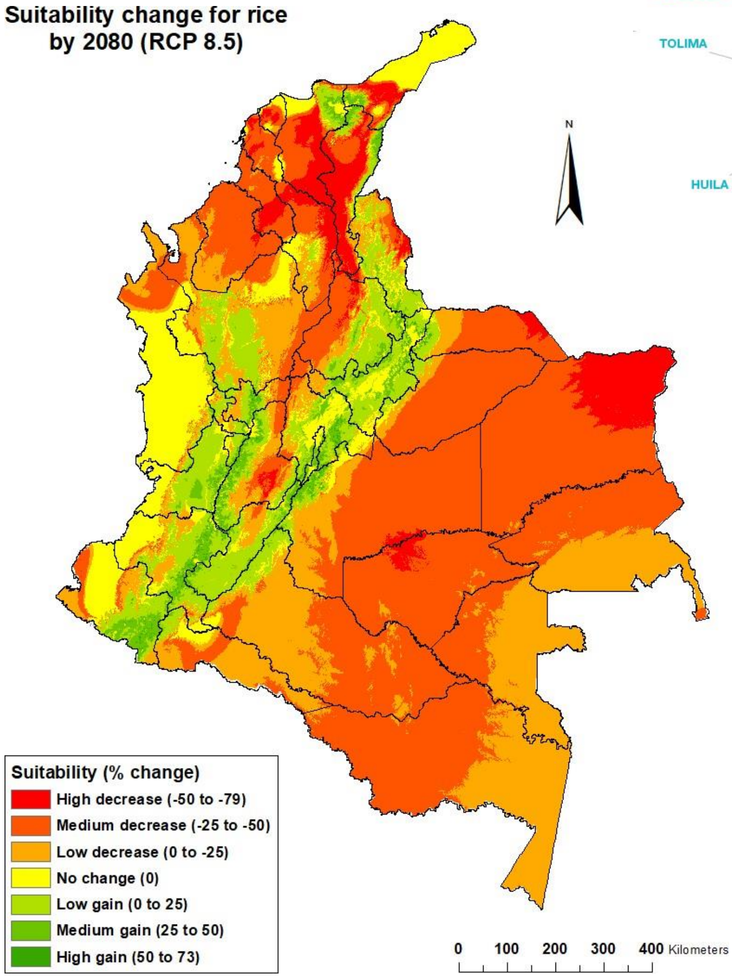

FIGURE 19 : SUITABILITY CHANGE (%) BY 2080, RCP 8.5, FOR RICE IN COLOMBIA ANDRES JINES AND AUTHOR

4 Analysis and discussion

4.1 The burden and vulnerability of the *caleño* plate

The carbon footprint of the caleño plate has been calculated (figure 20), as well as the changes of climate suitability of crops in the future predicted. Thus, is the caleño plate self-destructing?

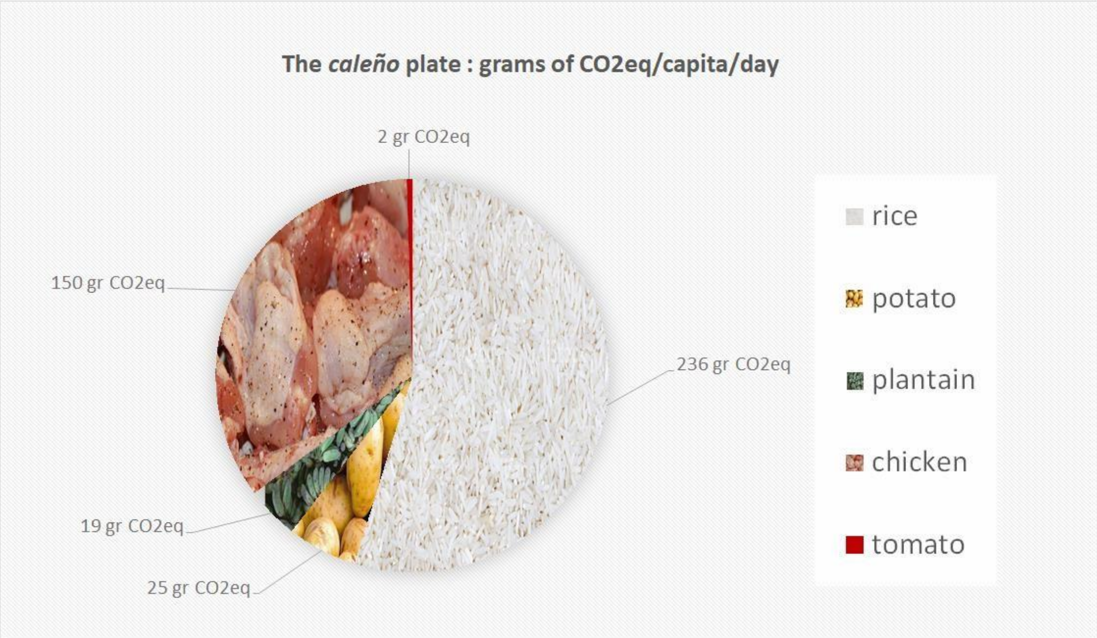

FIGURE 20 : EMISSIONS (GRAMS CO2EQ) OF THE *CALEÑO* PLATE. AUTHOR.

By multiplying CO2eq emission factors by quantities of product consumed per capita per day, the caleño plate is found to produce 431,5 grams of CO2eq (rf figure 20). It is difficult to appreciate the level of importance of carbon emissions without having a base of comparison. Indeed, all human activity has a footprint, should we know when it could be considered as "critical". The majority of diets' carbon footprints compare vegetarian diets to omnivorous diets to show the environmental burden of red meat (Veeramani, Dias, et Kirkpatrick, 2017 ; Hendrie *et al.*, 2014) which, beyond having a high carbon footprint, requires large quantities of available water and lands, thus contributes to the eutrophication and acidification of our ecosystems (de Vries et de Boer, 2010 ; Pimentel et Pimentel, 2003) whose global consumption is constantly increasing. The case of this study is a little particular as it does not include a portion of red meat, and chicken meat contributes to a lesser extent to the deterioration of the planet. Generally speaking, the *caleño* plate seems to have a lower carbon footprint than other “meals”: a meal with a meat portion in India would produce 1110 grams CO2eq (meal composed in accordance with nutritional recommendations for a man) (Pathak *et al.*, 2010), a meal with a portion of chicken in France would produce 1350 grams Co2eq and 505 grams of CO2eq for a vegetarian meal (Agribalyse®). However, these comparisons must be treated with the greatest care, as the techniques for calculating the carbon footprint, or even the methodologies for constructing the typical "meal", are all different. There is no harmonization in the methodologies that can actually allow the constructed meals to be compared between different countries. Rice is the first “burden” in the caleño plate, a result that goes against the common assumption of environmental burden of meat, hence the importance of integrating quantities of consumption in a carbon footprint. Rice is highly consumed in Colombia, several times a day, and the country will be forced to import even more rice in the future according to the climate change predictions.

Is the *caleño* plate bound to disappear? Results from the sustainability predictions are contrasted. If some parts of the territory will experience a loss of optimal conditions to produce food, other territories will become optimal for cultivation. Out of the four products, tomato and potato are most vulnerable crops in their production regions. Although when looking at the national level (cf appendices 5, 6 and 7 for maps at the country level), rice is the crop who will experience the greatest loss of sustainability in the entire country. However, crop sustainability and the opening of new markets also depend on the land topography, easy access to fields for machines and transport routes to be able to distribute products to cities. Climate change causes increasingly strong climatic events such as heavy droughts and landslides during rainy seasons. Landslides and blocked routes are recurring events in Colombia, whose repetition is increasing, thus it could be interesting to take into account logistics when assessing the sustainability of a food system in an exercise to prevent future changes in a country due to climate change.

When analyzing results from both methodologies, we can say that the rice sector should be on the urge to find strategies to change practices in order to avoid a future important loss of cultivated areas and yields. Chicken is the second biggest burden of the plate, and contributes to a larger extend to future loss of suitability for crops like tomato. Potato and plantain, in the Colombian context, contribute to a lesser extend to global warming, however production will be strongly impacted by climate change for the potato sector. Climate change will define the future geographies of food production, as some areas will not be optimal for crops. However, when defining the way we are producing food, carbon emissions and global warming is not of interest. It should be the case, as having restrictive policies or rules for food production today could avoid having severe restrictions due to climate change tomorrow.

4.2 WHAT LEVERAGES FOR CHANGE?

Changing diets

Nutritional recommendations are turning towards dietary patterns that are good for our health but also sustainable for the environment. International institutions such as the Eat Lancet Commission of Food, Planet and Health has launched the “planetary health diet” (Willett *et al.*, 2019), an environmental friendly diet recommendations where a smaller meat portion is considered, or even replaced by plant-based proteins and more vegetables. Although, it has been proven that the environmental positive effects of little reductions of the meat portion in Europe is cancelled out by a higher intake of cereal, vegetables and fish, thus do not result in overall benefits (Tukker *et al.*, 2011). For Cali, the challenge may be precisely not to change the typical plate and avoid the nutritional transition towards processed foods or/and a higher intake of meat. Indeed, for Cali the meat portion is small compared to other countries, although could be easily replaced by vegetable proteins such as lentils to decrease carbon emissions. Lentils or beans are typical foods in Colombia, legumes naturally provide nitrogen to soils, and cultivated in rotation with other crops, can reduce the use of synthetic nitrogen fertilizers. However, lentils production in Colombia has dropped sharply, due to the arrival on the Colombian market of lentils produced in the United States and Canada, which are much more affordable, and today, Colombia imports most of the lentils consumed in the country. Another recommendation for a healthy and environmentally friendly diet would be to enhance the consumption of a more diversified diet (changing rice for other cereals for example) but also promote native and ancestral foods. Colombia is one of the countries with the highest biodiversity, and is home to a large mosaic of cultures. However, agriculture has become more homogeneous, and so has the plate. The return to a more diversified diet and the reintroduction of traditional foods would reduce the environmental burden of the plate by promoting local production, and support a more diversified rural economy in the process. However, some studies state that even radical changes in food consumption patterns would provoke quite small environmental impact changes (Sáez-Almendros *et al.*, 2013) and changing consumption habits and preferences is complex and the trade-offs between nutrition, sustainability and enabling consumers to make choices according to their preferences will need to be considered.

changing production processes

LCA analysis and prediction of potential impacts of climate change on crops and yields are a good information base for implementing strategies to change agricultural production practices. The variability in carbon footprints for one product shows the potential to reduce GHG emissions related to diets through improvements in the upstream agricultural sectors (Friel *et al.*, 2009). Changing agricultural practices today means ensuring the survival of the industry in the future. The productive sectors must themselves be aware of the quantities of NH4 and N2O emitted and try to change their methods towards an agriculture less dependent on synthetic nitrogen fertilizers, or by combining cultivation, forestry and pasture so that CO2 emissions could be countered through improved carbon sequestration in soil. Such results from the study also should work as incentive to policy makers to try to diversify the agriculture production in Valle del Cauca for example, where a large part of the land was deforested to grow sugar cane, and intensive monoculture depletes the soil. The assessment predicted a sharp drop of suitability for rice fields. This trend could be altered by both using new varieties and management practices adapted to changing environmental conditions or by moving production to regions of the country likely to be more suitable (Castro, 2018). In addition, the results from the carbon footprint assessment go against the current and strong food-systems research holding that local food systems are preferable to systems at larger scale. Many assume that eating local food is more ecologically sustainable and socially just but “local” is not automatically synonymous with environmental sustainability (Purcell, 2006), and real efforts on changing practices should be done.

Eventually, one should admit the difficulty in advocating for changes in diets, or agricultural practices, as long as such importance is given to the economic variable. Indeed, price is what determine the presence of a specific product on our plate, not the environmental or geographical variables. Quick interviews at the Cavasa wholesale market confirmed the dynamic as origin of the products depended on prices of crops. To give more credit to the environmental variable, IPCC suggested “factoring environmental costs into food” (IPCC, 2019), as previous studies also suggested meat taxes, or subsidized fruit and vegetables. LCA analysis of food products therefore calls for an understanding of sustainability that prioritizes the environmental pillar first (see Figure 18), which involves a change in attitudes and ways of thinking about the systems. Doppelt in the Power of sustainable thinking (Doppelt, 2008) says: “global warming and today's other ecological and socioeconomic problems are not technical in nature, rather they represent a crisis of thought.”

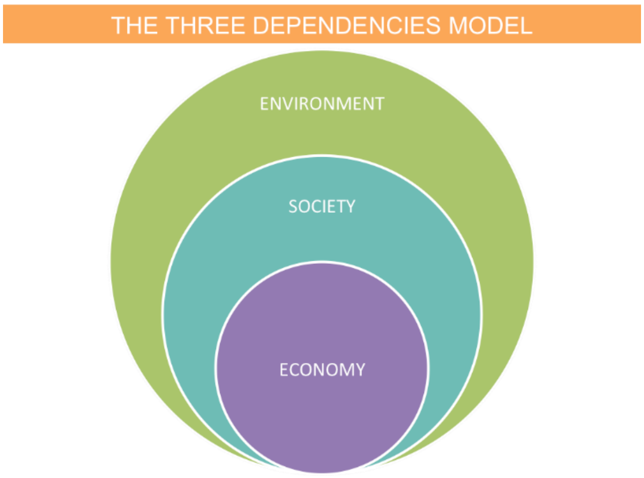

FIGURE 21 : THE 3 NESTED DEPENDENCIES MODEL. AUTHOR, BASED ON BOB DOPPELT, 2009.

4.3 Critical review of the methodology

4.3.1 Lack of data and approximates

First, there were a lack of robust data for the identification of the most consumed products in Cali as the study was based on one statistical study and five academic studies. DANE produces a good amount of statistical data, but it is not analyzed by the institutions and takes time to be released (the results of the ENSIN 2015 have still not been published). In addition, ENSIN studies provide information on the frequency of consumption of certain products or groups of products (as in the case of ENSIN 2010), or the frequency of purchase and quantity purchased (as in the case of the ENIG study) Therefore it is difficult to establish food patterns easily and many assumptions have to be made. Second, the choice to focus on five products only can skew the composition of the typical plate, and it should have been better to include more products into the assessment to be closer to reality. In addition, excluding imported products from abroad also distorts the composition of the plate. A real study on the food consumption of Cali's inhabitants, with a 24-hour reminder of a good sample of the population, would be essential in order to update the information in the literature on Cali's food consumption, and could be a basis for further studies on food environments, or link food consumption to the city's nutritional issues.

The Carbon footprint requires time and resources to access all the necessary information for all activities of the life cycle. For this study, given the time available, average data were used, that calls into question the representativeness and relevance of the results obtained. Concerning agricultural practices, the production costs analysis provided by official actors were quite general. Information on capital goods (such as the plastic bag covering the plantain bunch, a very widespread practice) was not taken into account as it does not appear on the official documents. Similarly, losses, whether during production, harvesting, processing or transport, were not included because there were no data available, whereas percentages of loss could have had a significant impact on the results. Averages were used for certain activities : methane emissions factor of rice fields, economic allocation for rice sub products, one common emissions factor for all pesticides, exclusion of emissions factor for wastewater treatment from poultry transformation. Nonetheless, the methodological exercise in the time given involved building assessments in approximate information, and despite the mentioned limitations above, the results in the present study are in line with the available literature on carbon footprint of food products.

Information on the path of a product from the farm to Cali is also difficult to identify. The travel from fields to city is composed of a multiplicity of traders and intermediaries who extend the supply chain and make it more complicated to have a full transparency on the origin of products. Furthermore, the origin of the products given by DANE is not necessarily the origin of production. By cross-referencing origins of products with data on production areas (Agrimin, Ministry of Agriculture database), results do not necessarily match. A socio- economic study on supply chains from farm to city would be interesting for this purpose. Finally, there is a consensus that a comprehensive understanding of food consumption requires other impact categories to seize the long-term environmental implications of dietary patterns (Heller, Keoleian, et Willett, 2013). Using only GWP provides a limited perspective of the complexity of the environmental implications and trade-offs associated with food production and dietary patterns. It would be worth continuing this work by carrying out a study on water footprint but also on the use of pesticides and their impact on biodiversity, as Colombia is a heavy user of chemicals, and such use of pesticides is a threat to public health and future of our environment.

4.3.2 Lack of real information in the sustainability prediction

The main limitation of the Ecocrop methodology is that it cannot account for animal products, which have a heavy environmental footprint and represents an important part of current diets. In addition, Ecocrop maps are theoretical; they do not take into account the actual geographic locations of crops, natural parks, land use or soil composition. It is therefore advisable to look at these maps as far back as possible. A step forward would be to cross- reference Ecocrop prediction maps with real land use maps, for example. Finally, Ecocrop is based on two climatic parameters (temperature and precipitation), but the conditions under which a crop can be grown also depend on the composition of the soil, slope of the plots which determines the mechanization of practices, among others.

4.3.3 A multitude of ways

Although efforts are made to homogenize the methodologies and standards (British standard PAS 2050, ISO 14040 and 14044, the International Reference Life Cycle Data System (ILCD), Product Category Rules (PCR)), the implementation the standards is also executed in different ways(different system boundaries, different scenarios, different allocations, different inclusions and exclusions, etc.). Differences in methodologies and approaches make the situation for decision makers even more challenging.

4.4 Advantages of the approach

The large amount of detailed information required for a carbon footprint with a Life Cycle Analysis approach is the strength of such a methodology but it is also its limitation like it was aforementioned. Life cycle analysis is a meticulous methodology. It illustrates well the complexity of the food system, which is broken down into a multitude of flows that need to be understood. Identifying and assessing each of indirect and direct emissions allows to capture all of the processes that lie behind the production of our food and identify the hotspots, giving us the possibility to seize the scale of our food systems. The carbon footprint methodology, following the international norms (PAS 2050) is also an advocacy for transparency. By looking in detail at the modes of production, processing, origins, transport, companies and actors involved need to give transparent and real data on how the processes are made, companies or sectors are obliged to give transparent insights on how processes are undertaken. Such call for transparency is also a strong challenge when collecting data for a LCA analysis, as some actors do not tend to communicate on their processes.

Assessing the sustainability of a City's consumption gives a territorial perspective, and bring results closer to reality. Linking carbon footprint and climate resilience in a territorial perspective of a city gives an insight on the city's food supply system, its demand for food, the localization of the production zones, the identification of the supply chains, the actors ect; which is a good starting point to mapping logistics of food in the territory.

Finally, the combination of current environmental footprint (carbon footprint) and vulnerability to future climate change helps to give an idea of "the big picture" (everything that lies behind our daily plate) and introduces a temporal notion that makes it possible to visualize the dangers and to identify the flaws and major weaknesses of our food systems. The Ecocrop methodology is a good way to show what an unsustainable food system means, and calls on food system actors to act to avoid future difficulties when it comes to producing our food. The combined methodology is a gate between today and tomorrow. While a carbon footprint makes it possible to see the environmental impact of a product is, the Ecocrop methodology makes it possible to visualize this impact and to show what this impact could implyin the same food system under study.

4.5 Next steps

The proposed methodology, the questions it raises, and the results it brings, act as a basis for thinking and questioning our systems. Next steps for this research will be to disseminate the results in a didactical way to create more awareness around Cali's food and the intricate relation with the environment (to policy makers and consumers). It would be also interesting to communicate on the methodological process through the construction of a guide that allows other cities, regions, communities to produce similar results and make the combined methodology replicable. Cali is already aware of the threats associated to climate change. However, in its Integral Plan to Adaptation and Mitigation to Climate Change (CVC, 2016), activities related to sustainable food production are very poor.[3] Efforts to producing more knowledge about Cali's food system, integrating automatically the environmental dimension should be continued. For example, the methodology with other environmental impacts (water contamination, biodiversity loss) to underline the critical issue related to the heavy use of pesticides in Colombian agriculture. This study also underlined some gaps that could be

[3] the strategical axis on "agro ecological systems adapted to climate" contains only two proposals, first of which is to promote sustainable food production systems with the training to agro-ecology and follow-up of producers in the rural zone of Cali, whose indicators for this activity only concern numbers of training sessions carried out. The second activity is related to the promotion and support of urban agriculture, a totally inadequate response to the

city’s food security situation.

subjects to further studies : a socio-economic study on supply chains from farm to city, a study of how food offer is constructed in the city (food environments), a review of mitigation to climate change policies at the municipal, regional and national level and a analysis at the organisation of the institutions to question the ability for institutions to tackle such and intersectionnal subject that is the sustainability of our food systems.

Conclusion

The methodology has allowed us to show the impact of the consumption of our food on the production of our food, in a given territorial area. It provides valuable information to actors from the sectors and policy makers: where the productive regions are (areas a city depends on for its food), the activities that emit most GHG and therefore where efforts from the sectors should be focused on, the areas most vulnerable to climate change and therefore the impacts in terms of food supply for the city, the areas that could open up to food production, food consumption dynamics that show the food demand that must be fulfilled. We looked at the environmental impacts of consumption of food, and also look at the production side and implications of climate change on productivity. This methodological proposal is another contribution to the production of knowledge on our food systems whose objective is to help cities and communities to shift towards more sustainability. Cities have the power to set up projects that aim to make food systems more sustainable (the intersectional project of Belo Horizonte, the ban on trans fats in New York, the current wave of pesticides bans from French cities, among many others). As stated in the introduction, food systems are key in the fight against climate change: they are the problem and the solution and policy-makers need to start looking at it. Few efforts are being done, because the issue is cross-cutting and difficult to deal with by institutions that are built on separate departments and are compartmentalized. It is essential that food systems can constantly have an idea of their impacts, and at the same time, a visibility on what might be changed by climate. This type of proposal such as the one we presented rely on a large amount of information thus only can be replicable if the data is available. The methodology needs to be improved, however the scope given by the combination of two existing methodologies can be a strong tool to analysis the threats and opportunities of a food system.

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APPENDICE 1 : LITERATURE REVIEW ON FOOD CONSUMPTION IN CALI. AUTHOR

Survey	National Survey of the Nutritional Situation, ENSIN 2010 - DANE	Dufour, 2015. *Evolución del régimen alimentario de las mujeres de barrios pobres entre 1990-1995 y 2008*	Municipality of Cali, 2009. *Exploratorio de percepcion de seguridad alimentaria en el municipio de Santago de Cali*	Health Ministry of Colombia and FAO, 2010. *Perfil nacional de consumo de frutas y verduras*	Arciniegas, L,.Peña, J . 2017. *La transición alimentaria y nutricional en el modelo alimentario de los hogares caleños (Cali - Colombia).*
Panel	Cali. 536 households surveyed.	Cali. 88 women from poor neighborhoods surveyed.	Cali. 968 households surveyed.	Results for Valle del Cauca region from the national ENSIN 2010 survey	45 inhabitants of Cali
Date	2010	2008	2009	2010	2017
Unit	Products consumed at the highest frequency	Frequency of items consumed per women per day in 2008	Percentage of consumption	Percentage of people consuming the item	Results from qualitative interviews
Per foodgroup	1. **rice** or pasta 94,4 2. bread or arepa 83,9 3.**Roots and plantains** 60,8 4. Milk 40,7 5. Eggs 23,7	1. **rice** 1,92 2. fresh fruit juice 1,08 3. bread wheat 1 4. coffee 0,99 5. **roots, tubers, plantains** 0,73 6. legumes 0,52			-Arroz -verduras - pollo -papa -platano
Cereals, roots and plantains			1. **rice** 96% 2. **potato** 91% 3. **plantain** 87% 4. pasta 78% 5. bread 50%		
Fruits			1. lulo 78% 2. Banana 78% 3. mango 73% 4. orange 70%	1. lemon 21% 2. tomate de árbol 19 % 3. banana 16 % 4. pineapple 14 %	
Vegetables			1. **Tomato** 94% 2. onion 80% 3. Scallion 80%	1. **tomato** 64% 2. carrot 48 % 3. onion 47 % 4. scallion 31 % 5. cabbage 19 %	
Proteins			1. **chicken** 92% 2. Beef meat 87% 3.eggs 86% 4. Legumes 85%		

APPENDICE 2 : LOCATION AND MEAN DISTANCES BETWEEN INPUTS PRODUCTION (PESTICIDES AND FERTILIZERS) AND FARMS. AUTHOR.

PRODUCT	FIRM	ORIGIN	TOMATO AND PLANTAIN		POTATO		RICE	
			km - Cali	Mean	km- Pasto	Mean	Km - Ibague	Mean
Fertilizers	Monomeros	Baranquilla	1255	450	1635	817	1000	500
	Colinagro	Puerto Tejada	35		360		285	
	Yara	yocoto (valle del cauca)	60		455		211	
			km - Cali	Mean	Km- Pasto	Mean	Km - Ibague	promedio
Pesticides	Dow	Baranquilla	1255	982	1635	1362	1000	726
	Bayer	Soledad (Barranquilla)	1255		1635		1000	
	Adama	Soacha	437		817		177	
	Distance farm-city		tomate	platano	80		60	
			97	140				

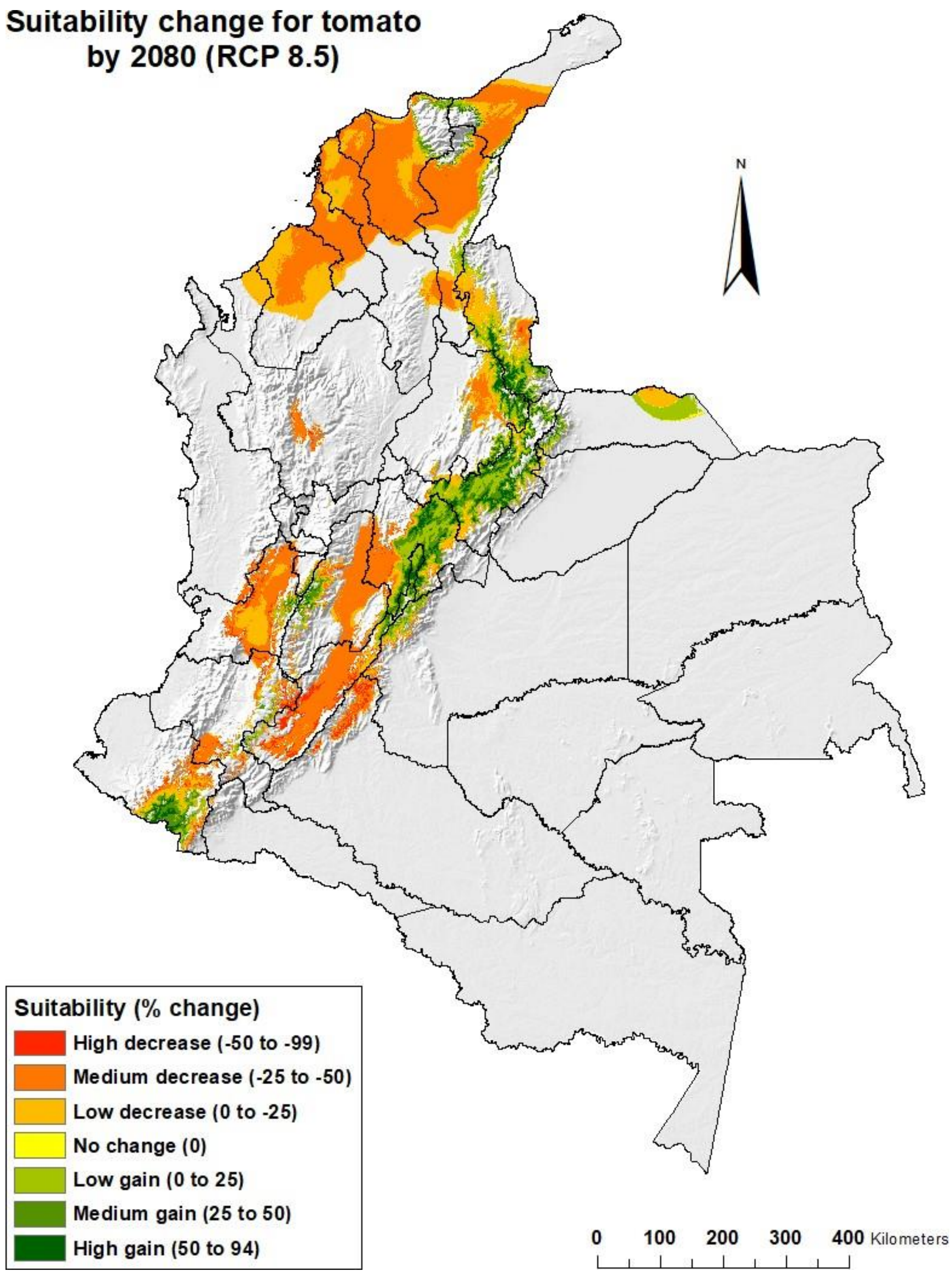
APPENDICE 3 : CLIMATIC PARAMETERS OF CROPS. AUTHOR.

		Potato	Tomato	Plantain	Rice
Scientific name		***Solanum tuberosum***	***Lycopersicon esculentum***	***Musa acuminata x balbisina***	***Oryza sativa***
Temperature requirements (Celcius)	Absolute Min	10	10	18	10
	Optimal min	12	16	23	22
	Optimal max	18	22	28	28
	Absolute Max	25	30	38	35
Rainfall (annual, mm)	Absolute Min	600	600	1000	1000
	Optimal min	800	1000	1200	1500
	Optimal max	1000	1300	3000	2000
	Absolute Max	2800	1800	4000	4000

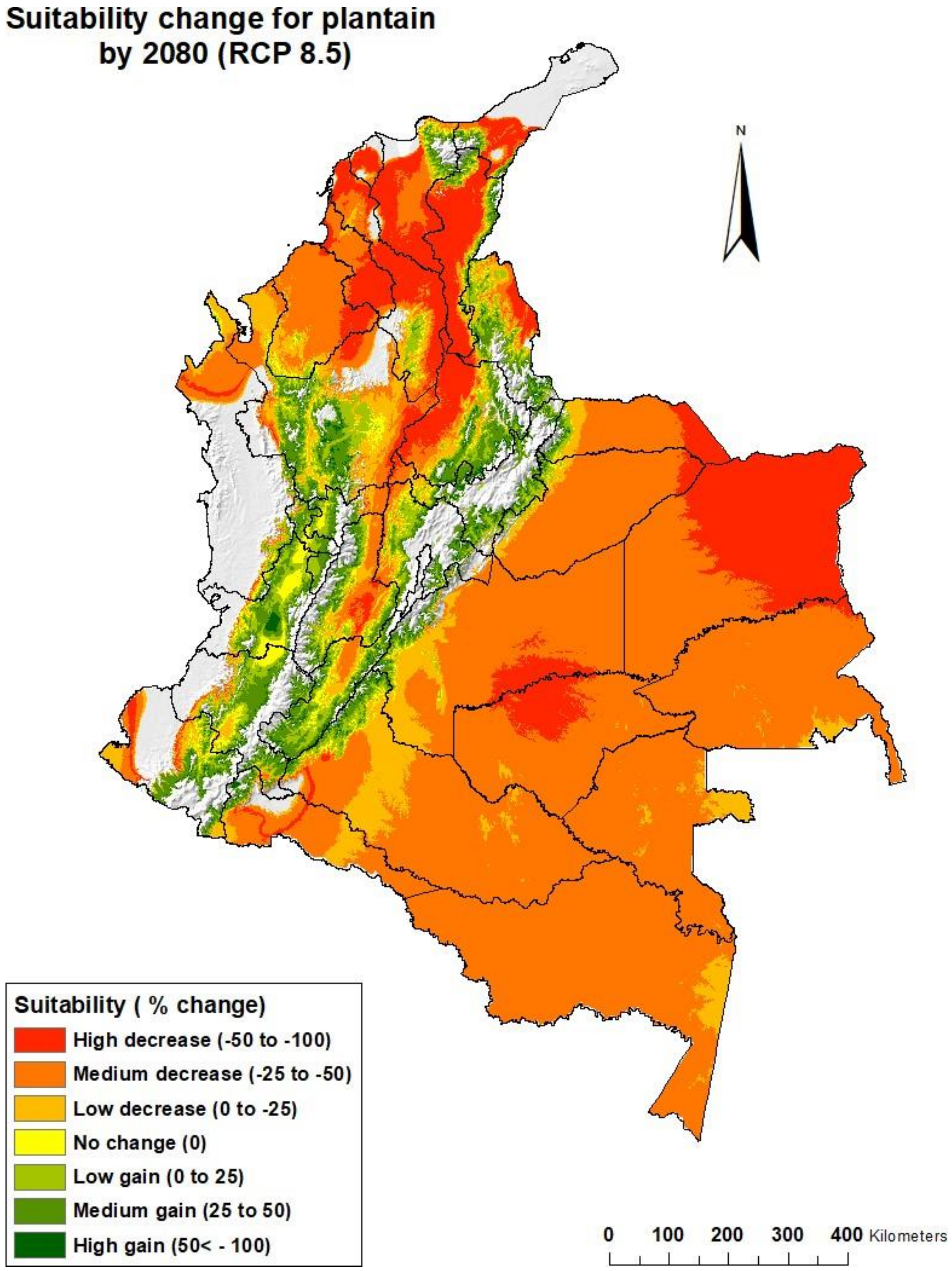
APPENDICE 4 : QUANTITATIVE RESULTS OF THE ECOCROP MODEL. AUTHOR.

Percentage of suitability change	-100 - -50	-50< - - 25	-25< - -1	0	0< - 25	25< - 50	50< - 100	Total
Platano - VALLE								
Hectareas	6044	21497	32640	319256	477672	468281	70039	1395430
Percentage	0,4	1,5	2,3	22,9	34,2	33,6	5,0	100,0
Tomate - VALLE								
Hectareas	60293	627835	345586	1025	38736	25586	5039	1104100
Percentage	5,46	56,86	31,30	0,09	3,51	2,32	0,46	100,00
Arroz - TOLIMA								
Hectareas	99613	495700	652452	159267	581325	383625	41956	2413937
Percentage	4,1	20,5	27,0	6,6	24,1	15,9	1,7	100,0
Papa - NARIÑO								
Hectareas	34612	453534	532288	5127	110358	88273	141976	1366168
Percentage	2,53	33,20	38,96	0,38	8,08	6,46	10,39	100,00

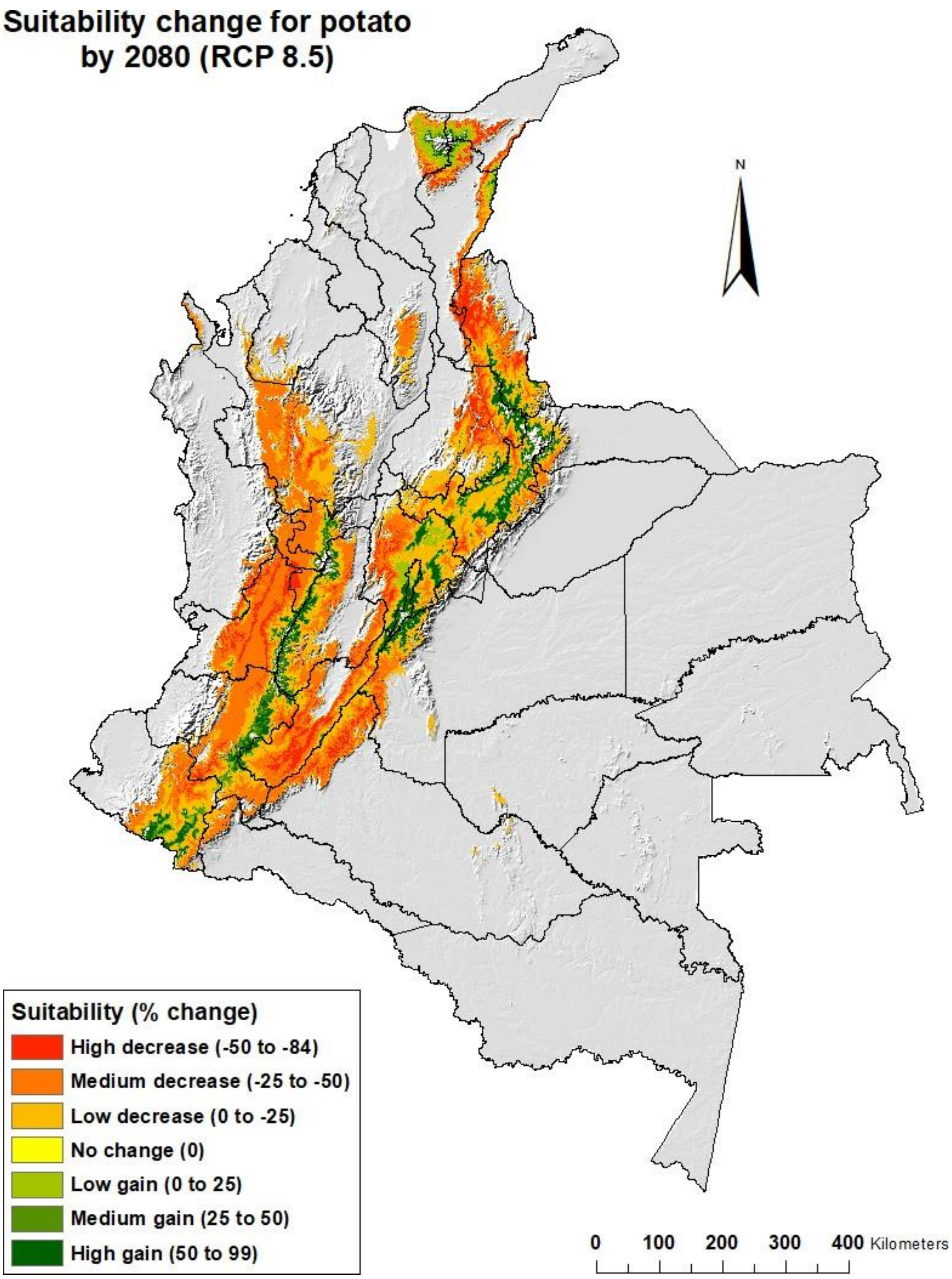
APPENDICE 5 : SUITABILITY CHANGE (%) BY 2080, RCP 8.5, FOR TOMATO IN COLOMBIA ANDRES JINES AND AUTHOR



APPENDICE 6 : SUITABILITY CHANGE (%) BY 2080, RCP 8.5, FOR PLANTAIN IN COLOMBIA
ANDRES JINES AND AUTHOR



APPENDICE 7 : SUITABILITY CHANGE (%) BY 2080, RCP 8.5, FOR POTATO IN COLOMBIA ANDRES JINES AND AUTHOR



Résumé

Les villes s'étendent, et avec elles augmentent leurs impacts environnementaux, par l' approvisionnement de la population urbaine en nourriture, en eau et en énergie. Le changement climatique menace également nos systèmes alimentaires : la production même, et la capacité des personnes a s'alimenter. Dans ce contexte, cette étude vise à développer une approche méthodologique pour mieux évaluer et utiliser l'information sur la durabilité environnementale d'un système alimentaire. La proposition consiste à évaluer l'empreinte carbone à l'aide d'une méthodologie d'analyse du cycle de vie (ACV) et à la compléter par la méthodologie Ecocrop qui permet de prédire les changements en terme « d'adéquation climatique» de cultures spécifiques dans l'espace et dans le temps, dans le but d' évaluer à la fois les impacts du régime alimentaire d'une ville sur l'environnement, ainsi que les impacts potentiels du changement climatique sur ce régime. L'étude de cas porte sur la ville de Cali, département de Valle del Cauca, Colombie, et se concentre sur les cinq produits alimentaires les plus consommés (par jour) à Cali, déterminés comme le "caleño typical plate". Les résultats ont montré que « le plat caleño » émet 431,5 grammes d'équivalent CO2. La portion de viande (volaille) a l'empreinte carbone la plus élevée par kg (2,04 kg CO2eq/kg), suivie du riz (1,46 kg CO2eq/kg), du plantain (0,28 04 kg CO2eq/kg), de la pomme de terre (0,23 04 kg CO2eq/kg) et de la tomate (0,09 04 kg CO2eq/kg). Le modèle Ecocrop a montré que le changement climatique pourrait ouvrir de nouvelles zones de culture pour le plantain (68% de la région sera plus apte à sa culture), alors que la pomme de terre et surtout le riz auront moins de zones adaptées à leur culture régions (perte de 60% de zones cultivables pour le riz au niveau national). Cette méthodologie permet de lier d'un côté la consommation et ses impacts sur l'environnement, ainsi que la production, qui sera elle-même impactée. Cette proposition peut être un outil important pour les décideurs, en particulier pour notre étude de cas à Cali, où une bonne partie des produits est produite dans la Valle del Cauca ou en Colombie.

Mots clés : Analyse du cycle de vie, Systèmes alimentaires, changement climatique, méthodologie d'évaluation, régimes alimentaires durable

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