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UNIVERSIDAD AUTÓNOMA DE SAN LUIS POTOSÍ

FACULTADES DE CIENCIAS QUÍMICAS, INGENIERÍA, MEDICINA
Y CIENCIAS SOCIALES Y HUMANIDADES

PROGRAMA MULTIDISCIPLINARIO DE POSGRADO EN CIENCIAS AMBIENTALES

AND

TH KÖLN - UNIVERSITY OF APPLIED SCIENCES

FACULTY SPATIAL DEVELOPMENT AND INFRASTRUCTURE SYSTEMS

INSTITUTE FOR TECHNOLOGY AND RESOURCES MANAGEMENT IN THE TROPICS AND SUBTROPICS

ANALYSIS OF POTENTIAL REDUCTION OF ATMOSPHERIC EMISSIONS FROM HARVESTING PROCESS IN SUGARCANE FIELDS IN TAMASOPO - MEXICO AND CAMPOS DOS GOYTACAZES - BRAZIL

THESIS TO OBTAIN THE DEGREE OF
MAESTRÍA EN CIENCIAS AMBIENTALES
DEGREE AWARDED BY UNIVERSIDAD AUTÓNOMA DE SAN LUIS POTOSÍ
AND
MASTER OF SCIENCE
NATURAL RESOURCES MANAGEMENT AND DEVELOPMENT
DEGREE AWARDED BY TH KÖLN – UNIVERSITY OF APPLIED SCIENCES

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COLOGNE, GERMANY AUGUST 12, 2021

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PROYECTO FINANCIADO POR:
TRANSFORMATION OF BRAZILIAN ORGANIC RESIDUE MASSES INTO RECYCLABLE MATERIALS AND ENERGY SOURCES (TRABBIO)

DEUTSCHER AKADEMISCHER AUSTAUSCH DIENST (DAAD)

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FACULTY SPATIAL DEVELOPMENT AND INFRASTRUCTURE SYSTEMS

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CON EL APOYO DE:
DEUTSCHER AKADEMISCHER AUSTAUSCH DIENST (DAAD)

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RESUMEN

El aumento de las emisiones de gases de efecto invernadero, principalmente debido a la quema de combustibles fósiles y al cambio de uso del suelo, ha producido variaciones en el clima a nivel mundial. La agricultura es uno de los sectores económicos más vulnerables frente a los impactos generados por el cambio climático. Es por ello que actualmente, el reto de la humanidad es desarrollar soluciones innovadoras para afrontar la complejidad de la sostenibilidad agrícola.

Por otro lado, la caña de azúcar es uno de los cultivos que más contaminantes emite a la atmósfera, principalmente generados por la quema de la caña de azúcar antes y después de la cosecha. Gran parte de estos contaminantes atmosféricos son precursores del cambio climático, y, también, repercuten en la salud y calidad de vida de las comunidades. Asimismo, esta práctica agrícola provoca el paulatino deterioro del suelo, afectando directamente a la producción de caña de azúcar. Consecuentemente, varios países productores de caña de azúcar han establecido normas o disposiciones para eliminar esta práctica agrícola, y, una opción para eliminarla es la mecanización de la cosecha. Sin embargo, su implementación puede generar impactos sociales, ambientales y económicos que deben ser analizados sistémicamente para evitar potenciales fracasos durante el proceso de transición tecnológica. Es por esta razón que esta investigación, a través del método MICMAC, se centró en identificar las variables asociadas a la reducción de la quema de caña en Campos dos Goytacazes (Brasil) y Tamasopo (México) para, posteriormente, analizar su interrelación directa e indirecta, y, así, determinar las oportunidades y limitaciones en cada localidad para la reducción de la quema de caña de azúcar.

A través de este análisis se evidenció que a pesar de que la transición tecnológica es un paso inminente para la sustentabilidad del cultivo de caña de azúcar, ciertos factores como la legislación, la innovación tecnológica y la percepción de los actores involucrados frente a las consecuencias de la quema de la caña de azúcar, es lo que define en los sitios de estudio la velocidad y el posterior éxito de este proceso de cambio hacia una cosecha en verde.

Palabras clave: Caña de azúcar, cosecha, quema, emisiones atmosféricas, variables.

ABSTRACT

The increase in greenhouse gas emissions, mainly due to the burning of fossil fuels and land use change, has led to changes in the global climate. Agriculture is one of the economic sectors most vulnerable to the impacts generated by climate change. For this reason, the challenge facing humanity today is to develop innovative solutions to address the complexity of agricultural sustainability.

On the other hand, sugarcane is one of the crops that emits the most pollutants into the atmosphere, mainly due to the burning of sugarcane before and after harvesting. Most of these atmospheric pollutants are precursors of climate change and have an impact on the health and quality of life of communities. Moreover, this agricultural practice causes the gradual deterioration of the soil, directly affecting sugarcane production. Consequently, several sugarcane-producing countries have established regulations or dispositions to eliminate this agricultural practice, and one option to eliminate it is the mechanization of harvesting. However, its implementation implies social, environmental, and economic impacts that must be analyzed systemically to avoid potential failures during the technological transition process. It is for this reason that this research, through the MICMAC method, focused on identifying the variables associated with the reduction of sugarcane burning in Campos dos Goytacazes and Tamasopo, to subsequently analyze their direct and indirect interrelationship, and, thus, determine the opportunities and limitations of each locality for the reduction of sugarcane burning.

Through this analysis, it became evident that although the technological transition is an imminent step for the sustainability of sugarcane cultivation, certain factors such as legislation, technological innovation, and the perception of the stakeholders regarding the consequences of sugarcane burning, is what defines in the study sites the speed and subsequent success of this process of change towards green harvesting.

Key words: Sugarcane, harvest, burning, atmospheric emissions, variables.

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Abbreviation and Acronyms

AFOLU	Agriculture, forestry, and other land use
Al	Aluminum
ASFLUCAN	Fluminense Association of Sugarcane Producers
ATACA	Congreso de la Asociación de Técnicos Azucareros de Centroamérica
ATACORI	Asociación de Técnicos Azucareros de Costa Rica
CCA	Comisión para la Cooperación Ambiental
CH_4	Methane
CNC	National Peasant Confederation
CNPR	National Confederation of Rural Landowners
CO	Carbon monoxide
CO_2	Carbon dioxide
CO_2eq	Carbon dioxide equivalent
COAGRO	Rio de Janeiro State Agroindustrial Cooperative Ltda.
CONADESUCA	National Committee for Sustainable Sugarcane Development (Mexico)
EMBRAPA	Brazilian Agricultural Research Company
FAO	Food and agriculture organization of the United Nations
GDP	Gross domestic product
GHG	Greenhouse gases
ha	Hectare
HFCS	high fructose corn syrup
IBGE	Brazilian Institute of Geography and Statistics
IMSS	Mexican Social Security Institute
INEGI	National Institute of Statistics and Geography (Mexico)
K	Potassium
MAGERIT	Metodología de Análisis y Gestión de Riesgos de los Sisitemas de Información
masl	Meters above sea level
Mg	Megagram
Mn	Manganese
N_2O	Nitrous oxide
NAFTA	North American Free Trade Agreement
NH_3	Ammonia
NO_x	Nitrogen oxides
O_3	Ozone
OCDE	Organization for Economic Cooperation and Development
OMM	World Meteorological Organization
PAH	Polycyclic aromatic hydrocarbons
PM	Particulate matter
PNUMA	United Nations Environment Programme
PROALCOOL	Brazilian National Bioethanol Program
RF	Radiative forcing
S	Sulfur

SAGARPA	Mexican Ministry of Agriculture and Rural Development
SDG	Sustainable Development Goals
Si	Silica
SO_2	Sulfur dioxide
TRABBIO	Transformation of Brazilian Organic Residue Masses into Recyclable Materials and Energy Sources
UNFCCC	United Nations Framework Convention on Climate Change
VOC	Volatile organic compounds

1 Chapter I: Introduction

1.1 Research Background

Sugar, from sugarcane, is one of the worldwide most consumed agroindustry products and approximately 65% of its production is located in six countries: Brazil, India, China, Thailand, Pakistan, and Mexico (Arcudia *et al.*, 2018). It was introduced to America with the conquest, due to the favorable climatic and edaphological conditions. From this moment, it has been expanded widely throughout the continent, shaping its history and economy (Aguilar-Rivera, 2010).

An important phase of sugar cane production is harvest, in which crop burning is an agronomic practice widely used around the world (Rojas, 2012; CCA, 2014). It allows the removal of leaves, facilitates cutting, increases sucrose concentration, scares poisonous animals, and facilitates the industrial processing of the stems (Valadares, 2007; Cunha *et al.*, 2015). Furthermore, the predominance of an extensive agricultural model based on a predatory and economic use of natural resources incited the use of this practice (Aguilar, 2010; Ramos & Alves, 2006). Thus, until today most sugar cane producers consider burning as a vital and irreplaceable agricultural practice for an efficient and profitable harvest (Rojas, 2012).

On the other hand, burning in sugarcane harvest generates the emission of particulate matter, black carbon, greenhouse gases, ozone depletion gases, and other toxic gases (Mugica, 2012; CCA, 2014). Atmospheric emissions produced by burning sugarcane fields pollute the atmosphere, contribute to climate change, and also generate health problems for workers and nearby communities (Valadares, 2007). For instance, they can have highly toxic and carcinogenic compounds due to incomplete combustion and the presence of pesticides (CCA, 2014). Besides atmospheric emissions, the use of this practice in the sugarcane fields causes the alteration of soil properties, such as loss of nitrogen and organic material, and the reduction of microorganism's population (Rojas, 2012).

As a result, Mexico and Brazil have implemented laws for the gradual reduction of pre and post burning of sugarcane (Aguilar, Olvera and Galindo, 2013; dos Santos and de Matos, 2017). Mechanization is one technological innovation used to comply with government regulations. Moreover, it has additional advantages such as production increase, fertilizer reduction, and labor cost reduction (Ronquim, 2010; Cunha *et al.*, 2015). Despite the legal requirements and all the benefits, harvest mechanization implies some restrictions such as high investment, unemployment, lack of operational capacity, and topography (Rigo, 2012).

1.2 Problem statement

The increase in GHG emissions, mainly due to the burning of fossil fuels and the change in land use, has already produced variations in the global climate. Agriculture is one of the economic sectors that could face the greatest impacts (Mendelsohn, 2008). Thus, the challenge of agriculture is to develop innovative solutions to face sustainable complexity (Fischer, Shah and van Velthuizen, 2002).

For instance, sugar cane is one of the crops that emitted most GHG emissions worldwide (FAO, 2021), mainly because of preharvest burning (Ribeiro and Pesquero, 2010).

Agriculture is a complex system, thus, the change of burning as an agricultural practice involved many actors, interests, and objectives that should be understood to prevent long-term failures (Barati *et al.*, 2019). Sugar cane production represents the main agricultural activity in Tamasopo, Mexico, and Campos dos Goytacazes, Brazil. Their productivity is low and on average is below 50 tons per hectare (Aguilar-Rivera, 2011; Cunha *et al.*, 2015). However, it generates a big quantity of direct and indirect jobs (Ronquim, 2010; Aguilar, Olvera and Galindo, 2013). This low productivity is a barrier to the investment and implementation of sustainable practices such as green harvesting technologies (Magalhães, 2007; Aguilar, Olvera and Galindo, 2013). Therefore, a qualitative structural analysis of burning at harvest is proposed, to analyze the role of the variables and their interrelationships, and thus, create strategies for the sustainability of this practice.

1.3 Objectives

1.3.1 Main objective

- To analyze the potential reduction of atmospheric emissions from the harvesting process in sugarcane fields in Tamasopo - Mexico and Campos dos Goytacazes – Brazil.

1.3.2 Specific Objectives

- To define the current context of harvesting, in relation to emissions reduction, in Tamasopo and Campos dos Goytacazes.

- To identify the economic, political, social, environmental, and technological variables in sugarcane burning from each study area.
- To assess the strategic variables to reduce the atmospheric emissions generated in sugarcane harvest in the study areas.

2 Chapter II: Conceptual Framework

2.1 Climate change

The Earth receives radiation emitted by the sun, a portion of which is reflected back into space, and the other portion is absorbed and distributed internally through atmospheric and oceanic circulations (Martínez and Fernández, 2004). However, any natural or anthropogenic substances and process that alters the Earth's energy balance and cause changes in the global climate are called radiative forcing (RF) (Martínez and Fernández, 2004; IPCC, 2013; Flores, 2016). For instance, greenhouse gases (GHG) such as water vapor, CO2, CH4, N2O, O3 which are presented in the atmosphere play a fundamental role in the Earth's energy balance, as they retain part of the thermal radiation emitted by the Earth's surface (Flores, 2016). This process maintains the Earth's average temperature at 15 °C, favoring the development of life on the planet (Flores, 2016). However, in the last century, climate anomalies have been experienced as a result of the increase in the concentration of these gases (Martínez and Fernández, 2004). Human activities - especially those related to energy production, transport, industrial processes, and agriculture- have significantly influenced Earth´s climate (Chalco Vera, 2018). Moreover, even if GHG emissions stabilize, the warming effects will persist for a long time, as they tend to persist in the atmosphere for many years (IPCC, 2013). See Figure 1.

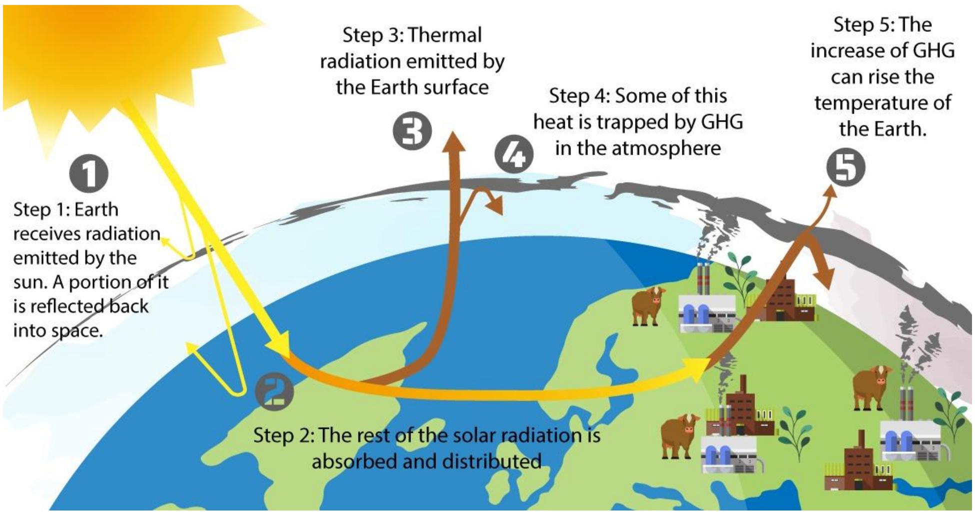


Figure 1. Greenhouse effect
Own elaboration
Source:(Martínez and Fernández, 2004; IPCC, 2013; Flores, 2016)

Thus, the United Nations Framework Convention on Climate Change (UNFCCC) defines climate change as a consequence produced directly or indirectly by human activity that alters the composition of Earth's atmosphere and that differs from natural climate variability observed during comparable time periods (IPCC, 2007). Since the pre-industrial period, the atmospheric concentrations have increased to unprecedented levels (IPCC, 2013), causing the increase of about 1 °C in the Earth's temperature (FAO, 2019), as shown in Figure 2.

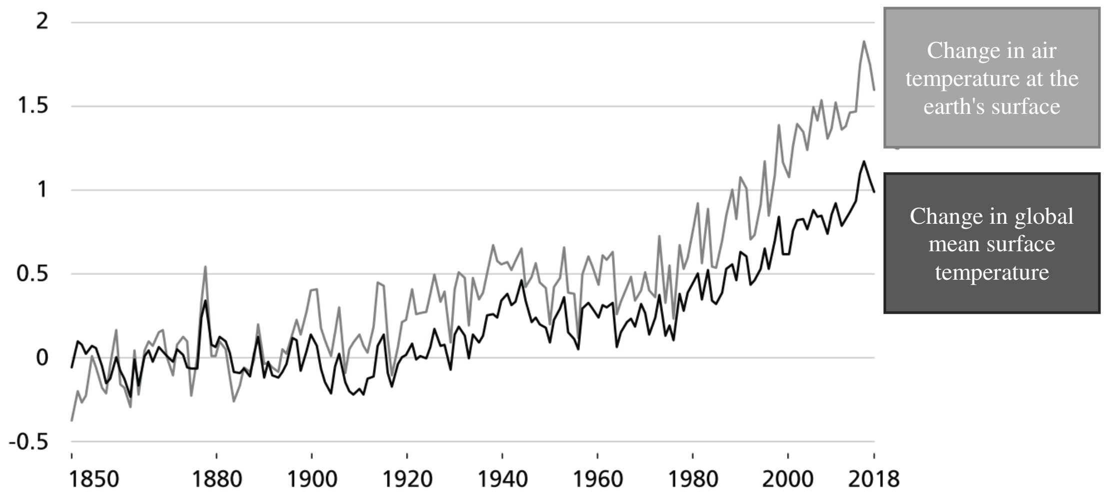


Figure 2. Change in terrestrial temperature (ºC) from 1850 to 1900
Source: (IPCC, 2019)

This is mainly attributed to GHG emissions resulting from the burning of fossil fuels such as coal and oil, deforestation and land use change (IPCC, 2013; de los Angeles, 2016). These emissions have generated additional stresses on the planet, as they have produced variations in the frequency and intensity of climatic phenomena, negatively affecting human beings, and ecosystems (IPCC, 2019). Some of these impacts may be long-lasting or irreversible (FAO, 2019). For instance, climate change has caused variations in the climatic zones of many regions of the world, consequently, many species of plants and animals have experienced changes in their distribution, abundance, and seasonal activities. (IPCC, 2019).

As GHG emissions continue to rise, humanity is expected to face increased risks, many of which will not be anticipated (IPCC, 2019). The risk level consequent from climate change will depend not only on the increase in the Earth's temperature but also on the evolution patterns of population, consumption, production, technological development, and management of natural resources (IPCC, 2019).

The anomalous or extreme impacts, caused by climate change, have aroused the interest of scientists, academics, international organizations, governmental institutions, and civil society; promoting the inclusion of this issue as a priority in the development agendas (Martínez and Fernández, 2004). For this reason, in 1992, the UN Conference on Environment and Development in Rio de Janeiro adopted the United Nations Framework Convention on Climate Change (UNFCCC). This Framework defined climate change and became one of the main legal and global instruments to control GHG emissions (Chalco Vera, 2018)). Moreover, it has been established that prompt intervention is required to mitigate climate change by reducing GHG emissions and promoting the adaptation of society and ecosystems (IPCC, 2014).

It has been reaffirmed in the Paris agreement, in 2015, in which nations collectively agreed to continue with the mitigation efforts to hold the increase of global temperature to well below 2°C regarding the pre-industrial levels, with the aim of not exceeding 1.5°C (Flores, 2016). To achieve this goal it is estimated that, by 2030, CO_2 emissions have to be reduced by 45% compared to 2010 and reach net zero by 2050 (FAO, 2019).

However, by 2014, CO_2 emissions recorded were 60% higher than in 1990. If this increase tendency continues, it is estimated that emissions will rise at a rate of 2.5% per year. If this were the case, by 2050, atmospheric CO_2 concentrations would exceed the established acceptable limits (well below 2°C) (López and Gómez, 2015). The effects of the increase in global temperature will have a differentiated impact on different regions of the world, socioeconomic groups and even genders. Moreover, it will accentuate inequalities in access to health, food, basic services, education and employment (de los Angeles, 2016). Thus, the decisions which are made today are decisive for the wellbeing of future generations (FAO, 2019).

2.2 Climate change and agriculture

Land provides food, fiber, and livelihoods for humans, leading to increased land use change in recent decades (Chalco Vera, 2018). These changes in the use of land have contributed to an increase in GHG emissions, loss of biodiversity, and deterioration of natural ecosystems (IPCC, 2019). Moreover, the increase in the consumption habits of a growing world population demands an extensive and intensive agricultural production (IPCC, 2019); which has increased since the "Green Revolution" due to the development of technology such as machinery, chemical fertilizers, pesticides, and irrigation systems (Chalco Vera, 2018). Thus, it can generate greater risks due to pollution, water scarcity, and soil degradation (IPCC, 2019).

Soil is both a source and a sink for GHGs, thus it plays a key role in the exchange of matter and energy between the land surface and the atmosphere (IPCC, 2019). For instance, soil is a potential reservoir of carbon (Flores-Jiménez *et al.*, 2016), and its vegetation contribute with the absorption and re-distribution of it among the living and dead biomass, and soil organic matter (Chalco Vera, 2018). On the other hand, when ecosystems are transformed into cultivated areas, they can generate large GHG emissions by releasing CO_2 from the original vegetation and soil (Chalco Vera, 2018). Nowadays, croplands and grasslands have replaced natural terrestrial ecosystems, making it one of the largest terrestrial biomes on the planet (Chalco Vera, 2018), by occupying more than 70% of the Earth's ice-free land surface (IPCC, 2019).

Agriculture, forestry, and other land use (AFOLU) is one of the sectors which contributes to more GHG emissions into the atmosphere (Flores, 2016). This is mainly due to deforestation, and, crop and livestock management practices (IPCC, 2014). For instance, large GHG emissions are generated during the soil preparation of the cultivated areas, mainly due to burning practices and/or the decomposition of biomass (Chalco Vera, 2018). From 2007 to 2016, AFOLU is responsible for 24% of the global GHG anthropogenic emissions (Soto-Cabrera *et al.*, 2020), which constitute 13%, 44% and 81% of global CO_2, CH_4 and N_2O emissions, respectively (IPCC, 2019)(Figure 3). However, this percentage does not include indirect emissions from this activity, such as the manufacture of fertilizers, the production, and the use of agricultural machinery, or transportation (IPCC, 2019). Therefore, the development of policies to regulate agricultural practices is vital to mitigate the effects of climate change, while contributing co-benefits for adaptation (IPCC, 2014).

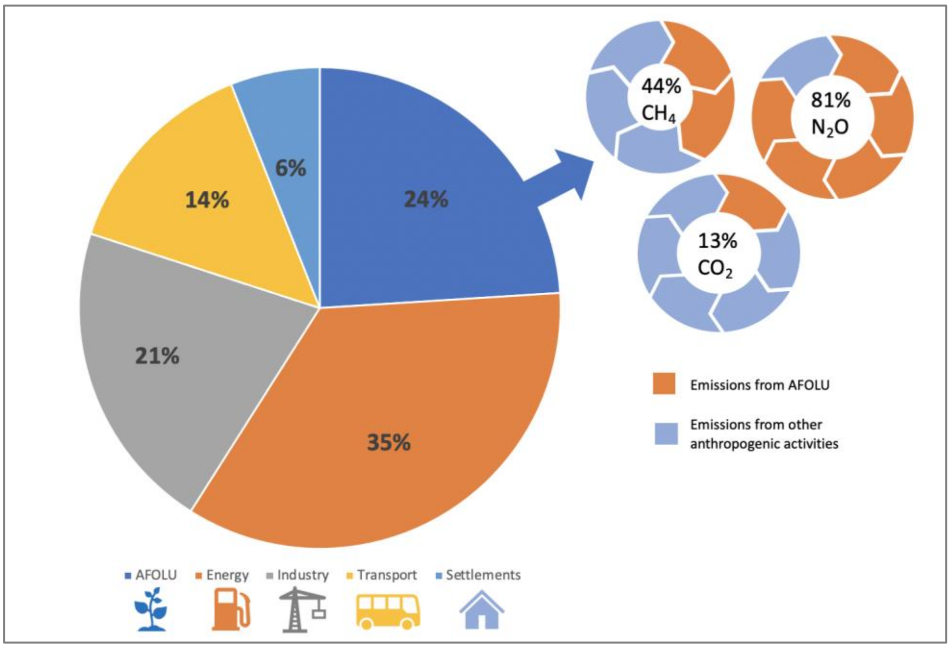


Figure 3. Global GHG emissions
Own elaboration
Source: (FAO, 2016; IPCC, 2019)

On the other hand, climate change can directly affect agriculture due to: 1) the change of precipitation and temperature patterns, and 2) the increased magnitude and frequency of extreme events (IPCC, 2019). As well as, through indirect effects such as pest pressures, pollination failures, and interference with other ecosystem services that can affect agricultural productivity (Zhao and Li, 2015). For instance, with a temperature increase of 1.5°C or more, local crop production yields in tropical regions, such as Central and South America, are expected to decrease, having major consequences on food security and poverty (FAO, 2019). Another important consequence of climate change is land degradation, which can trigger large social and environmental losses, leading to undesirable transformations such as social conflicts, migration, and poverty (IPCC, 2019). Sustainable land management with a systemic approach can contribute to reduce the vulnerability of terrestrial ecosystems and land fields to extreme weather and climate events caused by climate change (Chalco Vera, 2018; IPCC, 2019).

Consequently, by assessing crop production systems as well as climate change, economic, environmental and social factors must be considered, "*such as how to (1) balance short-term and long-term goals; (2) increase productivity, profitability, and sustainability; (3) introduce new technologies and transfer them to growers; (4) meet environmental regulations; (5) deal with contradictions between climate change and crop production; and (6) balance competition of food and energy in resources*" (Zhao and Li, 2015).

2.3 Burning in agriculture

Fire in nature constitutes an important process for the degradation of biomass, especially in ecosystems where the decomposition rates are extremely slow (Running, 2006). The combustion of biomass can be complete or incomplete and it can be triggered by natural or anthropogenic causes (Flores, 2016). Biomass burning has taken a significant role in shaping the landscape and the biotic components of ecosystems (Mistry *et al.*, 2005). Humans have taken an important part in this process by increasing the frequency and behavior of fires (Mistry *et al.*, 2005), mainly due to the preparation of the agricultural land and the cleaning of vegetal residues after the harvest or fallow (Flores, 2016). Figure 4 shows the biomass (kg C/m^2) burned from 1997 and 2014, and the emission sources.

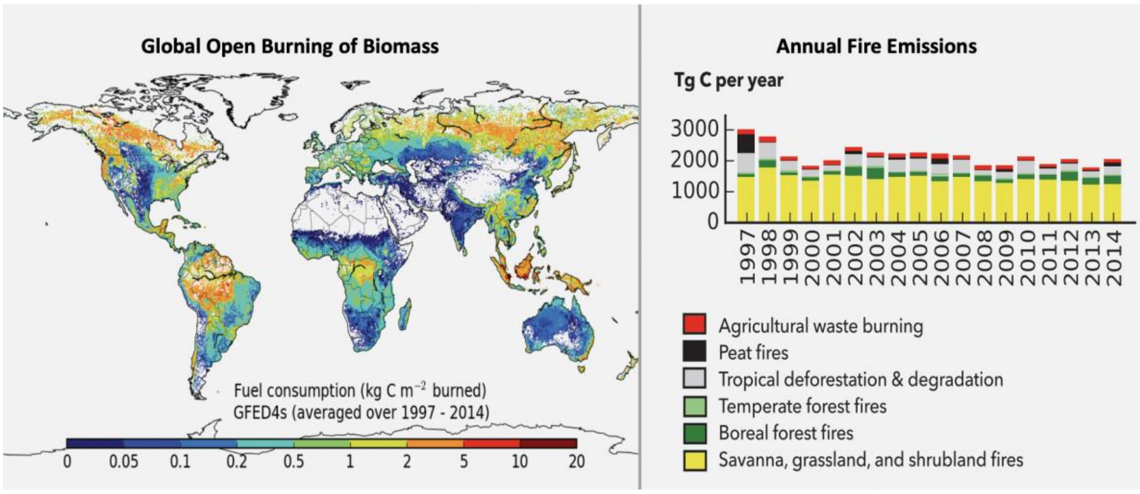


Figure 4. Global Open Burning of Biomass (1997-2014)

Source: (Cassou, 2018)

Note: Analysis of daily, monthly, and annual burned area using the fourth-generation global fire emissions database (GFED4)

Fire management in agriculture is based on ecological, phenological, and seasonal knowledge (Armatas *et al.*, 2016). It constitutes a worldwide long-standing practice, especially in rice, wheat, maize and sugar cane crops (Cassou, 2018)(Figure 5).

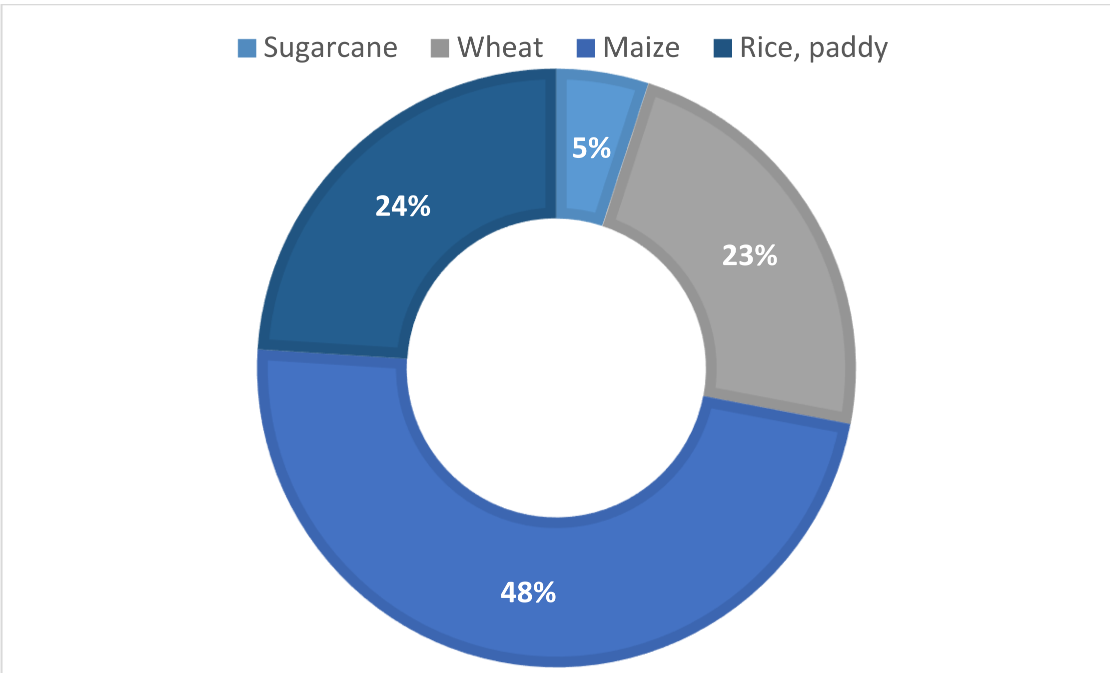


Figure 5. Burning of crop residues by major crop, 2014

Own elaboration

Source: (Cassou, 2018)

Note: Accounts for dry matter biomass by FAOSTAT data

On the other hand, biomass burning has important impacts on soil characteristics, as the change of pH, components, moisture, and microbiota (Cabrera and Zuaznábar, 2010; Cassou, 2018). Although biomass burning returns some nutrients to the soil, which in the short term can provide a fertility burst, most of the organic matter and nutrients are lost with the high temperatures (Cassou, 2018). The continuous loss of nutrients and organic matter leads to soil impoverishment, progressively reducing agricultural yields over the years (Cabrera and Zuaznábar, 2010). This, also, promote the additional use of fertilizers which can increase the emission of nitrogen compounds to the atmosphere (de los Angeles, 2016).

Besides, emissions from biomass burning are characterized by the generation of air pollutants such as carbon dioxide (CO_2), carbon monoxide (CO), particulate matter (PM), polycyclic aromatic hydrocarbons (PAH), volatile organic compounds (VOC), nitrogen oxides (NO_x), ammonia (NH_3), sulfur dioxide (SO_2), and additional traces of other toxic gases (de los Angeles, 2016; Cassou, 2018). Combustion conditions, fuel, edaphology, and the presence of pesticides vary the components and amounts of the emissions (de los Angeles, 2016; Flores, 2016).

In terms of global emissions, biomass burning produces approximately 40%, 32%, 20%, and 50% of the world's carbon dioxide (CO_2), carbon monoxide (CO), particulate matter (PM), and polycyclic aromatic hydrocarbons (PAH), respectively (CCA, 2014). These greenhouse gases and short-lived climate pollutants, emitted into the atmosphere, can alter the balance of the radiative forcing, contributing to climate change (Mugica, 2012; Flores-Jiménez *et al.*, 2019).

Agricultural burning adversely affects air quality, human health, ecosystems, visibility, and physical infrastructure (de los Angeles, 2016). The high concentrations of air pollutants, at specific moments of the year, can cause health problems for workers and communities, such as eye irritation, skin allergies, respiratory and cardiovascular problems, including cancer, and premature death (de los Angeles, 2016; Cassou, 2018). In addition, the emission of SO_2 and NO_x from biomass burning can contribute to the generation of acid rain, which can affect soil, vegetation and corrode urban structures. (Cassou, 2018). Besides the emission of air pollutants, agricultural burning may eventually cause accidental burning of natural ecosystems or nearby residential areas (Biaggi, 2018).

Despite its harmful consequences, this practice is widely accepted among agricultural communities (Chalco Vera and Acreche, 2019). Burning is generally perceived as a natural practice which effects are commonly overlooked (Cassou, 2018). The perpetuation of biomass burning as an agricultural practice is the result of social traditions and perceptions (Baca, 1995; Lara, Caso and Aliphat, 2012). For example, crop residues commonly are seen as waste, instead of a resource, so burning is seen as an easy and inexpensive option to remove them (Flores, 2016). Indeed, it is used to prepare fields by preventing pests and diseases for the coming crops (Cassou, 2018). Although the cost-benefit ratio of burning varies on many factors, farmers have a favorable perception of biomass burning, as they tend to perceive only the immediate costs and not the effects that may occur in the long term, which magnitude may be greater (Cassou, 2018). Moreover, even if farmers perceive the disadvantages of burning, their lack of access to technology, equipment, and knowledge to change this practice is limited (Cassou, 2018).

The negative effects on people's health and the environment resulting from biomass burning are not so evident as they are external costs of the agricultural production system (Cassou, 2018). These externalities can be amended through policies that regulate or restrict this activity, as well as incentives or fees to disincentive it (Cassou, 2018). However, it is difficult to measure and regulate them, as they are non-point sources which are carried out over extensive open areas (de los Angeles, 2016). Furthermore, institutional support is needed to enable the technical and economic viability of alternatives to combustion (Cassou, 2018).

Likewise, it should be considered that communities hold practices and skills based on their experience, knowledge, perceptions and values that allowed them to face their realities (Wamsler *et al.*, 2016), which also could increase their resilience and reduce their vulnerability to a range of factors related to climate change (Williams and Hardison, 2013).

2.4 Sugarcane

Sugarcane is a C4 type plant, which, due to its photosynthetic efficiency, fixes large amounts of CO_2 from the atmosphere in the form of sugars (Cabrera and Zuaznábar, 2010), which are mainly accumulated in the form of sucrose in its unbranched stems (Alvaro, Ortiz and Biaggi, 2016). This sweet component was the reason for its domestication (Mejía and Saldarriaga, 2013), and for the generation of new varieties with higher yields and greater resistance to the different local conditions such as climate, soil, diseases, and pests where sugarcane is grown (de los Angeles, 2016). Sucrose has been extracted and processed to obtain more than a hundred products of which sugar, alcoholic beverages, and recently ethanol stand out (Córdova *et al.*, 2014; Alvaro, Ortiz and Biaggi, 2016). Thus, sugarcane is the commercial plant with the highest biomass yields, due to the quantities of sugar and fiber obtained in short periods of time (Iturra, Silva and Díaz-Ambrona, 2011).

Sugar cane is a perennial grass, mainly cultivated in the intertropical zone located between the Tropics of Cancer and Capricorn (Aguilar-Rivera, 2011). It is native to India and was introduced to Europe with the Muslim expansion, and, later to America with the conquest (Rojas, 2012). Since then, it has been expanded widely throughout the American continent, shaping its history and economy, due to the favorable climatic and edaphology conditions and its initial rising demand as a luxury product (Aguilar-Rivera, 2010).

Sugar cane production in Latin America started as a colonial model, in which sugar cane plantations were developed in extensive rural territories under the dominion of the owners -mostly European descendants- and supported by the labor of indigenous or slaves (Ramos and Alves, 2006; Aguilar-Rivera, 2010). Its production, inherited from the colony, remains until today, however, now its dynamic and structure are shaped by market conditions (OCDE and FAO, 2017).

Sugar cane is characterized by being a monoculture crop as its sprouts can be harvested for five to seven years on an annual basis. As a consequence, the monoculture has caused soil deterioration such as erosion, nutrient depletion, loss of organic matter, pH changes, compaction, and the increasing dependence on material and energy inputs supplied by humans (Aguilar-Rivera, 2011; Queiroz *et al.*, 2020). Other environmental problems due to sugar cane production are deforestation, loss of biodiversity, habitat fragmentation, and atmospheric emissions (Aguilar-Rivera, 2011).

According to Aguilar (2011), main phases of sugar cane production are:

a) Establishment phase: Is the period, when stems emerged from a recently planted area, or, as a consequence of a regrowth after the harvest.

b) Tillering (formative) phase: Is a physiological process of multiple underground branching that generates from compact nodal joints of the primary stem.

c) Grand growth phase: It started with the tiller stabilization for the formation and elongation of cane. In addition, leaf growth occurs at this stage. It is considered the maturity period of the stems. However, only 40 or 50% of the initial tillers became usable cane.

d) Ripening and maturation phase: Vegetative growth decreased, and sucrose synthesis and accumulation occurred from the bottom to the top of the cane.

e) Harvest: It should be done, at sugar cane peak maturity that occurs 12 to 18 months after the germination phase and before its flowering. The cane must be cut at the base of the stem and at an appropriate height to eliminate immature internodes.

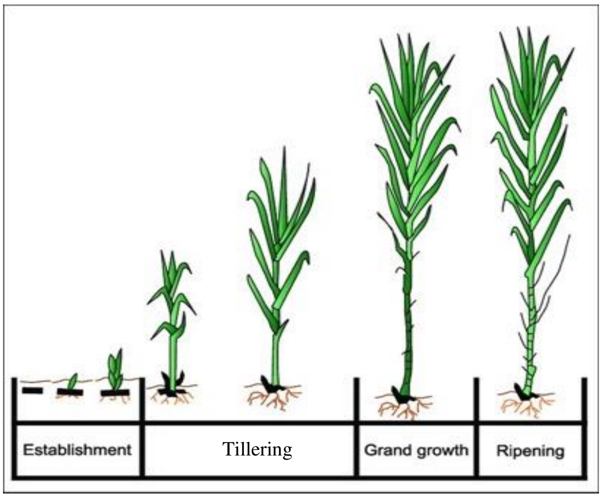


Figure 6. Sugar cane growth phases
Source: (Wiedenfeld et al., 2015)

During this last phase, the straw should be removed, it could be done at the end of harvest or by burning it before cutting. This phase includes sugarcane deliverer to mills and the removal of agricultural residues from the field. CCA (2014), mentioned that agricultural residues are usually removed by open combustion.

Average yields vary from 40 to 150 Mg/ha, but these depend on specific meteorological and edaphological factors at each growth stage (Romero, Digonzelli and Scandaliaris, 2009; Flores, 2016), as they are shown in Figure 7. It should be noted that not many regions of the world have an adequate combination of these factors to supply their national and international demand (Iturra, Silva and Díaz-Ambrona, 2011).

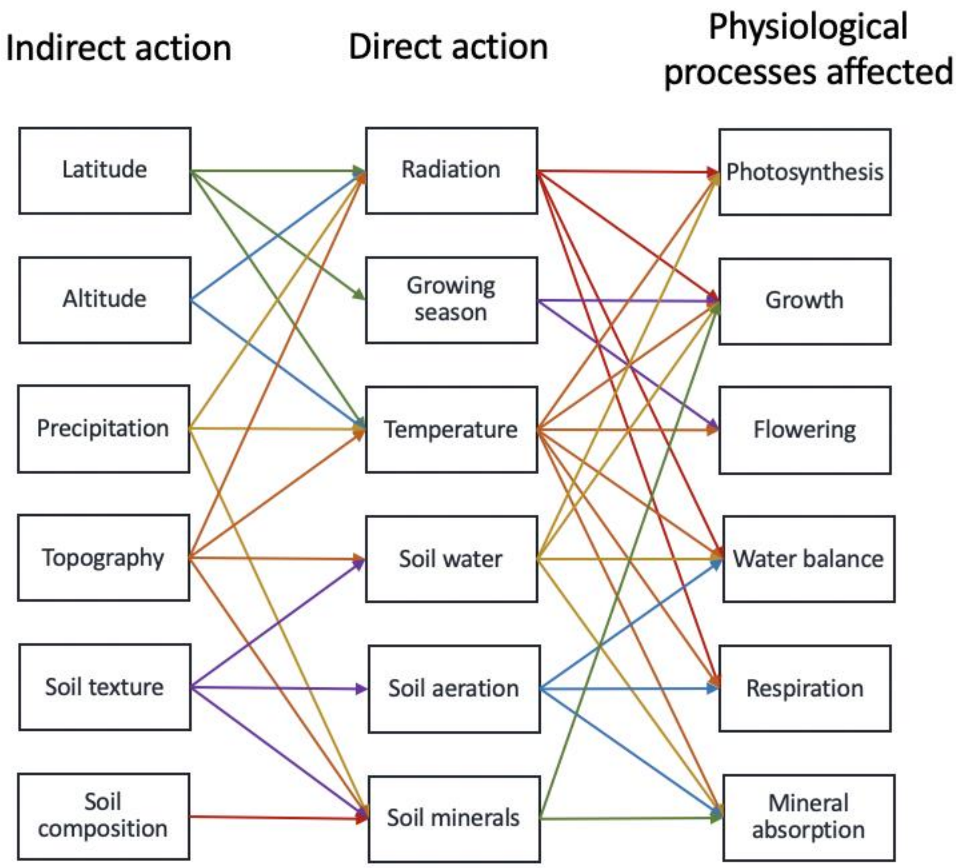


Figure 7. Sugarcane production factors
Source: (Flores, 2016)

2.5 Sugarcane Harvest Approaches

Initially, the sugarcane fields were harvested manually by cutting the cane with machete. Later, to improve efficiency, agricultural practices such as burning were applied. In the last years, agricultural technology has improved by the introduction of new instruments, such as machinery for cutting, cleaning and collecting (Iturra, Silva and Díaz-Ambrona, 2011). This evolution has been shaped by market requirements, labor efficiency and production costs (Benítez, 2016). For example, countries such as Cuba, Brazil and Australia have developed integral technological harvesting models based on their own characteristics that have allowed them to generate substantial advances in terms of sustainability, profitability and efficiency (Lozano and Salazar, 2016).

Harvesting is one of the most important stages in sugarcane production and must be adapted to the specific conditions of the area (Romero, Digonzelli and Scandaliaris, 2009). The process consists of different stages, which are straw removal, upper leaves cutting, stalk cutting at the base of the soil, cane grouping, and cane lifting. The order of these stages may vary according to the type of harvest (Benítez, 2016), as can be seen in Figure 8.

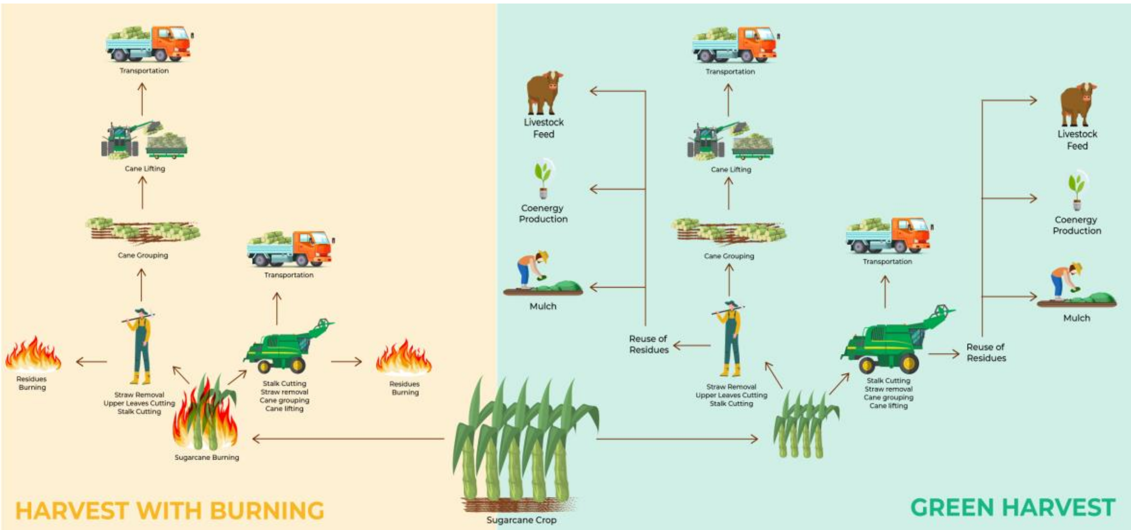


Figure 8. Types of sugarcane harvest
Own elaboration
Source: (Benítez, 2016)

Its main objective is to obtain the highest production per unit area (FAO, 2019). Therefore, it must be efficient to collect sugarcane stalks from the field with minimal losses and with a low presence of foreign matter such as leaves and soil (Romero, Digonzelli and Scandaliaris, 2009). Its importance lies in the fact that sucrose production can be affected by harvest intrinsic factors (Iturra, Silva and Díaz-Ambrona, 2011). The type of harvest defines the profitability of its production since it conditions the logistics and transportation costs of the raw material to the mill (Valeiro and Biaggi, 2019). Moreover, regardless of the type of harvesting, any change in this process impacts the total cost of production by 25% to 35% (Biaggi, 2018).

Consequently, it must ensure that it is conducted at the lowest possible cost and in the shortest possible time (Biaggi, 2018). Ideally, sugarcane should not be burned, loaded, or transported roughly to avoid losses during its processing due to the advancement of its natural fermentation due to biochemical and microbiological processes (Iturra, Silva and Díaz-Ambrona, 2011). For instance, sugarcane harvest should be done less than twenty-four hours before sugarcane delivery, otherwise, the sucrose enters into an oxidation-reduction process, affecting the yield (de los Angeles, 2016). It does not only affect sugar industry but also cane growers (Singh *et al.*, 2019). As a result, the cost-benefit of the activities and decisions carried out during harvest must be considered (Iturra, Silva and Díaz-Ambrona, 2011). One efficient solution is appropriate, quick and efficient communication between the sugarcane producers and the industry personnel to reduce post-harvests delays (Singh *et al.*, 2019).

According to (Alvaro, Ortiz and Biaggi, 2016), the sugarcane cutting process could be conducted manually, semi-mechanized or integral. The type of harvesting and the state of the cane (erect or fallen reed) directly influences the logistic and the cost of transportation to the mill (Romero, Digonzelli and Scandaliaris, 2009), which must be efficient to recover the maximum amount of sugars and thus avoid yield losses (Biaggi, 2018).

The manual system is considered the most rudimentary and artisan harvest type. The manual cut of sugar cane has been done by skilled laborers who use hand knives, axes, or blades to cut the cane and remove its leaves (Alvaro, Ortiz and Biaggi, 2016; Valeiro and Biaggi, 2019). The workers also stack the cane to finally load it in the truck for its transportation to the mill (Alvaro, Ortiz and Biaggi, 2016). At the mill, the manually harvested cane is washed to remove mineral impurities before entering the juice extraction system (Iturra, Silva and Díaz-Ambrona, 2011). This practice is rarely used, due to the high demand of labor and time (Benítez, 2016).

A semi-mechanized system consists of the use of manual work combined with technology to facilitate the process (Alvaro, Ortiz and Biaggi, 2016). As with manual harvesting, a crew of workers cut and stack the cane, but it is loaded into trucks by machinery (Vilaboa and Barroso, 2013). Currently, it is the most widely used by sugarcane producers (Benítez, 2016).

The integral system refers to mechanize the whole harvest process (Alvaro, Ortiz and Biaggi, 2016), through the use of modern machines that cut, clean and loaded the cane directly onto trucks for its transportation (Romero, Digonzelli and Scandaliaris, 2009). It can harvest an average of 700 Mg of cane per day of work. However, this can vary according to a series of meteorological, topographic, logistical, and crop row distribution factors (Romero, Digonzelli and Scandaliaris, 2009). The operation of this machinery requires specialized personnel capable of operating and maintaining it, to exploit its full potential and avoid losses (Romero, Digonzelli and Scandaliaris, 2009).

Despite the development of harvest technology, there are still restrictions for the use of integral systems. For example, ground imperfections such as unevenness, depressions, and the presence of stones and roots can cause damage to the machine or generate yield losses by not cutting the stems at the ground level (Valeiro and Biaggi, 2019). As a result, the quantity and quality of cane delivered to the mill directly depend on the efficiency of the harvester's operation (Valeiro and Biaggi, 2019). Moreover, some places over the world are facing labor scarcity, due to hard work conditions during harvest. Thus, sugarcane producers, by the use of machinery, are overcoming this problem and also reducing cost production (Singh *et al.*, 2019).

Mechanization should not be considered synonymous with harvesting without burning as it is can be combined with this agricultural practice (Ribeiro and Pesquero, 2010). Generally, regardless of the type of harvest, burning is part of this process as it facilitates the cane cutting and elimination of residues (Vilaboa and Barroso, 2013). This translates not only into a reduction in cutting time and effort but also into a reduction in short-term production costs (de los Angeles, 2016).

On the other hand, in the world, agricultural activities are moving towards sustainable production systems that are more economically efficient, less aggressive to the environment, and improvement of working conditions (Romero, Digonzelli and Scandaliaris, 2009). Green harvest is an alternative that significantly contributes to sugarcane sustainability as it promotes harvesting without burning biomass and the use of vegetal residues left in the field (Romero, Digonzelli and Scandaliaris, 2009). Therefore, it reduces the generation of atmospheric emissions, improves soil properties, and fulfils environmental and quality standards (Mejía and Saldarriaga, 2013; Benítez, 2016; Cassou, 2018).

Green harvest can be manual or mechanized (Biaggi, 2018). However, for the implementation of this technique is considered indispensable the use of technology to avoid negative effects in productivity and profitability of sugarcane production (Mejía and Saldarriaga, 2013). As a result, new technology should be continually generated to adapt to crop conditions and sugarcane mills requirements (Romero, Digonzelli and Scandaliaris, 2009).

However, mechanization for green harvesting has generated new social, economic and environmental concerns such as unemployment and soil compaction (Mejía and

Saldarriaga, 2013; dos Santos and de Matos, 2017). It can generate a change in the intrinsic properties of the soil, caused by the increased compaction due to the passage of machinery (Cabrera and Zuaznábar, 2010). The decrease of the soil porosity and size of the soil aggregates reduces the rate of water infiltration, increases the soil bulk density and the mechanical resistance to root penetration, and changes the soil organic carbon stocks (Tolentino de Lima *et al.*, 2017). In addition, if mechanization is performed incorrectly, it can also generate economic losses, related to the affectation to the crop regrowth; and, to the addition of mineral and vegetal material in the product delivered to the industry (Scaranello, 2017). Moreover, harvest mechanization impacts the employment of the most vulnerable population such as cane cutters and small producers (Ronquim, 2010). It promotes the job loss of hundreds of workers who had a low level of education or training (dos Santos and de Matos, 2017). Besides the reduction in the number of employees, the employment profile would change because of the increasing demand for technical and qualified workforce (Moraes, 2007). Thus, labor policies should be implemented to retrain and relocate workers in order to reduce the social cost of technology implementation (Mertens, 2008).

Consequently, the uncertainty about its disadvantages has generated different levels of implementation among the sugarcane producing areas of the world (Romero, Digonzelli and Scandaliaris, 2009). However, the imposition of increasingly strict controls and limitations on the burning of sugarcane fields, in most countries has meant an additional boost for green harvesting (Romero, Digonzelli and Scandaliaris, 2009).

The main characteristics of each harvest type can be seen in Chart 1.

Characteristics	**Manual / Semi-mechanized harvest**		**Mechanized harvest**	
	With burning	Without burning	With burning	Without burning
Foreign matter	2% a 4%	1,5% a 2%	10% a 12%	8% a 10%
Green cut	-	Greater difficulty and labor. Higher costs.	-	Lower difficulty. High investment for the acquisition of machinery.
Efficiency	2 – 4 Mg/man/day	5 – 7 Mg/man/day	45 Mg/hour	30 Mg/hour
Transport	Lower efficiency	Lower efficiency	Higher efficiency (better accommodation)	Higher efficiency (better accommodation)
Cost per Mg (approx.)	Burning: 0,5 USD/Mg Cutting: 3 USD/Mg	Cutting: 3 USD/Mg Manual loading: 2 USD/Mg	Burning: 0,5 USD/Mg Cutting and loading: 1 USD/Mg	Cutting and loading: 1 USD/Mg

	Truck loading: 1 USD/Mg	
Dwell time after cutting	High: between 25 – 40 hours (Whole cane).	Small: between 4 – 10 hours (Chopped cane).
Other	Adaptable to the characteristics of the terrain.	Land adaptation is needed for machinery movement.
	Less sucrose loss during transport (whole cane).	Higher sucrose losses during transport (chopped cane).
	Adaptable for all type of cane varieties.	Adaptable only for appropriate cane varieties.
	High workforce (tough working conditions).	Less workforce

Chart 1. Harvest characteristics with and without burning
Own elaboration
Source: (Vilaboa and Barroso, 2013; González, 2016; Biaggi, 2018)

2.5.1 Straw uses

Sugarcane straw, which is also known as trash, consists predominantly of sugarcane green tops and dry leaves (Santos *et al.*, 2017; Carvalho, Cerri and Karlen, 2019). Green tops are all the green leaves on the top of the sugarcane and those attached in last stalk nodes, while dry leaves are those senescent leaves attached in the stalk and dried leaves recently deposited on the ground (Santos *et al.*, 2017). Its generation varies according to sugarcane variety, vegetative stage, edaphological conditions, climatic conditions, and management of agricultural practices (Nunes *et al.*, 2017). However, the straw composition is approximately 54% dry leaves and 46% green tops (Nunes *et al.*, 2017). As a consequence of the difference among their structural characteristics and composition, they should be separated for decision making on straw management (Santos *et al.*, 2017).

As a result of the transition to green harvest, motivated mainly by laws, the relevance of new approaches to straw management in the sugarcane industry has considerably increased in the last decades (Ronquim, 2010; Carvalho, Cerri and Karlen, 2019). Thus, a layer between 10 to 20 Mg of straw is left on the soil surface per ha per year where green harvest is conducted (Carvalho, Cerri and Karlen, 2019). Such large volumes of straw can be left in the field for its natural decompose as a source of nutrients and organic matter but it also can be used in energy cogeneration, biofuel production, or, as feed for livestock (Romero, Digonzelli and Scandaliaris, 2009; Vilaboa and Barroso, 2013; Nunes *et al.*, 2017; Santos *et al.*, 2017). For this purpose, the harvesting machines have been adapted and optimized to collect the straw and deliver it to the industry for further use (Strachman and Milan-Pupin, 2011).

Residues retained in sugarcane fields provide numerous benefits such as nutrient recycling, increased microbial activity, water storage, carbon storage, increased organic matter, erosion control, soil aggregate stability, and weed control (Romero, Digonzelli and Scandaliaris, 2009; Leal *et al.*, 2013; Vilaboa and Barroso, 2013; Nunes *et al.*, 2017). This improvement of the soil quality can be reflected in crop yields (Santos *et al.*, 2017). However, it is suggested to consider climatic conditions and soil characteristics before its use (Romero, Digonzelli and Scandaliaris, 2009; Vilaboa and Barroso, 2013). In some cases, its combination with the application of vinasse can cause or aggravate the saturation of potassium in soil (Nunes *et al.*, 2017).

The improvement of soil characteristics, by the use of a straw, can allow the reduction of the use of fertilizer in sugarcane crops (Iturra, Silva and Díaz-Ambrona, 2011). However, it should be noted that despite its benefits, the recycling of nutrients from straw does not occur at the same proportion as their decomposition (Nunes *et al.*, 2017). Furthermore, large volumes of straw on sugarcane crops can increase pests, cause accidental fires, and rise the emission of N_2O (Santos *et al.*, 2017). For example, the increased populations of pests such as spittlebug (*Mahanarva fimbriolata*), sugarcane borer (*Diatrea saccharalis*), and sugarcane billbug (*Sphenophorus levis*) can have repercussions on crop yield (Nunes *et al.*, 2017), due to damage produced to stalks, tillers, leaves, and root system (Leal *et al.*, 2013).

Thus, alternative uses of sugarcane straw must be balanced between energy production and the maintenance of soil ecosystem services and crop yield (Carvalho, Cerri and Karlen, 2019). Firstly, straw should be used to meet the soil needs of crops, and, its remaining can be sold to the industry (Leal *et al.*, 2013). An effective strategy, considering the high concentrations of nitrogen, phosphorus, and potassium in green tops, is to use this fraction of straw on the soil as its nutrient contribution is higher (Santos *et al.*, 2017). Besides dry leaves have fewer nutrients, they have lower decomposition rates and moisture content making them better for energy production (Santos *et al.*, 2017).

The increasing demand for cleaner sources provided an opportunity to use straw as a potential use for bioenergy production (Carvalho, Cerri and Karlen, 2019). With the modernization of cogeneration systems using bagasse and, in some cases straw, the electricity generated not only can meet the self-consumption supply of the sugarcane mills but can also turn them into net exporters of electricity (Nunes *et al.*, 2017). For instance in Brazil, several companies are using straw as feedstock for electricity production which has the potential to mitigate GHG emissions compared to other energy sources (Carvalho, Cerri and Karlen, 2019). Despite the willingness to use straw as bagasse for energy generation, both have different chemical and physical characteristics that make it difficult to use them together (Leal *et al.*, 2013; Santos *et al.*, 2017). It constitutes one of the major limitations as straw can alter the operation of the boiler, so it needs the adaptation of the machinery (Santos *et al.*, 2017; Carvalho, Cerri and Karlen, 2019). Moreover, the separation of the green tops from the dry leaves is required as they have different composition and moisture content (Santos *et al.*, 2017). However, until now the possibility of separating them on the field during harvest has been restricted (Santos *et al.*, 2017).

Moreover, concerning second-generation ethanol production from straw has the potential to increase biofuel production, although its economic viability is still questionable (Nunes *et al.*, 2017). Besides, the technological feasibility of using straw for ethanol production, its use is still limited because of the pre-treatment and cleaning requirements (Santos *et al.*, 2017).

2.6 GHG emissions from burning of sugarcane

At the beginning of American colonization, burning pre-harvest in sugar cane crops was not a common practice as landowners had slave labor (Alvarado, 2007). However, the predominance of the extensive model that pursued the predatory and economical use of natural resources incited the misuse of it (Aguilar, 2010; Ramos & Alves, 2006). Over the years, the sugar industry also adapted to the supply of burnt cane (Valeiro and Biaggi, 2019). Consequently, until today most sugar cane producers consider this practice vital and irreplaceable for an efficient and profitable harvest (Rojas, 2012).

Burning is an agricultural technique widely used in sugarcane harvesting (de los Angeles, 2016). This is done a few days prior to cutting, verifying that the sucrose concentration is adequate (González, 2016). Its main purposes are: 1) to remove unnecessary foliage, 2) to scare away animals, 3) to facilitate the work of the cutters, 4) to eliminate pests from the soil that could affect next crops, 5) to reduce transportation costs, 6) to facilitate its industrial processing, 7) to prepare the soil for next crops (Rojas, 2012; Vilaboa and Barroso, 2013; CCA, 2014; de los Angeles, 2016; Biaggi, 2018). However, the main reason for its use, in manual and mechanical harvesting, is related to the reduction of production costs in the short term. For example, a cutter can cut an average of 2 Mg of green cane in an 8-hour workday, compared to 6 Mg of burnt cane in the same workday (Vilaboa and Barroso, 2013).

However, the use of burning in the cane fields causes the alteration of soil properties such as loss of nitrogen and organic material, and the decrease of soil microorganisms (Rojas, 2012; de los Angeles, 2016). Moreover, sugar cane burning produces the emission of gases such as CO_2, CH_4, N_2O, NO_x, O_3, PAHs, particulate matter (PM) and trace elements such as aluminum (Al), silica (Si), sulfur (S), potassium (K), and manganese (Mn), which pollute the atmosphere, contribute to climate change, and also generate health problems for workers and nearby communities (Valadares, 2007; Mejía and Saldarriaga, 2013;

González, 2016; Queiroz *et al.*, 2020). In extreme cases, this practice can alter local meteorological conditions such as humidity, evapotranspiration, and even rainfall (Vilaboa and Barroso, 2013; Flores, 2016).

The amount and types of gases generated by burning at harvest depends directly on the biomass of the crop, the efficiency of the combustion process and the chemicals (fertilizers and pesticides) used on the crop (Flores, 2016). Approximately the biomass burned constitutes 28% to 30% of the crop. It depends on geographical, edaphological and meteorological factors, as well as the variety planted (Flores, 2016). On the other hand, the efficiency of the combustion process depends mainly on the moisture content of the biomass to be burned (Chalco Vera and Acreche, 2019). Subsequently the lower moisture, the better the combustion process (Flores, 2016). The use of fertilizers and pesticides also increase the amount of components that can be volatilized by burning sugarcane (Flores, 2016).

However, sugarcane emissions have increased gradually; for instance, in 2017, sugar cane crops emitted a total of 1.323,78 Gg of CO_2eq. America with 53,4% is the largest generator of CO_2eq emissions (FAO, 2021). Moreover, by contrasting the emissions produced, in America, between corn, sugar cane, wheat and rice; sugar cane cultivation occupies the third place of CO_2eq emissions as it is shown in Figure 9 (FAO, 2021). Additionally, a study conducted in Southeastern Brazil, in 2005, determined that black carbon constitutes 64% of the total mass of aerosols generated from sugar cane burning. This component is also a precursor of climate change and can cause serious health problems.

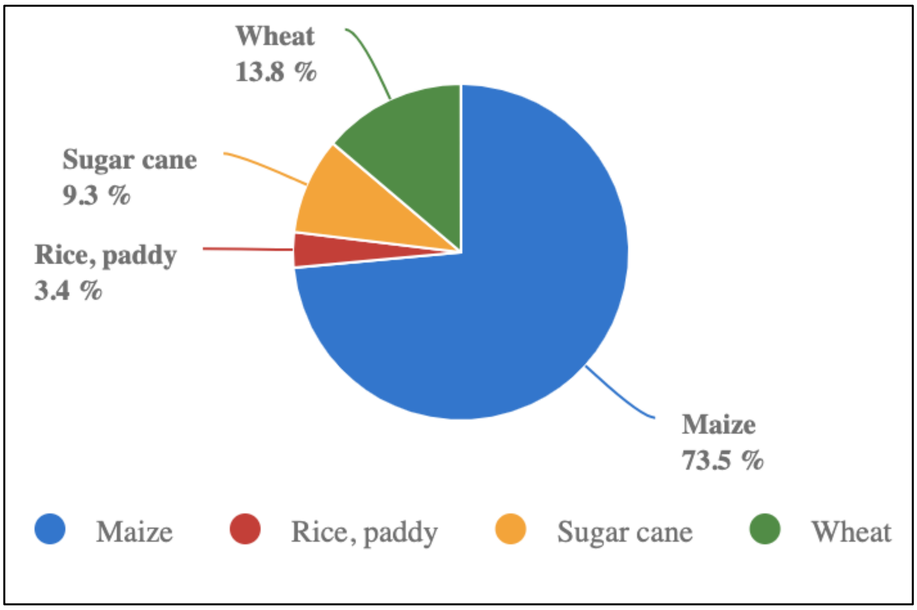


Figure 9. Emissions by crop type (CO2eq) in America (2017)
Source: (FAO, 2021)

Brazil and Mexico are among the countries with intensive biomass burning as an agricultural practice (Cassou, 2018). As it can be seen in the Figure 10, Brazil and Mexico are among the largest emitters of CO_2eq worldwide.

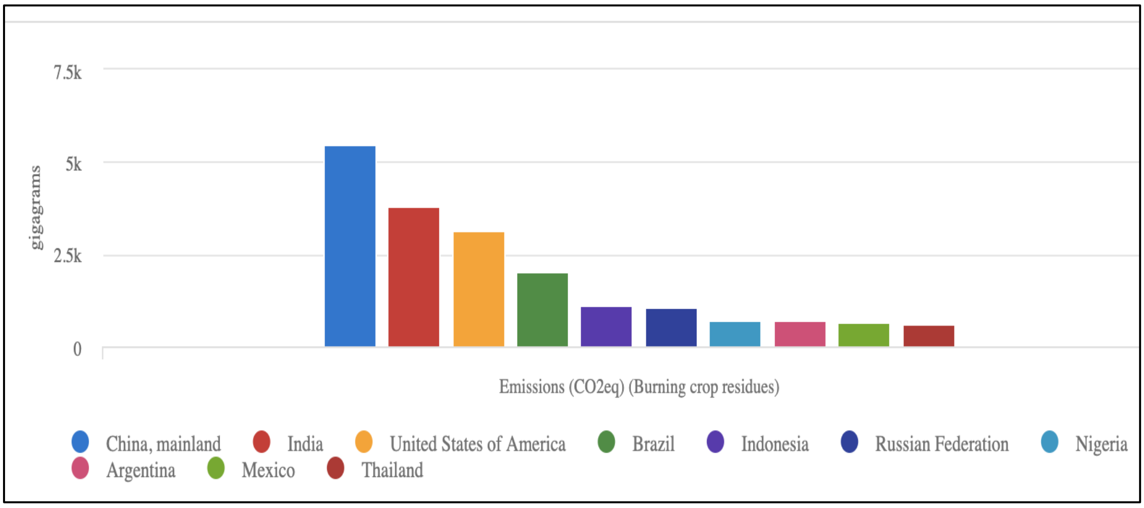


Figure 10. Top 10 CO_2eq emitters in 2017
Source: (FAO, 2021)

The products of this combustion, especially the particulate material, can cause incorrect oxygenation of the blood, respiratory system and eye irritation, acute and chronic respiratory diseases (Mejía and Saldarriaga, 2013). For instance, black carbon generated, by sugarcane combustion, contains large amounts of potassium that in contact with water have a high corrosive power that affects structures, living things and humans (Mejía and Saldarriaga, 2013).

On the other hand, studies and research related to GHG emissions establish that CO_2 released into the atmosphere as a result of burning is recovered during the following crop period (Chalco Vera and Acreche, 2019). Therefore, its quantification is often discarded (Flores, 2016). Nevertheless, the emission of GHGs such as methane (CH_4) and nitrous oxide (N_2O) are not considered within this recovery and it is established that for each Mg burned, 2.7 kg of CH_4 and 0.007 kg of N_2O are produced (Benítez, 2016).

The emission of nitrogen components such as N_2O is an indicator of soil nutrient loss as a result of sugarcane burning (Flores, 2016). Nitrogen losses constitute approximately 11.68 kg/ha (Benítez, 2016). Nutrients play a vital role in sugarcane production as it regulates crop growth and juice quality (Singh *et al.*, 2019). Fire straw removal influences the soil organic matter content and alters the nutrient profile of the soil (Queiroz *et al.*, 2020).The continuous loss of nutrients and organic matter from the soil leads to soil impoverishment which causes the decrease in crop yields (Cabrera and Zuaznábar, 2010). This is exacerbated by sugarcane monoculture and the inadequate agricultural management practices (Cabrera and Zuaznábar, 2010; Oliveira *et al.*, 2021).

The negative effects of burning can also be perceived in the sugarcane fields as production losses due to the exposure of the remaining stalk tissues to pests (Caio, 2013). In addition, sugarcane burning can induce accidental fires which can destroy other cultivated areas, ecosystems, and residential areas (Biaggi, 2018). The rising awareness of its consequences has reduced the acceptance of this agricultural activity (Vilaboa and Barroso, 2013), increasing the social pressure to develop harvest alternatives (Biaggi, 2018). As a consequence, sugarcane burning limits the social and environmental sustainability of this crop due to the adverse effects presented (Chalco Vera and Acreche, 2019). Although CO_2 emissions can be proportionally absorbed by future crops, the damage resulting from this agricultural practice must be taken into account in decision making (Cabrera and Zuaznábar, 2010).

2.7 General problems of the sugar agroindustry

Technological development, environmental impacts and globalization have transformed the uses of sugarcane, which was initially considered only as a source of food, which has resulted in profound productive and socioeconomic transformations (Aguilar-Rivera, 2011). Therefore, in order to maintain the sugarcane agroindustry, major productivity and competitiveness challenges must be faced (Aguilar-Rivera, 2011).

The regulation of the world market is driven by the relationship between world sugarcane production and consumption (Santillán-Fernández et al., 2017). This is reflected in the capacity of the productive units to maintain or increase their participation in the national and international markets (Aguilar-Rivera, 2011). The major issue that sugar agroindustry has to overcome is the prices fluctuation of sugarcane derivatives, as it directly affects the production, and cause the elimination of non-competitive producers (Aguilar-Rivera, 2011; Santillán-Fernández *et al.*, 2017).

Technological development, increase in productivity and diversification of sugarcane products can ensure its economic viability (Aguilar-Rivera, 2011). These circumstances demand producers to optimize, modernize and reorganize their crops to ensure the survival of the sugar agroindustry (Santillán-Fernández *et al.*, 2017).

However, it mainly affects industries and producers in developing countries as they are the most exposed to world market prices (FAO, 1999). Consequently, the fall in the prices of sugarcane derivatives, instead of stimulating a decrease in the supply of developing countries, forces them to increase production to survive, causing the bankruptcy of the industries and producers who have the least possibilities of survival (FAO, 1999). Thus, in this uncontrolled competition, the social cost is very high (FAO, 1999). For instance, in Mexico, the low competitiveness and high production costs of sugar agroindustry resulted in the crisis of this sector which requires the government protection to survive (Aguilar-Rivera, 2011; Santillán-Fernández *et al.*, 2017).

On the other hand, the demand of sugar and ethanol, the main sugarcane derivates, is influenced by sociodemographic changes, population's income level, and competition with other products (Santillán-Fernández *et al.*, 2017). The growing social concern about health problems associated with sugar consumption has led to a reduction in its consumption (Santillán-Fernández *et al.*, 2017; OCDE and FAO, 2020). For this reason, the substitution of sugar in the market for low-calorie or lower-cost sweeteners has been increasing (Aguilar-Rivera, 2011; Santillán-Fernández *et al.*, 2017). Likewise, in the case of ethanol, low world oil prices limit its competitiveness in the market as an alternative fuel (Santillán-Fernández et al., 2017).

Another problem currently facing the sugar agribusiness is the mitigation of the environmental impacts generated by this economic activity (Córdova *et al.*, 2014). The current agricultural model has made great efforts to increase crop yields at the expense of the socio-environmental problems that it may arise (Sarandón, 2020). In the case of sugarcane production, the environmental impacts are mainly due to 1) the increase in the extension of the fields, 2) pollution, 3) intensive use of resources and 4) loss of diversity due to monoculture; which altered the ecosystem stability (Pérez, Peña and Alvarez, 2011; Córdova *et al.*, 2014; Sarandón, 2020). This dynamic of agricultural exploitation has not only affected the supply of sugarcane, but also the quality of it, which has compromised the continuity of this activity over time (Sarandón, 2020).

2.8 Technological innovations in agriculture

Technological innovation is defined as the process to develop a new device, technique, practice, or process to improve current conditions, and, also the integration of it into the productive system (Temple *et al.*, 2011). It should cover technology creation, manufacture, adaptation, adoption, and disposal (Anadon *et al.*, 2016). Technological innovation in the agricultural field refers to the research and development of alternatives that can improve agricultural efficiency, reduce food waste, increase the reuse of residues and improve crop adaptation (FAO, 2019). However, technological innovation implies that the researcher is not limited to generate an invention or knowledge to increase economic growth and improved human well-being; he or she, also, should be responsible, directly or indirectly, for ensuring its implementation (Temple *et al.*, 2011). For which economic, environmental, and social issues have to be thoroughly considered (Jeyarajan, 2018).

Keeping in mind that the sustainable development was defined by the United Nations commissions and summits as development that meets human present needs without compromising the ability of future generations to meet their needs (Anadon *et al.*, 2016). In this concept, the potentials and limitations of technological innovations should be analyzed to ensure compatibility with economic, environmental, and social dimensions (Temple *et al.*, 2011). Moreover, technological innovation can be considered a key component of sustainable development, as it constitutes one of the Sustainable Development Goals (SDG) that were established by the United Nations; and it can also be an instrument to achieve the others (Anadon *et al.*, 2016).

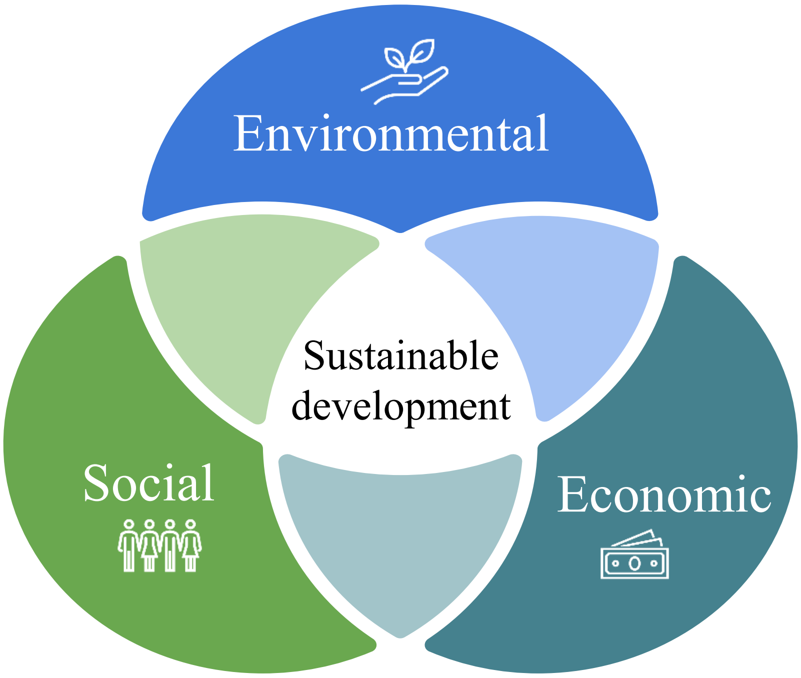


Figure 11. Sustainable dimensions
Own elaboration based on UN, 1987

Therefore, a systemically and holistic analysis is needed to manage technological innovations and to strengthen the long-term capacities of the agricultural systems (Cancino *et al.*, 2018). In other words, technological innovation emerges as a complex adaptive system that involves many factors, actors, and institutions functioning simultaneously from local to global scales (Anadon *et al.*, 2016).

The local background is a determinant in technological innovation, as it ensures coherence between organizing the 1) production process, 2) technological choices, 3) environmental issues and 4) collective values (Temple *et al.*, 2011). Moreover, innovation is shaped by a set of multilevel and interrelated actors and institutions (Anadon *et al.*, 2016). Thus, the degree of coherence of them shapes the paradigms that can eventually determine research choices (Temple *et al.*, 2011). The study of past experiences and the interrelationships that characterize a system can greatly improve the understanding of the dynamics between these factors to achieve sustainability (Anadon *et al.*, 2016).

On the other hand, innovation is driven primarily by highly resourced actors generating power imbalances (Anadon *et al.*, 2016). Technological innovation in agricultural systems is normally based on a diffusionist and linear approach, which is historically promoted by developed countries (Temple *et al.*, 2011). Scientists and researchers considered as the "inventors" develop technologies, in research centers in developed countries, which are transferred to agricultural producers around the world as "users" (Temple *et al.*, 2011; Jeyarajan, 2018). Consequently, technological improvement in developing countries depends on the supply of international markets (Temple *et al.*, 2011). It should ensure labor quality improvement, high production capacity, and low costs to be accessible to all agricultural producers (Romero, Digonzelli and Scandaliaris, 2009). However, this linear diffusion model, in most of the cases, has little impact on the improvement of crop production systems as developing countries mainly rely their agriculture on family labor, and, their resources are highly reliant on diverse sociopolitical variables (Temple *et al.*, 2011).

Technological innovations in agriculture have been focusing on the adoption of new agriculture methods, mechanization, and improvement of biotechnology (Singh *et al.*, 2019). However, another constraint that they are facing is related to current institutions, understanding them as government rules, norms, and incentives (Anadon *et al.*, 2016). As they are not always aligned with sustainable development objectives because impoverished, marginalized and future populations often lack the economic and political power to lead their innovation in order to fulfill their needs (Anadon *et al.*, 2016).

Agricultural technological innovations have also contributed to the maintenance of the sugarcane agroindustry, promoting its sustainable development by improving quality standards, complying with environmental norms, maximizing its production, and improving its competitiveness in the market (Strachman and Milan-Pupin, 2011). In addition, its expansion and development have generated technology that allows it to reduce its social and environmental externalities, such as pollution and climate change (López and Gómez, 2015). Furthermore, the development and introduction of new technology, besides reducing costs, can expand the diversification of sugarcane products such as ethanol, cellulosic biofuel, and other coproducts, which can contribute to the adaptation to climate change (Zhao and Li, 2015)

In the case of sugarcane harvesting, the awareness of burning impacts on communities and the environment, emphasized by the benefits of using agricultural residues for agronomic and energy purposes, has driven the adoption of technologies to support green harvesting (Romero, Digonzelli and Scandaliaris, 2009). It is, also, increasing the availability of new harvesters adaptable to different topographic conditions which incorporate more efficient cut and cleaning systems (Romero, Digonzelli and Scandaliaris, 2009). However, its worldwide implementation has been limited, for instance, only Australia and the United States are fully mechanized (Maldonado and Arteaga, 2016). This is because limitations can arise at all stages of technological innovation (Anadon *et al.*, 2016). For example, more than half of sugarcane fields are located in hilly areas where mechanized operation is complicated (Zhao and Li, 2015). Besides, the social cost of reduced employment in the field, in the short and medium term, is another constraint that must be analyzed (Mertens, 2008). Subsequently, the compatibility of social, environmental and economic objectives such as increasing productivity; protecting the environment, and reducing social inequalities must be ensured to achieve sustainability through technological innovation (Temple *et al.*, 2011).

3 Chapter III: Cases of study

3.1 Sugarcane production in Mexico and Brazil

3.1.1 Brazil

Sugarcane cultivation was introduced in Brazil in 1532 (Veiga, Vieira and Ferreira, 2006). Despite its great economic importance, its history is marked by periods of stagnation and accelerated growth (Cunha *et al.*, 2015). For many years, sugarcane was considered the most important crop in this country (Queiroz *et al.*, 2020), as it was responsible of Brazilian economic and technological development (Gomes *et al.*, 2020) and so far is of great social and economic importance (Queiroz *et al.*, 2020). Brazil is the world's largest sugarcane producer (Ronquim, 2010) with a yield exceeding 600.000 Mg (CONAB, 2021). Thus, the expansion of this crop has shaped the Brazilian landscape, economy and society by changing production relations, substituting crops and modifying labor relations (dos Santos and de Matos, 2017).

The oil crisis in the 1970s was the main trigger of the actual Brazilian production, as it promoted the implementation of public policies to generate ethanol as an alternative energy source (dos Santos and de Matos, 2017). The need to replace fossil fuels has given Brazilian sugarcane production an outstanding position as an energy alternative (Aguilar-Rivera, 2010), which has also driven Brazilian sustainable development (Oliveira *et al.*, 2021). As sugarcane cultivation represents for Brazil part of its contribution to the reduction of GHG emissions through the use of ethanol as an alternative to fossil fuels and through the use of sugarcane biomass for energy generation (Berra, 2004; Ronquim, 2010).

The production of biofuels implied the collaboration between the private and governmental actors, through subsidies and incentives that favored the investment of sugar industry to evolve the productive process to obtain ethanol, as well as the automotive industry for the development of flex-fuel car production (González and Castañeda, 2012).Therefore, the National Bioethanol Program (PROALCOOL) was created to expand sugar cane production to supply national and international market demand (FAO, 2013). Moreover, since 2000 the government has been established new incentives for the incorporation of new technology which has enabled the expansion of sugarcane cultivated areas, due to the need for fossil fuel replacement to supply vehicle demand (Veiga, Vieira and Ferreira, 2006; dos Santos and de Matos, 2017). The growing interest worldwide in the search for renewable and less polluting energy sources has increased the demand for biofuels such as sugarcane ethanol (dos Santos *et al.*, 2012).

Consequently, by 2004, the area cultivated with sugarcane in Brazil tripled compared to 1970, making Brazil the world's largest producer of sugarcane, sugar, and bioethanol (Veiga, Vieira and Ferreira, 2006).

In Brazil, sugarcane is grown mainly in the Center-South and Northeastern regions of the country (Iturra, Silva and Díaz-Ambrona, 2011), being São Paulo, Minas Gerais, Paraná, Alagoas and Pernambuco the states with the largest production (de Barros, 2006). For instance, São Paulo state is responsible for 60% of sugarcane production in the country (Ronquim, 2010).

Of the total sugarcane harvested in Brazil, 49% is used for sugar production, while 51% is used to produce other by-products of which ethanol is the most important one (Cunha *et al.*, 2015). The value chain of the sugar agroindustry in Brazil stands out for the diversity of complementary products besides sugar, including alcoholic beverages, alcohol for industrial purposes, cogeneration of electricity, cattle feed, inputs for the pharmaceutical industry, paper, biopolymers, and fertilizers (Mertens, 2008). See Figure 12. As a result, the sugarcane production generates more than 1.28 millions of direct jobs, 38% of which are dedicated to sugarcane cultivation and 62% to sugar and ethanol production (Julca-Briceño and Favo, 2011).

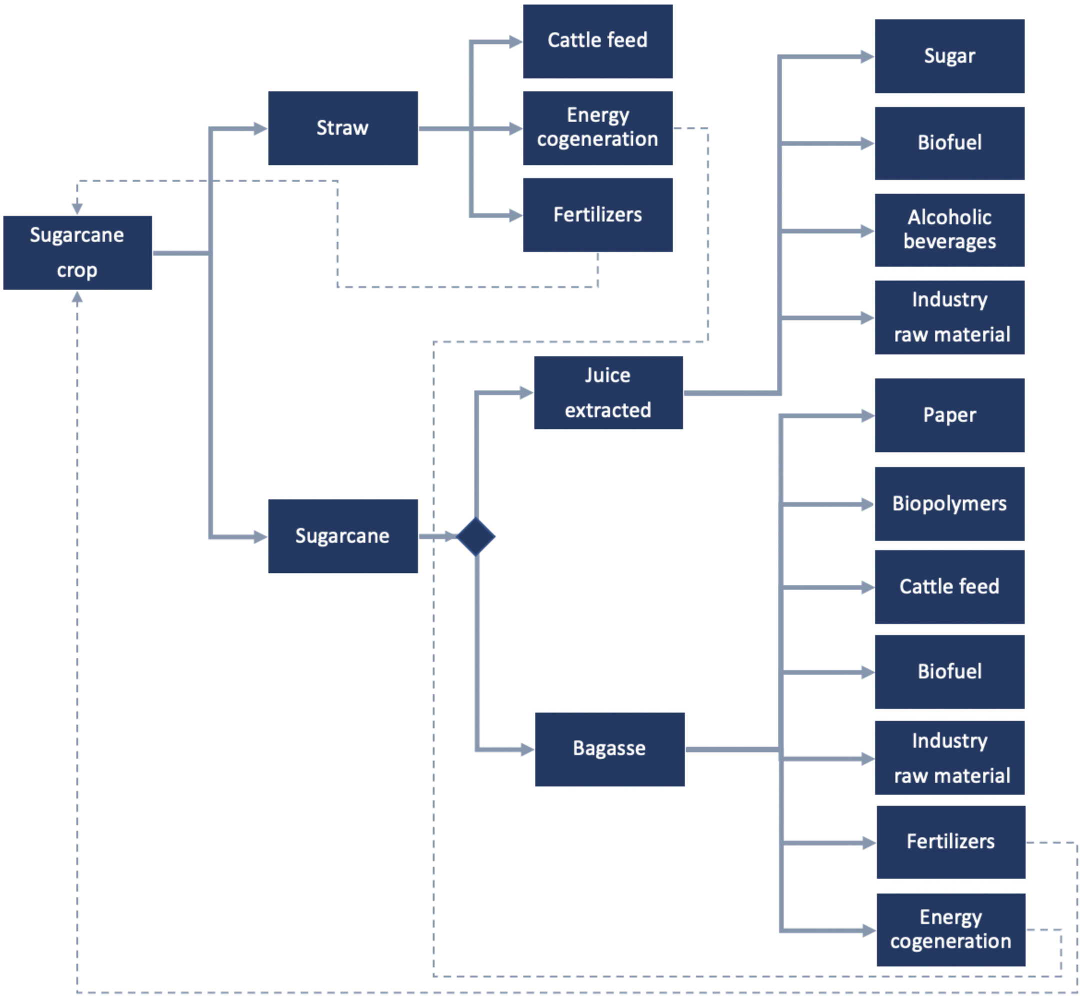


Figure 12. Brazilian sugarcane industry value chain
Own elaboration
Source: (Mertens, 2008; Cunha *et al.*, 2015)

On the other hand, land use and land cover change due to sugarcane cultivation is a highly controversial issue in Brazil (Strachman and Milan-Pupin, 2011; Soares-Filho *et al.*, 2012). In addition to the direct impact on ecosystems and their diversity, additional environmental pressures are generated, such as the reduction of soil fertility, generation of GHG emissions, and water and soil pollution (Soares-Filho *et al.*, 2012). Thus, in response to the effects of the growth of the sugar sector increases the necessity to look for sustainable alternatives to increase production efficiency, while the socio-environmental impact generated by this agricultural activity is reduced (Strachman and Milan-Pupin, 2011).

3.1.1.1 Campos dos Goytacazes

Sugarcane also is the crop with the most social and economic importance in the State of Rio de Janeiro, as it has the largest harvested area among the various agricultural products cultivated in the state (Santillán-Fernández *et al.*, 2014). Its productivity and cultivated area have presented variations related to climatic behavior, use of technology, supplies investment, and the renewal rate of sugarcane plantations (Veiga, Vieira and Ferreira, 2006). Although the State of Rio de Janeiro was one of the pioneers in the sugarcane industry, its current production does not exceed 2% of Brazilian sugarcane production (de Barros, 2006). However, it generates around R$175 million in each year; and employs directly and indirectly 15,000 people (Mendonça *et al.*, 2011). In the case of direct employment, the predominant type of employment relationship is the temporary, short-term contract, with the harvest phase being the one with the highest demand for labor (Veiga, Vieira and Ferreira, 2006).

Campos dos Goytacazes is a Brazilian municipality located between 21◦ 45’ 15” S and 41◦ 19’ 28’ W (Pedlowski *et al.*, 2002), in the North of the State of Rio de Janeiro inserted in the Atlantic Forest (Pereira, Oliveira and Lemos, 2005). The Atlantic Forest is a biome of great importance due to its high biological richness (Mateus *et al.*, 2017). However, today it is the second most threatened biome in the world, with a vegetation change of 40% at an annual rate of 4000 km^2 (Pereira, Oliveira and Lemos, 2005; Soares-Filho *et al.*, 2012), due to the growth of urban and rural settlements, industry and agriculture (Pereira, Oliveira and Lemos, 2005). Its remains have been reduced into fragmented, small, and isolated patches of less than 100 ha (Mateus *et al.*, 2017).

This municipality has a total area of 4,032.49 km^2, and an altitude of 11 masl (IBGE, 2021). The climate according to Köppen classification is Aw, characterized for been tropical humid with a hot rainy summer and dry winter, with an annual average temperature between 20 and 23◦C, and an annual average precipitation between 522 mm to 1635 mm (Pedlowski *et al.*, 2002). Campos dos Goytacazes presents a great diversity of soils, but the predominant is Haplic Cambisol (Inceptisol) (e Silva *et al.*, 2018; Oliveira *et al.*, 2021). Due to its location, climate, and soil characteristics, this municipality is located in an area of forest transition, with a predominance of seasonal semi-deciduous lowland forests (Mateus *et al.*, 2017).

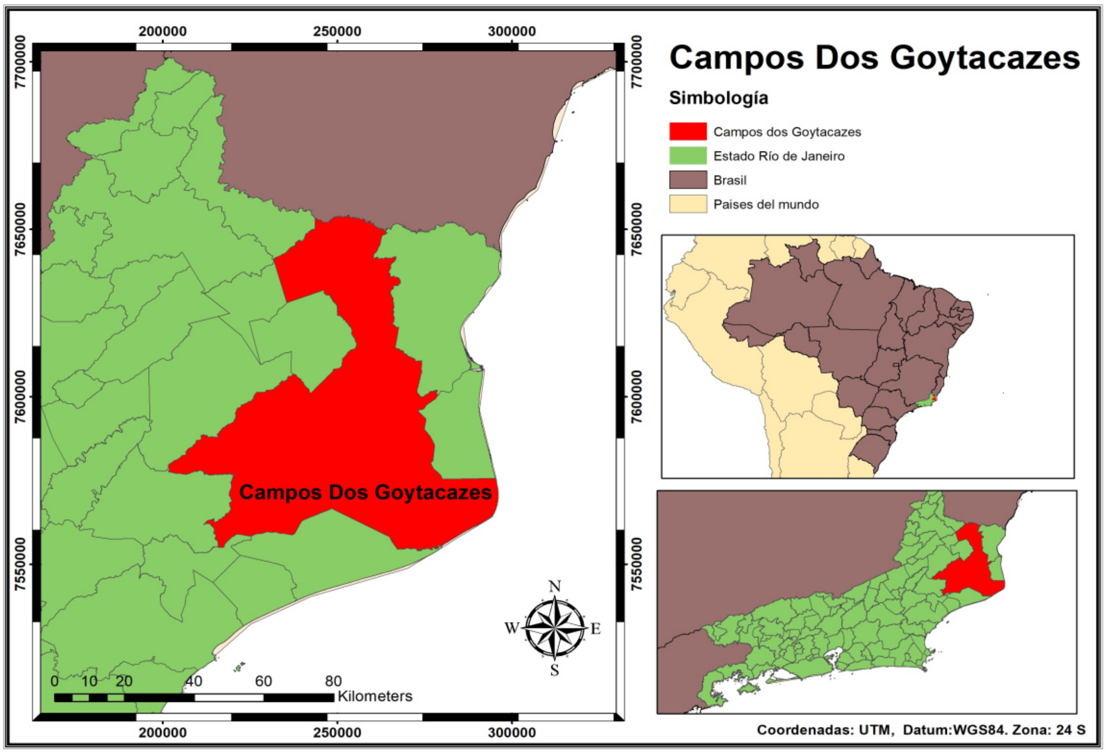


Figure 13. Campos dos Goytacazes
Own elaboration based on Pereira Passos Institute shp files (2018). Região Metropolitana do Rio de Janeiro – Municípios

Sugarcane cultivation in Campos dos Goytacazes is of great economic importance, as it is the largest producer in the State of Rio de Janeiro (dos Santos *et al.*, 2012), concentrating approximately 58% of the total harvested area of the state (Veiga, Vieira and Ferreira, 2006). Currently, the sugarcane planted area in Campos dos Goytacazes is about 30.487 ha with a production of 1.352.650 Mg (IBGE, 2021), used mainly for the production of sugar, anhydrous alcohol, and hydrated alcohol, with growth prospects in the short and medium term (Veiga, Vieira and Ferreira, 2006), as it is shown in Figure 14. The sugar produced is sold on the domestic and international markets, but the alcohol is sold only on the domestic market (Veiga, Vieira and Ferreira, 2006).

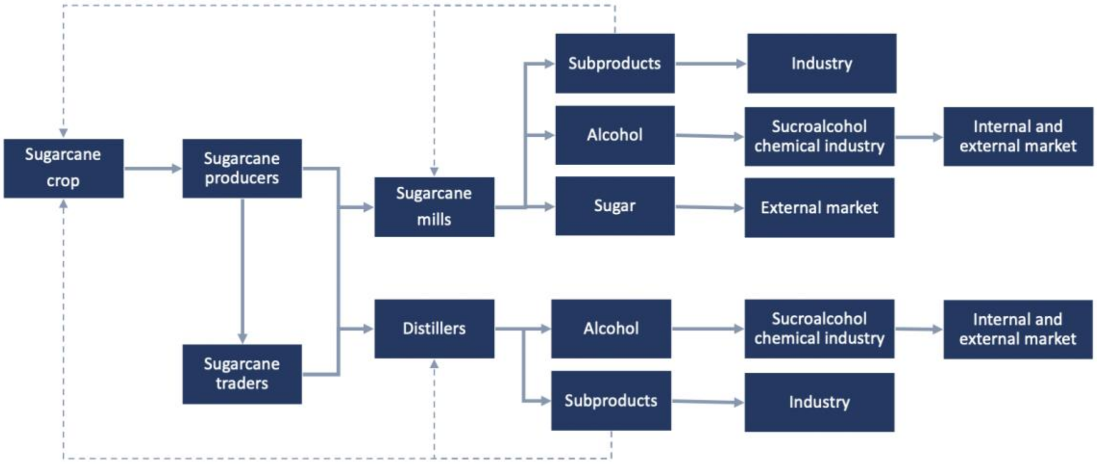


Figure 14. Sugarcane productions system in Campos dos Goytacazes
Own elaboration
Source: (Veiga, Vieira and Ferreira, 2006)

Since the 17th century, with the introduction of sugar cane, Campos dos Goytacazes has experienced social, economic, and environmental transformations around its production (Pedlowski *et al.*, 2002; Silva and Miranda, 2019; Gomes *et al.*, 2020). Initially, the region was controlled by the elites of sugar production, which used the slave workforce and altered the ecosystem to increase production (Magalhães, 2007; Silva and Miranda, 2019).

However, in 1929, due to the recession of the sugar international market and workforce competition with the oil industry, sugar cane production became a productive activity in crisis and dependence on the State (Silva and Miranda, 2019). The decline of sugarcane cultivation has been intensified in the 1950s due to competition with the oil industry, leading to the closure of sugar mills and production units (Silva and Miranda, 2019). Although PROALCOOL was implemented at the national level in 1975 to strengthen the sugarcane agroindustry, this program did not promote an increase in the cultivated area nor did it encourage the installation of sugar and alcohol mills in the region (Gomes *et al.*, 2020). As a result, the number of sugarcane mills has been continuously reduced in this municipality, with only two production units -Sapucaia (COAGRO) y Canabrava- currently in operation (Veiga, Vieira and Ferreira, 2006; Gomes *et al.*, 2020). (Figure 15). This has also caused the decline of approximately 12% of the area planted with sugarcane in the region (Gomes *et al.*, 2020).

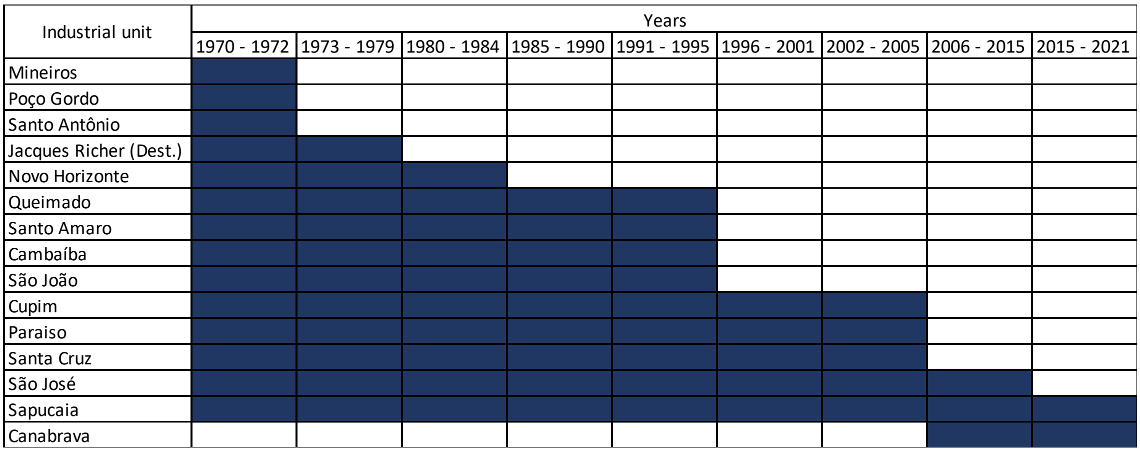


Figure 15. Closure of industrial units in Campos dos Goytacazes from 1970 to 2021
Own elaboration
Source: (Veiga, Vieira and Ferreira, 2006)

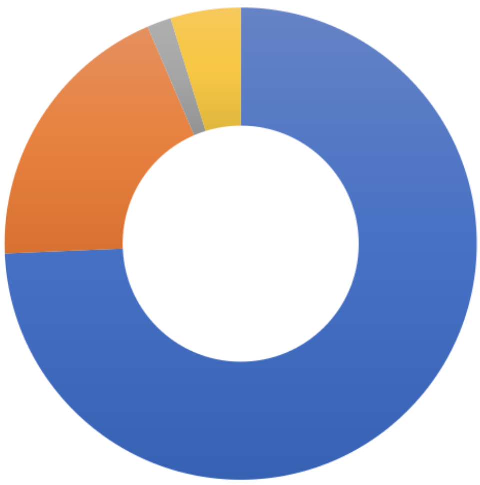
The production in this municipality is not homogeneous, there are four production strata based on Mg produced (Veiga, Vieira and Ferreira, 2006). These strata present a differentiated adoption of technology, which implies variations in their average productivity (Veiga, Vieira and Ferreira, 2006). However, producers in the region are characterized by being numerous and mostly of small scale, with a production of less than 41 Mg/ha, which is barely enough to survive (Veiga, Vieira and Ferreira, 2006). In addition, the machinery used by them for crop preparation and sugarcane harvesting is insufficient and old. (Veiga, Vieira and Ferreira, 2006). This is mainly due to the high cost of investment that producers must make to acquire harvesters and restructure sugarcane fields to make them suitable for mechanical harvesting, combined with a fragmented regional organizational structure (Veiga, Vieira and Ferreira, 2006). For this reason, sugarcane harvesting in the region is mostly conducted through intermediaries that have a good harvesting infrastructure and commercial advantages established with the sugar mills (Veiga, Vieira and Ferreira, 2006).

In Campos dos Goytacazes there are two organizations with a prominent role in sugarcane production. One of them is the Fluminense Association of Sugarcane Producers (ASFLUCAN), which represents all the producers in the region and aims to be the communication bridge between the producers, the industry, and the government (Inojosa, 2021). The second is the Rio de Janeiro State Agroindustrial Cooperative Ltda. (COAGRO), which was born in 2003 from the union of 57 sugarcane producers of the North Fluminense region, as a consequence of the production fall, mills closure, and the reduction of the labor force (COAGRO, 2021). It now has 9,800 cooperative members, and, currently manages Sapucaia mill, being the largest producer of ethanol and crystal sugar in the State of Rio de Janeiro (COAGRO, 2021). Its main objective is to ensure the economic growth of its members, by offering them the infrastructure needed to achieve the sustainable production of sugar and ethanol (COAGRO, 2021). For instance, COAGRO has invested in the mechanization of the harvest to overcome the limitations due to the ban on sugarcane burning, and to improve the working conditions of sugarcane production workers (COAGRO, 2021).

3.1.2 México

In Mexico's history, sugarcane production has been playing an essential role in society, economy, and politics (Aguilar-Rivera, 2010), as it has physiographic, climatic and edaphic characteristics that favor its cultivation (Aguilar, Olvera and Galindo, 2013). It was introduced in 1524 by the Spanish conquerors (García *et al.*, 2011). Currently, Mexico is considered one of the main producers of sucrose in the world (Flores, 2016). Moreover, sugarcane is one of the agricultural products with the highest national production and consumption (Aguilar, Contreras, Galindo, & Fortanelli, 2010).

In Mexico, 69% of the sugar produced is destined for the domestic market, 24,6% is exported mainly to the USA, and 6,3% is traded by the IMMEX program[1] (SAGARPA, 2021). As for the domestic market, 40 percent is destined for the food industries that use it as an input, and the remaining 60 percent is destined for direct consumption by the population (Mertens, 2008) (Figure 16).



Destination	MMt
Domestic market	3,94
Exports NAFTA	0,84
Exports other countries	0,57
Immex program	0,39

Figure 16. Sugar production destination
Own elaboration
Source: (SAGARPA, 2021)

It is grown in 22 states, as it is the raw material for the sugar industry, which has an annual average per capita consumption of 36.7 kg of sugar (SAGARPA, 2017). In the period 2017-2018, its production reaches 53´647.052 Mg (CONADESUCA, 2021). It generates around 4.40 million direct jobs and 2.2 million indirect jobs (García *et al.*, 2011;

[1] Temporary importation of industrial necessary inputs without payment of external trade taxes (general import tax, value-added tax, and countervailing duties).

Santillán-Fernández *et al.*, 2014). In the last years, the harvested area has been growing, though this has not been reflected in an increase in production (Flores, 2016).

Sugarcane has a cultivated area of 673,480 ha nationwide (Santillán-Fernández *et al.*, 2014). It is mainly cultivated in Veracruz (39.2%), Jalisco (10.5%), San Luis Potosí (9.1%), Tamaulipas (6.7%), Oaxaca (6.6%) and Chiapas (3.7%) (Arcudia *et al.*, 2018). As Veracruz, Jalisco and San Luis Potosí are the states with the largest cultivated area, they also can be considered as the largest emitters of GHGs from sugarcane burning (Flores, 2016). This taking into account that burning is a practice that is carried out in 90% of the area dedicated to this crop (Flores-Jiménez *et al.*, 2019)

Since the 1980s, the sugarcane industry began to present certain structural problems of deterioration, as evidenced by the growth of the cultivated area, which is not reflected in an increase in productivity, causing a drop in per capita agricultural GDP (Castillo *et al.*, 2020). Furthermore, the Mexican sugar industry has faced a challenge since 2008, when it was included in the North American Free Trade Agreement (NAFTA) (Mertens, 2008), which main goal is to eliminating tariffs, quotas and other trade impediments amongst Canada, USA and Mexico (Vorley, 2002). The cost of sugar production in Mexico is high compared to other countries such as Brazil, which makes it uncompetitive within NAFTA and globally, especially considering its direct competition with high fructose corn syrup (HFCS) (Mertens, 2008). It is for this reason that the pressure to reduce labor costs has promoted technological development in the field and industry, which is also influenced by the future shortage of personnel in the labor market, since the sugar chain is not very attractive to young people from rural areas (Mertens, 2008). However, sugarcane production has been affected by the lack of investment in the field (Santillán-Fernández *et al.*, 2014). Moreover, the poor diversification of sugarcane products has presented a continuous economic, environmental, and social crisis to this sector which survives based on state subsidies (Aguilar-Rivera, Galindo-Mendoza, *et al.*, 2010).

Mexico is contemplating the development of biofuels from sugarcane as part of product diversification (González and Castañeda, 2012). This measure could open up a scenario of complementarity with U.S. producers (Mertens, 2008). Diversification creates an opportunity for sugarcane growers to add value to their production in order to increase the price of their products (Aguilar-Rivera, 2011). However, the development of biofuels in Mexico is still at an incipient stage, so it is not possible to determine whether this is really a sustainable energy alternative (González and Castañeda, 2012). Thus, to achieve the diversification of its products, the Mexican sugarcane industry must overcome its deficit in technology, competitive capacity, and decent work (Mertens, 2008; Santillán-Fernández *et al.*, 2014). The actual value chain of the sugarcane industry can be seen in Figure 17.

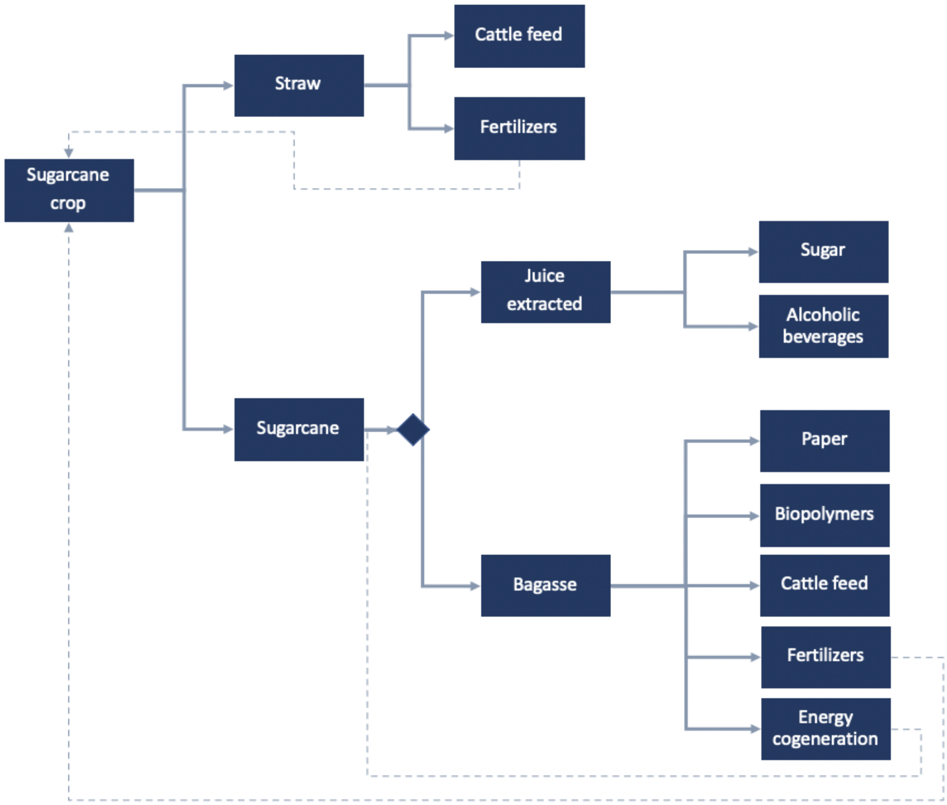


Figure 17. Mexican sugarcane industry value chain (Mertens, 2008)

Sugarcane organizations play a fundamental role in sugarcane production, grouping 95% of the country's sugarcane growers (Mertens, 2008). Their main objectives are to seek the social welfare of sugarcane growers, to manage the means and resources to improve production, and to be the bridge between the industry and growers (CONADESUCA, 2004). Both have a strong negotiating capacity with industry, producers and the government, which makes them a political force at local and national levels (Mertens, 2008). The organization with the largest number of members is the National Peasant Confederation (CNC) with 93,000 producers (Mertens, 2008), who are characterized by being producers with ejido[2] tenure and landholdings of 5-10 ha (CONADESUCA, 2004). A large number of members of this organization are marginalized, which limits their opportunities for investment in the field and the incorporation of technology to increase their production (CONADESUCA, 2004). On the other hand, producers owning between 5 and 80 ha of farmland are mainly associated with the National Confederation of Rural Landowners (CNPR) (CONADESUCA, 2004), which groups around 60,000 producers (Mertens, 2008). UNC-CNPR producers generally have good productivity and profitability, which allows them to make greater investments to improve their production conditions (CONADESUCA, 2004).

[2] It is a form of communal land tenure recognized by the Agrarian Law of 1917, based on ancestral forms of community organization for agrarian exploitation (Knowlton, 1998).

3.1.2.1 Tamasopo

Tamasopo municipality is located in the Huasteca region at the eastern of San Luis Potosí state, between 22° 15' - 21° 37' N, and 99° 09' - 99° 32' W (INEGI, 2009). The municipality has a total area of 1,326.41 km^2 (Pineda, 2013); and an altitude around 100 to 1800 masl (INEGI, 2009). Tamasopo has a population density is 21,7 people per square kilometer (Pineda, 2013). The climate according to Köppen classification is A(C) humid semicalid with annual temperature between 18°C and 26°C and the annual average precipitation is 800 to 2000 mm (INEGI, 2009; Pineda, 2013). The predominant types of soil are Leptosol (78,3%) and Vertisol (13,2%) (INEGI, 2009). Location, climate, and soil conditions support a varied vegetation cover of low deciduous forest, medium sub-evergreen forest, oak forest, and relicts of cloud forest (Giraldo, 2013).

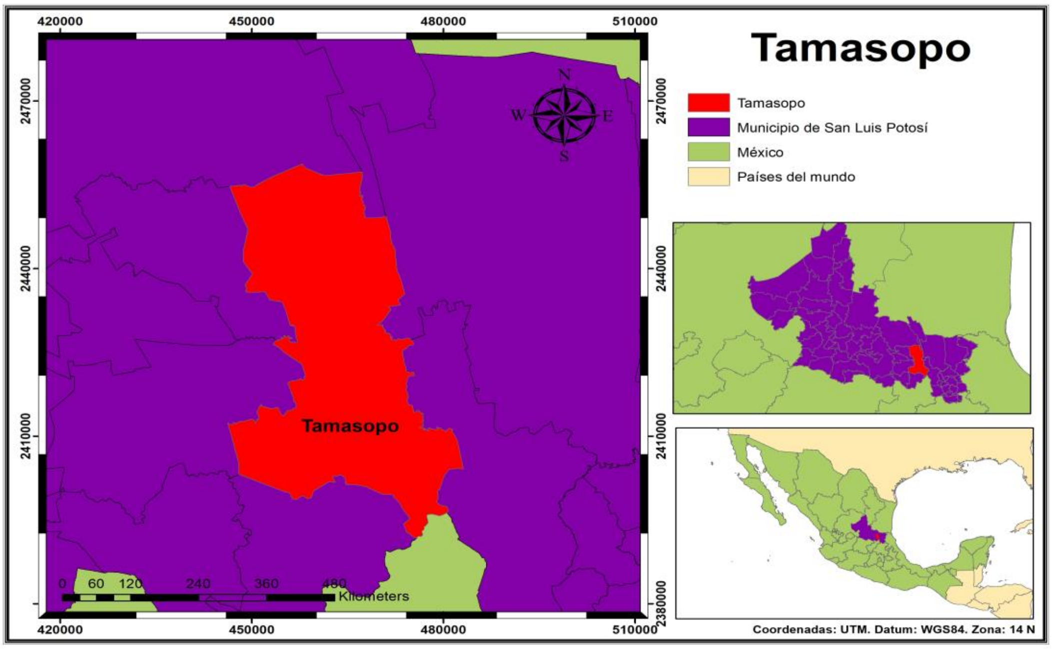


Figure 18. Tamasopo
Own elaboration based on shp files "División política municipal 1:250000" y "División política municipal 1:250000" (INEGI, 2019).

Tamasopo municipality, as being part of the Huasteca region, has physical and climatic characteristics that allowed the cultivation of sugar cane (Aguilar-Rivera, Galindo-Mendoza, *et al.*, 2010). It started as a colonist system in which indigenous people could grow sugarcane and sell their products to the nearby sugar mills for sugar production, or, to artisanal mills for the production of raw sugar called "piloncillo" or "panela" (Aguilar-Rivera, 2010), as is shown in
Figure **19**. The extension of the cultivation of sugar cane has changed the natural landscape, vegetation of the zone and the runoff of the basin, remarkably and irreversibly, mainly due to deforestation (Aguilar-Rivera, 2010; Giraldo, 2013). Moreover, sugar cane

production, in the Huasteca Potosina, is characterized by low production and profitability. As a result, it is considered survival agriculture with some limitations such as soil overexploitation, stressed crops, little or absent cane varietal renewal, poor field performance, and insufficient technological innovation (Castillo *et al.*, 2020).

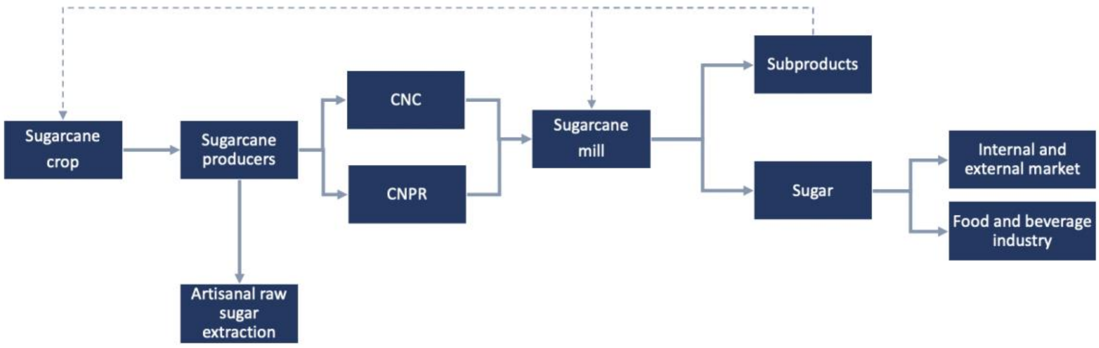


Figure 19. Sugarcane productions system in San Luis Potosí (CONADESUCA, 2004)

This crop is considered one of the most profitable crops in the region, which also allows farmers and their families to benefit from the medical care provided by the Mexican Social Security Institute (IMSS) (CONADESUCA, 2004). These motivate producers in marginal areas, with minimal land and low production (average of 25 Mg/ha), to continue growing the crop, even though sometimes its profitability is insufficient to subsist (CONADESUCA, 2004).

Alianza Popular sugar mill, located in Tambaca, is one of the four mills in the Huasteca Potosina region (Aguilar, Olvera and Galindo, 2013). In 2021, it receives sugarcane from an area of 18,972 ha corresponding mainly to the municipality of Tamasopo and its surroundings (Salazar & López, 2021), which is one of the oldest sugarcane production areas (Aguilar, Olvera and Galindo, 2013). Producers in this zone have an average area of 6,2 ha (Santiago, 2021).

This sugarcane cultivation area, as part of the Huasteca Potosina, is located in a flat to moderately steep terrain with slopes ranging from 0 to 20%, which would not impede its mechanization (Aguilar-Rivera, Contreras-Servin, *et al.*, 2010). However, (Salazar & López, 2021) mentioned in the interview (Annex 2: Interview results) that the topography is a limiting factor to mechanize harvesting in Tamasopo. Thus, 81% of the harvest in this area is semi-mechanized with pre and post burning (Flores, 2016). The main effect of this practice has been reflected in the decrease in production per hectare due to the loss of organic matter and soil nutrients (Flores-Jiménez *et al.*, 2019).

3.2 Reduction of sugarcane carbon footprint in Mexico and Brazil

The quantification, as well as the health and environmental consequences of greenhouse gases, is currently widely studied. Initially, burning regulations around the world focused on controlling this practice based on the analysis of the winds and the definition of schedules. However, this practice is less and less accepted (Cock, 1995). Some countries such as Mexico and Brazil have implemented laws for gradual reduction of burning practices previous to the harvesting of sugar cane (Aguilar, Olvera and Galindo, 2013; dos Santos and de Matos, 2017).

Brazil has adopted mechanization as the main strategy to eliminate burning during sugarcane harvesting to reduce emissions of air pollutants and improve soil quality (Ronquim, 2010). This measure also arose from the necessity to solve a social problem related to the precarious working conditions of those in charge of harvesting sugarcane manually (Strachman and Milan-Pupin, 2011). Thus, the State of São Paulo, as the largest sugarcane producer in Brazil (Ronquim, 2010), established in State Decree 42056, published in 1997, the differentiated and gradual elimination of burning sugarcane fields during the harvest until 2006 (Berra, 2004). This was rectified by State Law No. 11241, issued in 2002, which establishes a schedule for the elimination of burning until 2021 for mechanizable areas and until 2031 for non-mechanizable areas (Chaves and Bermúdez, 2006). It also defines mechanizable areas as those lands whose surface area is greater than 150 ha with a slope of less than 12% and with soils suitable for the use of machinery; and non-mechanizable areas as those that do not meet one or more of the criteria described above (Chaves and Bermúdez, 2006).

This law is complemented by the measures that must be adopted to conduct sugarcane burning, which considered the climatic, topographic, and environmental factors of the site to reduce atmospheric contamination, preserve conservation areas, and reduce impacts on nearby settlements and infrastructure (Chaves and Bermúdez, 2006). This legislation also establishes penalties in case of non-compliance with its dispositions (Chaves and Bermúdez, 2006). State Law No. 11241 generated changes in the harvesting system to reduce the environmental impacts of this agronomic practice and promoting the professional training of rural workers to minimize the social impact (Scaranello, 2017). Additionally, the Green Ethanol Protocol agreement has significantly triggered the mechanization of sugarcane harvest by anticipating the phase-out of burn harvest systems by 2014 (Nunes *et al.*, 2017).

Following this example, the State of Rio de Janeiro enacted State Law 5990 in 2011, which establishes the procedures to be adopted by sugarcane producers who use burning during the harvest. Moreover, it mandates the gradual elimination of sugarcane burning, stipulating 2020 as deadline for the total mechanization of the harvest of mechanizable crops and 2024 for non-mechanizable crops (Governo do Estado do Rio de Janeiro, 2011).

Currently, the evolution of the agricultural area promoted by the law is evident in the State of Sao Paulo, where 42 to 45% of the sugarcane is already harvested mechanically; and also at the national level, where an average of 35% of the cultivated area is already mechanized (Iturra, Silva and Díaz-Ambrona, 2011). In addition to the regulations, Brazil is developing and implementing new technology as strategies for the sustainability of sugarcane cultivation, among which we can highlight precision agriculture, genetic modifications of sugarcane, adaptation of harvesters, and new processes for obtaining subproducts from straw and bagasse (Iturra, Silva and Díaz-Ambrona, 2011; Strachman and Milan-Pupin, 2011; Scaranello, 2017). For instance, the Brazilian Agricultural Research Company (EMBRAPA), through the analysis of satellite images is contributing to the development of sugarcane precision agriculture for the reduction of GHG emissions (Strachman and Milan-Pupin, 2011). The transportation sector is also playing an important role in the modernization process of the sugarcane agribusiness, based on fuel savings and optimization of fleet operations to continuously feed the mills (Strachman and Milan-Pupin, 2011; Soares-Filho *et al.*, 2012).

Moreover, Brazil has created agreements with countries around the world, such as Germany, focused on the sustainable development of sugarcane production. For example, “CLIENT II - International Partnerships for Sustainable Innovation" programme, created by the German Federal Ministry of Education and Research, is promoting a German-Brazilian collaboration -called TRABBIO- oriented to develop innovative solutions to face sustainability challenges of sugarcane production systems in Campos dos Goytacazes in Rio de Janeiro (CLIENT II., 2020).

On the other hand, Mexico has no specific regulations to mitigate atmospheric emissions from sugarcane harvest despite its effects on human health, soil properties, and climate change. However, Mexico has established agricultural development plans that promote good practices for sugarcane cultivation (Flores-Jiménez *et al.*, 2019). For instance, the National Sugarcane Agroindustry Program, in line with the National Development Plan and the Sectoral Program for Agriculture and Rural Development, aims to achieve the welfare of the population dedicated to sugarcane cultivation, as well as to meet the objectives of the Sustainable Development Agenda (CONADESUCA, 2019). Thus, among its objectives, it includes the promotion of mechanization of the sugarcane field to achieve the progressive replacement of burning by green harvesting (Aguilar-Rivera, 2011; CONADESUCA, 2014, 2019).

In addition to regulating the commercial relationship between producers and the industry, the Law for the Sustainable Development of Sugarcane issued in 2005 establishes general provisions that promote research and technology development, pollution reduction, the adoption of sustainable soil management practices, and the use of residual sugarcane biomass (Mertens, 2008). Although the burning of sugarcane fields is not directly regulated by the Sugarcane Sustainable Development Law, the Mexican Official Standard NOM-015-SEMARNAT/SAGARPA, issued in 2007, establishes some technical specifications and procedures for the use of burning in forestry and agricultural areas (Flores, 2016).

In 2012, Mexico published the General Law on Climate Change, which empowers states and municipalities to develop public policies to adapt to climate change and generate actions to mitigate emissions of greenhouse compounds and gases (Flores, 2016). In the case of the State of San Luis Potosi, this has allowed the inclusion of provisions to manage GHG emissions in the Environmental Law, which contemplates open agricultural burning (Flores, 2016).

Despite existing regulations, mechanization of sugarcane harvesting has not been a relevant strategy for the sustainability of sugarcane production in Mexico, due to the fact that the fields are predominantly (70%) small -less than 4 ha- and are located on stony soils with steep slopes (48%) (Vilaboa and Barroso, 2013).

4 Chapter IV: Methodology

4.1 Data acquisition

4.1.1 Literature review

A review of the state of the art conducted out through scientific articles, previous studies, or physical and digital documents related to 1) historical background of the production of sugar cane in Tamasopo and Campos dos Goytacazes, 2) Limitations and advantages of harvesting approaches in Mexico and Brazil, and 3) Data regarding sugar cane burning in the study areas. This review provided information to create the conceptual framework (chapter II) and to define the context regarding the reduction of emission of sugarcane harvest in the study cases (chapter III). Moreover, it provided the information for PESTEL impact analysis of sugarcane harvest with burning and green harvest from Chapter V.

4.1.2 Qualitative data

At this stage, data on the field was obtained through semi-structured interviews and focus group discussions conducted online because of actual COVID-19 restrictions. These methods were used for identifying the factors involved in the transition process from sugarcane burning to green harvest, through the perspectives of three stakeholders: 1) sugarcane producers, 2) representatives of sugarcane organizations, and 3) academia or technological developers. It supports the identification of the variable sets, which are reflected in Chart 5 and Chart 7 from Chapter V.

The detail information resultant from the survey can be found in (Annex 2: Interview results).

4.1.3 Quantitative data

To conduct the PESTEL analysis, with the information found in the literature, the magnitude of each impact was defined, with 1 being the lowest and 3 the highest. This analysis will be further described in section 4.2.1.

The analysis of data for the MICMAC method was conducted through a participatory scoring of the level of dependence of the identified variables. It was carried out by a group of experts (between 4 and 6) composed of individuals from the three stakeholders defined above. The MICMAC method will be further described in section 0. The interaction among the actors for giving consensus data enables the exchange of their ideas, perspectives, and knowledge to achieve an effective assessment of the variables.

4.2 Methods

The process to analyze the potential reduction of atmospheric emissions from the harvesting process in the study cases is conducted in five steps, as it is shown in

. The research method used is based on quantitative and qualitative approaches to reflect the reality of the specific context of each study case.

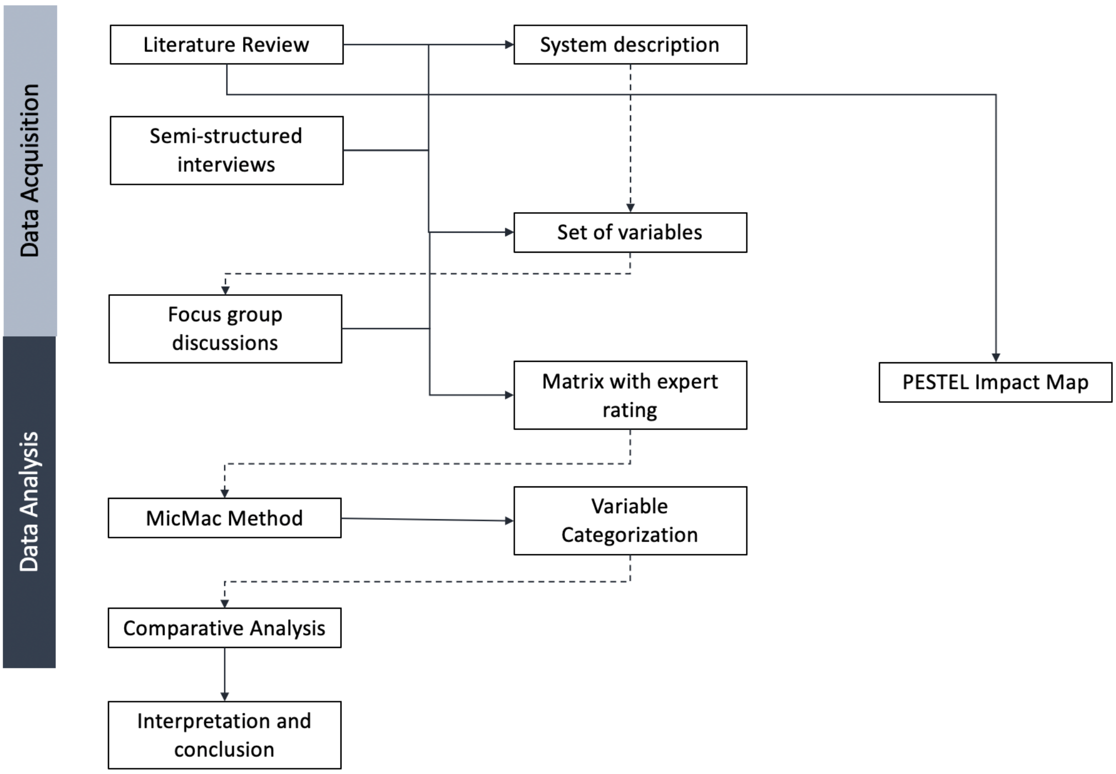


Figure 20. Flowchart of the research approach
Own elaboration

4.2.1 PESTEL impact analysis

PESTEL analysis is a tool that will contribute to evaluate the current context of the harvest situation with and without burning, by first identifying the factors of the two types of sugarcane harvesting (Aguilar-Rivera, 2011). In this case, according to PESTEL method, factors will be identified based on the literature review and the they will be divided into six categories: 1) political, 2) economic, 3) social, 4) technological, 5) environmental and 6) legal (Yüksel, 2012).

Then, they will be rate by assessing their impact. The first consideration will be if it is negative or positive, and the second will be its magnitude (Hussain, 2013). As an adaptation for this thesis, positive factors will be placed graphically on the right and negative factors on the left. Additionally, the magnitude will be rated as low = 1, medium = 2, and high = 3; as it is shown on Figure 21. Finally, the total values of the negative and positive impacts of harvesting with and without burning will be summed up to identify which practice has the most benefits.

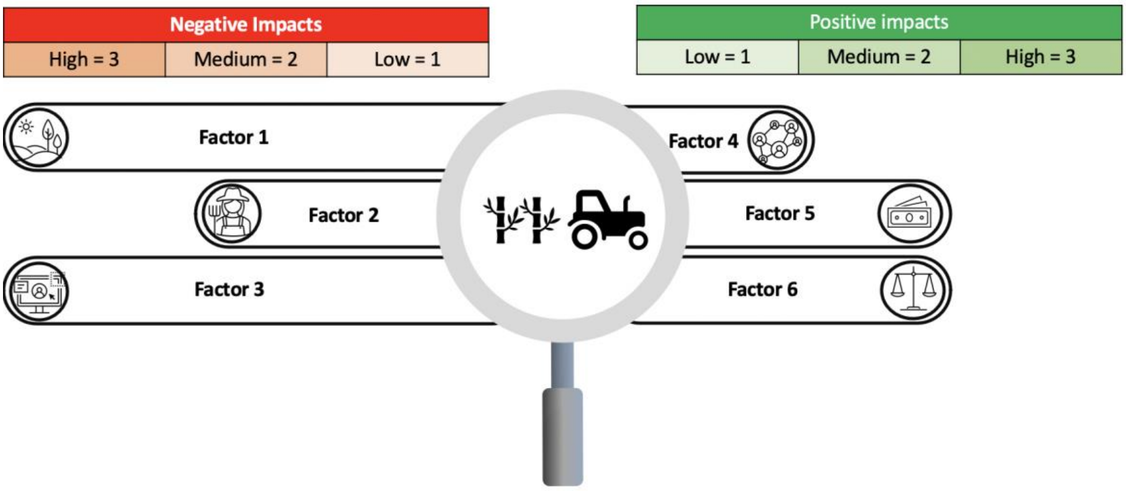


Figure 21. PESTEL Analysis Map construction
Own elaboration

4.2.2 Semi-structured interviews

This technique is used to collect general and specific information on a given topic, through dialogues with key individuals or groups. The semi-structured interviews encourage communication to identify the different points of view of the population regarding the studied problem (Geilfus, 2009). For the semi-structured interviews, a question guide for each stakeholder was developed (see Annex 1: Interview Guideline). With the support of this interview, the variables of each study case were identified.

4.2.3 MICMAC Method

Agriculture, as a complex system, has diverse factors and actors interrelated with each other (Barati *et al.*, 2019). Therefore, an appropriate method to understand this interrelation is MICMAC (Impact Matrix Cross-Reference Multiplication Applied to a Classification). This method was developed by Michel Godet and François Bourse (Ahmad *et al.*, 2019), and can be used as a qualitative structural analysis tool to describe the system, identify the connections among their components, and determine the direct and indirect variables that play a significant role in the system (Villegas-Vilchis *et al.*, 2020). For the case of this research project, the MICMAC structural analysis will constitute an important tool to understand the sugarcane production systems in Campos dos Goytacazes and Tamasopo by the identification and interrelation of the variables associated with the reduction of sugarcane burning, through the following phases:

Phase 1. Identification of variables

According to the method, a collective reflection of a group of experts should be used to obtain a homogeneous list of direct and indirect variables, as shown in Chart 2 (Barati *et al.*, 2019). Key stakeholders from each study case, such as landowners, sugarcane group leaders, technology developers or academia formed the group of experts. However, regarding the situation caused by COVID-19, the individuals in the expert group were first contacted separately and a semi-structured interview was conducted to understand the current context of the process of shifting from harvest with burning to green harvesting. The identified variables resultant from these interviews are presented in Chart 9 for Campos dos Goytacazes and in Chart 11 for Tamasopo. Subsequently, a meeting was held with each group of experts to select the relevant variables for each case study (Chart 4 and Chart 6). To conduct this phase, the following question was answered: what are the political[3], economic, technological, social and environmental variables that condition the reduction of sugarcane burning? (Villegas-Vilchis *et al.*, 2020)

Type of variables	Group name	Symbol	Description
Internal	Political	Var1 Var2 ..	
	Economic	..	
	Technological	..	
	Social	..	
	Environmental	..	
External	Political	..	
	Economic	..	
	Technological	..	
	Social	..	
	Environmental	..	

Chart 2. List of internal and external variables
Elaborated by Denisse González V.
Source: (Barati et al., 2019)

[3] Regulations and government

Phase 2. Built the structural analysis matrix

A system can be interpreted by the interrelation of its variables. Thus, a structural analysis matrix (Chart 3) allows to identify the connection between the variables (Villegas-Vilchis *et al.*, 2020). This procedure creates a common language among the group of experts, and at the same time organize and classify the ideas related with the influence between the variables (Barati *et al.*, 2019). The group of experts gives a value according to the degree of influence (0 no influence, 1 weak, 2 medium and 3 strong) between the pair of variables (Villegas-Vilchis *et al.*, 2020). It is explained graphically in Figure 22.

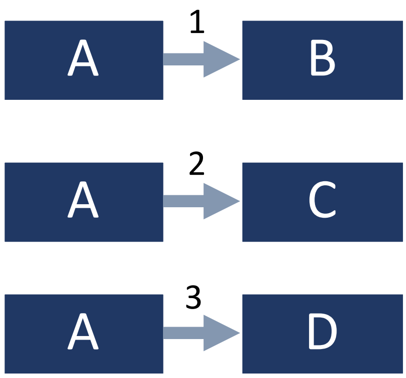


Figure 22. Direct influence between variables
Own elaboration
Sources: (Amutio, Candau and Mañas, 2012)

Due to logistical difficulties in coordinating with Mexico, a variant of this phase of the method was chosen. The matrix was sent to each stakeholder in the form of a survey through Google Docs. The results are then integrated to produce a single matrix (Chart 3). The data whose rating is the same are kept, while those with differences will be consulted with stakeholders until a consensus value is reached.

Variables	**Var1**	**Var2**	**..**	**Influence**
Var1	-	1	3	∑
Var2	1	-	2	∑
..	2	1	-	∑
Dependence	∑	∑	∑	-

Chart 3. Structural analysis matrix
Elaborated by Denisse González V.
Source: (Barati et al., 2019)

Phase 3. Identification of the strategic variables: It confirms the importance of certain variables, but also it reveals other variables which play an important role in the system, even though they were not identified at the begging of this method (Barati *et al.*, 2019). This phase is accomplished by using a direct classification, and an indirect classification (Villegas-Vilchis *et al.*, 2020).

The direct classification is obtained by the sum of the rows and columns of the matrix (Chart 3), in which the sum of the arrows corresponds to the influence of each variable on the others. The sum of columns indicates the dependence of each variable in relation to the others. These values allow the identification of essential variables in the system (Perez-Uribe and Vargas-Arévalo, 2017).

Then, the potential elevation of the matrix has to be done for the indirect classification (Villegas-Vilchis *et al.*, 2020). The indirect classification in the MICMAC allows us to rank of the variables in order of influence by the study of the diffusion of the impacts along the paths and the feedback loops (Perez-Uribe and Vargas-Arévalo, 2017). To calculate it, the power of the matrix must be increased by considering the number of paths and loops of length (1, 2, .. , N) that result from or arrive at each variable (Barati *et al.*, 2019). Generally, the classification should become stable after a multiplication of order 3, 4 or 5 (Perez-Uribe and Vargas-Arévalo, 2017).

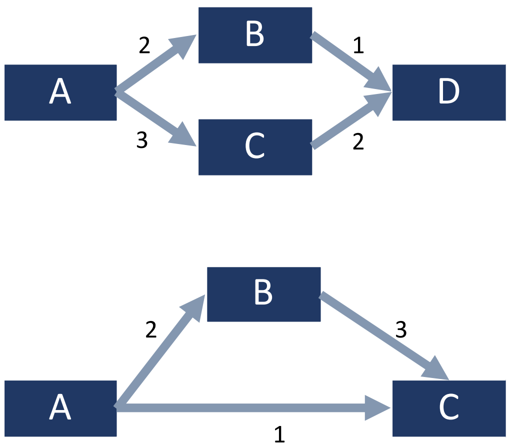


Figure 23. Indirect influence between variables
Own elaboration
Sources: (Amutio, Candau and Mañas, 2012)

As a result, the influence and dependence of each variable is represented graphically on a Cartesian plane, in which the abscissa (X) axis corresponds to the dependence and the ordinate (Y) axis corresponds to the influence (Villegas-Vilchis *et al.*, 2020). Through this method, two graphs will be obtained, one with the direct classification data and other with the indirect classification data. Based on the influence and dependence, the variables will be classified into four clusters (Saxena, Sushil and Vrat, 1990; Ahmad *et al.*, 2019):

- Cluster I: Autonomous variables. They are weak drivers and weak dependent variables. Thus, these variables are relative disconnect from the system, as they have few links with it, though some of them could be strong (Saxena, Sushil and Vrat, 1990).

- Cluster II: Dependent variables. They are strongly dependent variables but with a weak driving power (Saxena, Sushil and Vrat, 1990).

- Cluster III: Strategic variables. They have a strong driving power as well as strong dependence. These variables are considered key variables as they have the highest impact on the system. (Saxena, Sushil and Vrat, 1990; Villegas-Vilchis *et al.*, 2020).

- Cluster IV: Independent variables. They are strong driving variables with a weak dependence (Saxena, Sushil and Vrat, 1990).

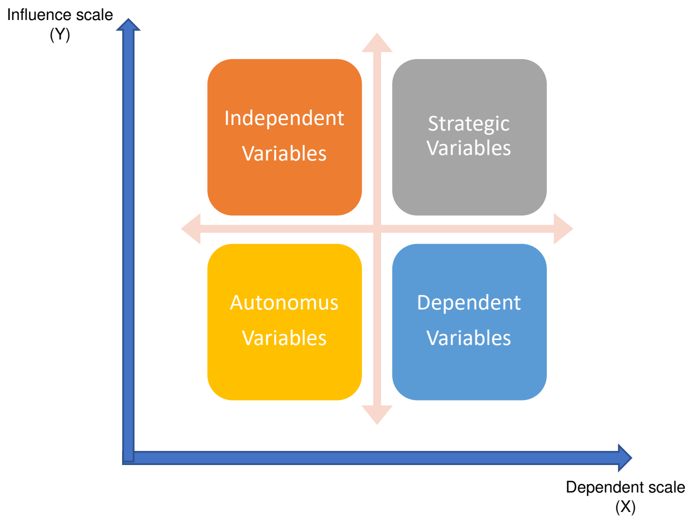


Figure 24. Influence-Dependence Graphic
Own elaboration
Sources: (Saxena, Sushil and Vrat, 1990)

Subsequently, with the information obtained from MICMAC method, the analysis will be conducted to address the main objective of the following research by comparing the results from Tamasopo and Campos dos Goytacazes.

5 Chapter V: Results

5.1 PESTEL impact analysis of sugarcane harvest

Through this method and based on the bibliographic information found (Chapter 2), a general analysis of the impacts generated by harvesting with burning and green harvesting was carried out, as shown in Figure 25 and Figure 26.

Figure 25 shows that green harvesting has four negative impacts with a total magnitude of 10, and nine positive impacts with a total magnitude of 16. Subtracting the value resulting from the negative impacts from the value of the positive ones results in a total of 6, which means that this agronomic practice has higher positive impacts.

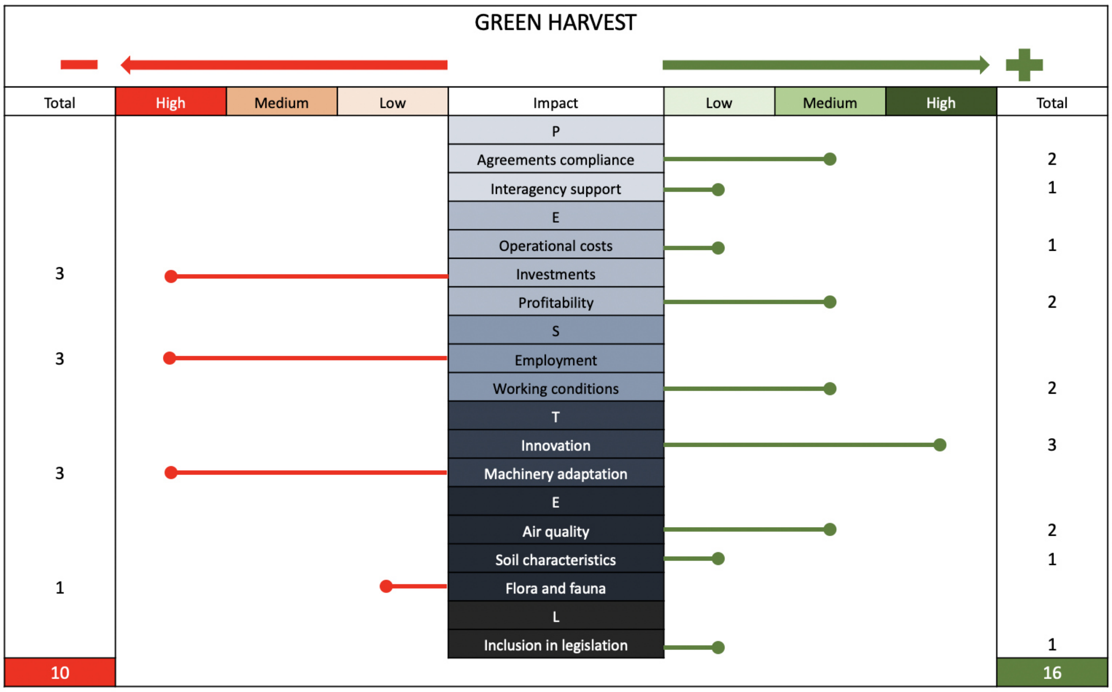


Figure 25. PESTEL - Green harvest
Own elaboration

On the other hand, Figure 26 shows that harvesting with burning has eight negative impacts with a total magnitude of 18, and five positive impacts with a total magnitude of nine. Subtracting the value resulting from the negative impacts from the value of the positive impacts gives us a total of -9, which means that this agronomic practice has more negative impacts.

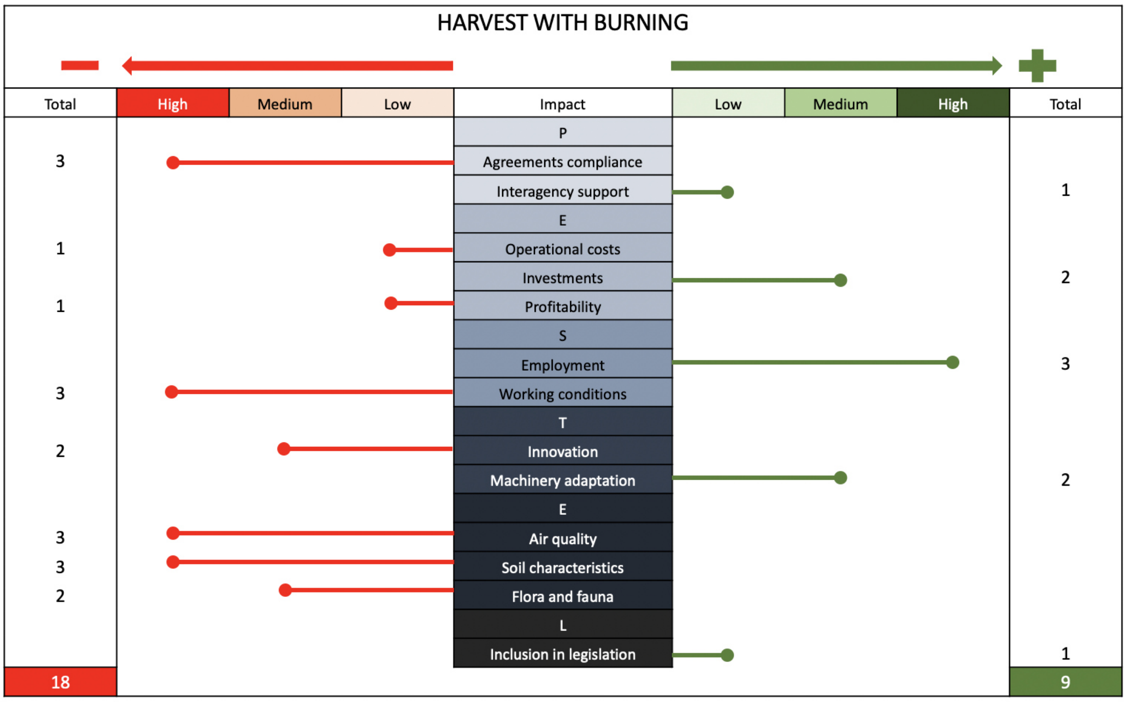


Figure 26. PESTEL - Harvest with burning
Own elaboration

Consequently, green harvesting could be a better practice, however, specific factors of sugarcane cultivation areas must be considered.

5.2 Campos dos Goytacazes

The group of experts from Campos dos Goytacazes was formed by Willian Pereira and Tamys Fernandes researchers from Federal Rural University of Rio de Janeiro, the producers Frederico Veiga and José Ricardo, and Tito Inojosa from ASFLUCAN. Based on the interviews with the stakeholders from the sugarcane agroindustry (Annex 2: Interview results), 46 variables were initially identified for Campos dos Goytacazes, as it can be seen in Annex 3: Campos dos Goytacazes variables and matrix. As a result of the collective reflection, Chart 4 shows the 24 most relevant variables related to the sustainability of the harvest in Campos dos Goytacazes, which were used in the matrix for analysis.

FACTORS OF CHANGE			
Group name	Item	Symbology	Description
Political	1	LEG	State environmental legislation (harvest)
	2	ASSOC	Association management
Economic	3	PCOST	Production cost (labor, machinery, operational)

	4	MINV	Machinery (harvester) investment
	5	PROF	Sugarcane profitability
	6	TCOST	Cane transportation cost
	7	LMO	Labor and machinery outsourcing (consortiums)
	8	FSCOAGRO	Financial solvency of COAGRO
	9	EMPDIV	Employment diversity in the State
	10	CLOSMILL	Closure of sugar mills
Technological	11	ALTERN	Research, development, and innovation of alternatives
	12	HADAPT	Harvester adaptability
	13	HAVAIL	Harvester availability in the market
Social	14	CAVAIL	Availability of cutters
	15	COMPWORK	Competent workmanship for the use of machinery
	16	DPROD	Diminution of sugarcane producers
	17	UNEMPL	Unemployment
	18	DISCP	Discouragement of producers
	19	LMIG	Labor migration
Environmental	20	LAND	Characteristics of the land (size, location, slope)
	21	DEGRAD	Soil, water, and air degradation
	22	FIRE	Arson (fire outside of planning)
	23	PEST	Pest incidence
	24	CC	Climate change

Chart 4. Campos dos Goytacazes relevant variables of harvest sustainability
Own elaboration

From the list of variables in Chart 4, the influence that each variable has in relation to the others is identified. For this purpose, a double-entry matrix was generated as it is shown in Annex 3: Campos dos Goytacazes variables and matrix, which has the ratings given by the experts in response to the question "Is there a direct influence relationship between variable x and variable y? In cases where the answer was negative, 0 was given. However, in the case of a positive answer, the degree of direct influence is asked; if the answer is weak, 1 is given, medium 2 and strong 3.

As a result of the application of the methodology, according to the matrix elaborated (Annex 3: Campos dos Goytacazes variables and matrix), the following results for dependence and influence were obtained by factor as it is present in Chart 5 and Figure 27.

FACTORS OF CHANGE		Influence	Dependence
State environmental legislation (harvest)	LEG	99	26
Association management	ASSOC	28	26
Production cost (labor, machinery, operational)	PCOST	56	66
Machinery (harvester) investment	MINV	19	6
Sugarcane profitability	PROF	32	42
Cane transportation cost	TCOST	17	23
Labor and machinery outsourcing (consortiums)	LMO	19	35
Financial solvency of Coagro	FSCOAGRO	31	39
Employment diversity in the State	EMPDIV	19	32
Closure of sugar mills	CLOSMILL	38	39
Research, development and innovation of alternatives	ALTERN	37	44
Harvester adaptability	HADAPT	40	25
Harvester availability in the market	HAVAIL	42	22
Availability of cutters	CAVAIL	34	40
Competent workmanship for the use of machinery	COMPWORK	22	34
Diminution of sugarcane producers	DPROD	44	44
Unemployment	UNEMPL	29	49
Discouragement of producers	DPROD	40	47
Labor migration	LMIG	32	48
Characteristics of the land (size, location, slope)	LAND	44	3
Soil, water and air degradation	DEGRAD	30	35
Arson (fire outside of planning)	FIRE	22	20
Pest incidence	PEST	21	17
Climate change	CC	41	29

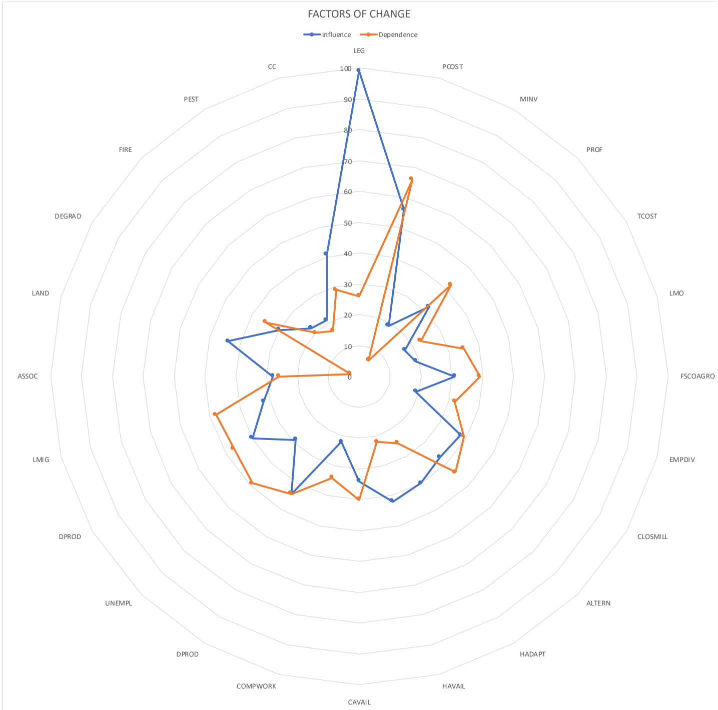


Chart 5. Campos dos Goytacazes – Sugarcane harvest influence and dependence results

Figure 27. Campos dos Goytacazes – Sugarcane harvest influence and dependence factors

Own elaboration

According to the results presented, it is noted that the variables with the greatest influence on the system are:

- State environmental legislation
- Production cost
- Sugarcane profitability
- Closure of sugar mills
- Harvester availability in the market
- Diminution of sugar cane producers
- Characteristics of the land (size, location, slope)
- Climate change

On the other hand, the variables with higher values of dependence are:

- Production cost
- Sugarcane profitability
- Research, development, and innovation of alternatives
- Diminution of sugar cane producers
- Unemployment
- Discouragement of producers
- Migration

It is observed that the variables: production cost, sugarcane profitability, and diminution of sugarcane producers are in both groups, thus they have great influence and dependence in the system.

Furthermore, with these results, using MICMAC software, the variables are positioned in the Cartesian plane, as shown in the maps of direct influence-dependence in Figure 28 and indirect influence-dependence in Figure 29.

Figure 28. Campos dos Goytacazes - Direct influence/dependence map
Own elaboration by using MICMAC software

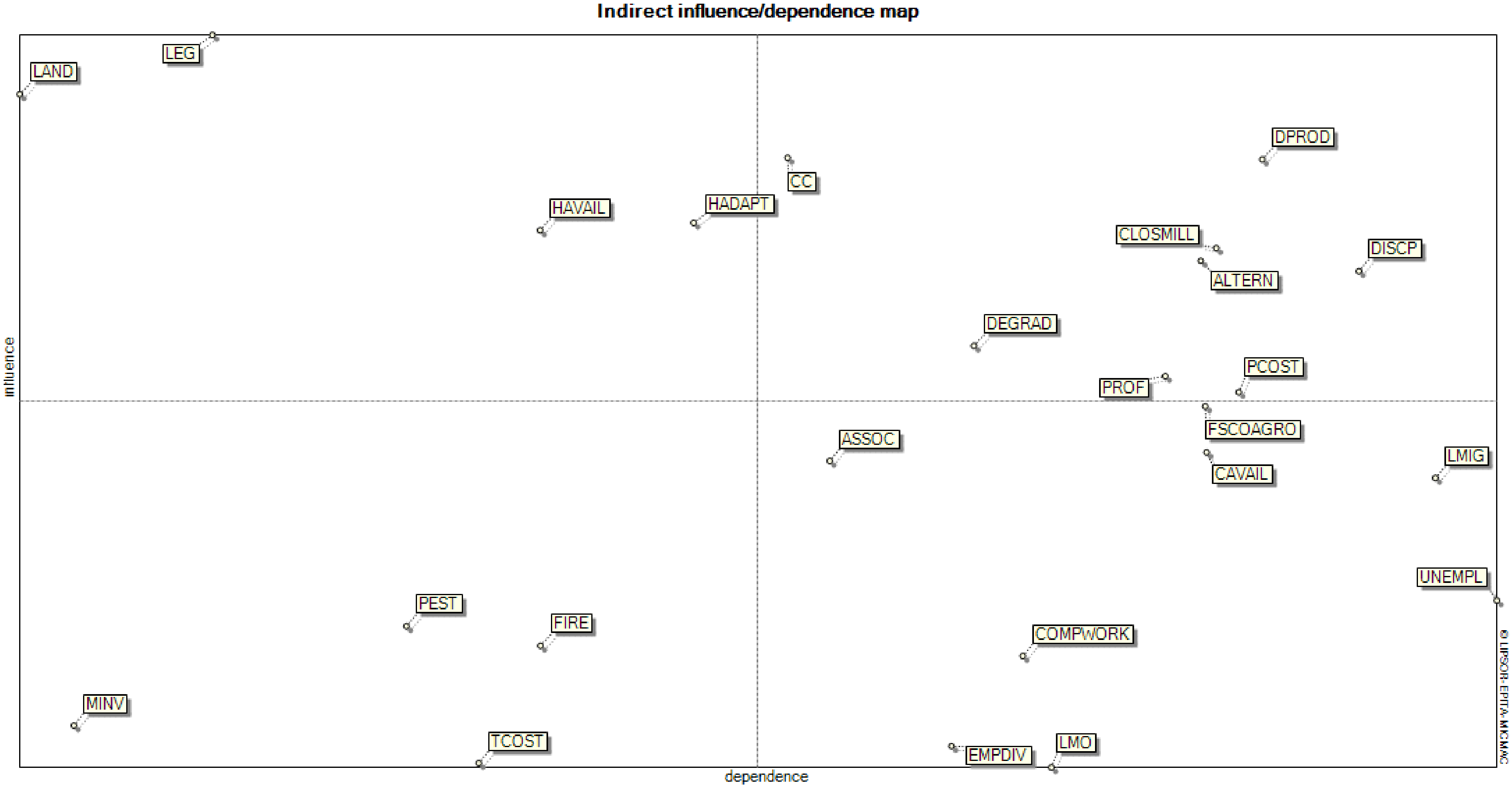


Figure 29. Campos dos Goytacazes - Indirect influence/dependence map
Own elaboration by using MICMAC software

5.3 Tamasopo

The group of experts from Tamasopo was formed by Ing. Irais Salazar Gómez and Ing. Enrique López Rubio, researchers from the National Center for Research and Technological Development for the Sugarcane Agroindustry of the Huasteca Potosina, A.C., Luis Ramiro García Chávez from CONADESUCA, and the producers belonging to the CNC, Luis Roberto Fortanelli, Erika Santiago Hernández, and Alfredo Rodríguez Juárez. Based on the interviews with the stakeholders from the sugarcane agroindustry (Annex 2: Interview results), 32 variables were initially identified for Tamasopo, as it can be seen in the Annex 4. Tamasopo variables and matrix. As a result of the collective reflection, Chart 6 shows the 17 most relevant variables related to the sustainability of the harvest in Tamasopo, which were used in the matrix for analysis.

FACTORS OF CHANGE			
Group name	Item	Symbology	Description
Political	1	SUSTLAW	Sustainable sugarcane development law
	2	SINORG	Producers’ organizations
	3	INCENT	Government incentives to producers
	4	NAFTA	Free-trade agreement (USA)
Economic	5	PCOST	Production cost (labor, machinery, operational)
	6	PROF	Profitability
	7	SQUAL	Sugarcane quality
	8	PDIV	Products diversification
	9	MDEM	Reduction in the demand for sugar (competition with other sweeteners)
Technological	10	ALTERN	Research, development, and innovation of alternatives
	11	HADAPT	Harvester adaptability
Social	12	WORKCOND	Cutters working conditions
	13	PCHAR	Producers characteristics (age, education)

	14	COMPWORK	Competent workmanship for the use of machinery
Envrionmental	15	LAND	Characteristics of the land (size, location, slope)
	16	DEGRAD	Soil, water, and air degradation
	17	CC	Climate change

Chart 6. Tamasopo relevant variables of harvest sustainability
Own elaboration

Likewise, from the list of variables in Chart 6 the MICMAC method is used to generate the matrix as shown in Annex 4.

As a result of the application of the methodology, according to the matrix elaborated (Annex 4. Tamasopo variables and matrix), the following results for dependence and influence were obtained by factor as it is present in Chart 7 and Figure 30.

FACTORS OF CHANGE		Influence	Dependence
Sustainable sugarcane development law	SUSTLAW	30	19
Producers' organizations	SINORG	33	34
Government incentives to producers	INCENT	17	18
Free-trade agreement (USA)	NAFTA	31	31
Production cost (labor, machinery, operational)	PCOST	33	39
Profitability	PROF	33	37
Sugarcane quality	SQUAL	28	40
Products diversification	PDIV	21	26
Reduction in the demand for sugar (competition with other sweeteners)	MDEM	30	21
Research, development and innovation of alternatives	ALTERN	33	38
Harvester adaptability	HADAPT	26	30
Cutters working conditions	WORKCOND	22	33
Producers characteristics (Age, education)	PCHAR	26	19
Competent workmanship for the use of machinery	COMPWORK	23	23
Characteristics of the land (size, location, slope)	LAND	26	28
Soil, water and air degradation	DEGRAD	27	25
Climate change	CC	24	21

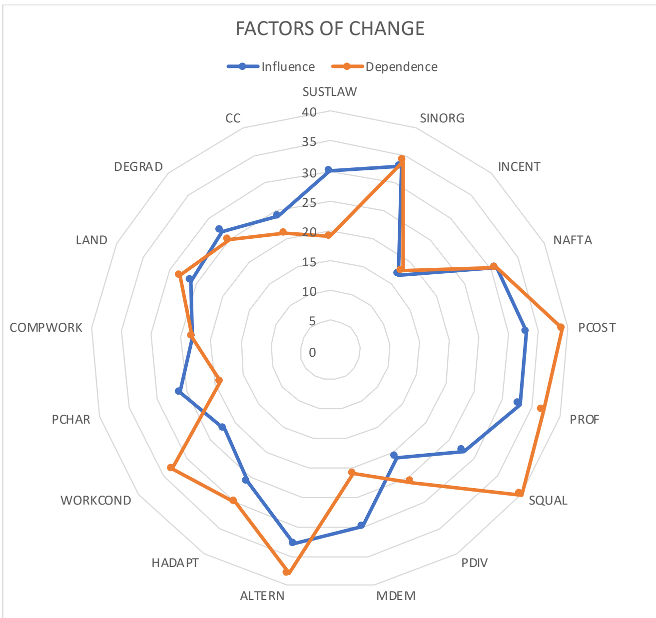


Chart 7. Tamasopo - Sugarcane harvest influence and dependence results
Figure 30. Tamasopo - Sugarcane harvest influence and dependence factors
Own elaboration

According to the results presented, it is observed that the variables with the greatest influence on the system are:

- Sustainable sugar development law
- Producers' organizations
- Production cost
- Free-trade agreement
- Profitability
- Research, development, and innovation of alternatives
- Soil, water, and air degradation
- Reduction in the demand for sugar (competition with other sweeteners)

On the other hand, the variables of highest dependence in the system are:

- Producers' organizations
- Production cost
- Free trade agreement
- Sugarcane quality
- Research, development, and innovation of alternatives
- Cutters working conditions

It is observed that variables: producers' organizations, production cost, free-trade agreement, and research, development, and innovation of alternatives are in both groups, thus they have great influence and dependence in the system.

Moreover, with these results, using MICMAC software, the variables are positioned in the Cartesian plane, as shown in the maps of direct influence-dependence in Figure 31 and indirect influence-dependence in Figure 32.

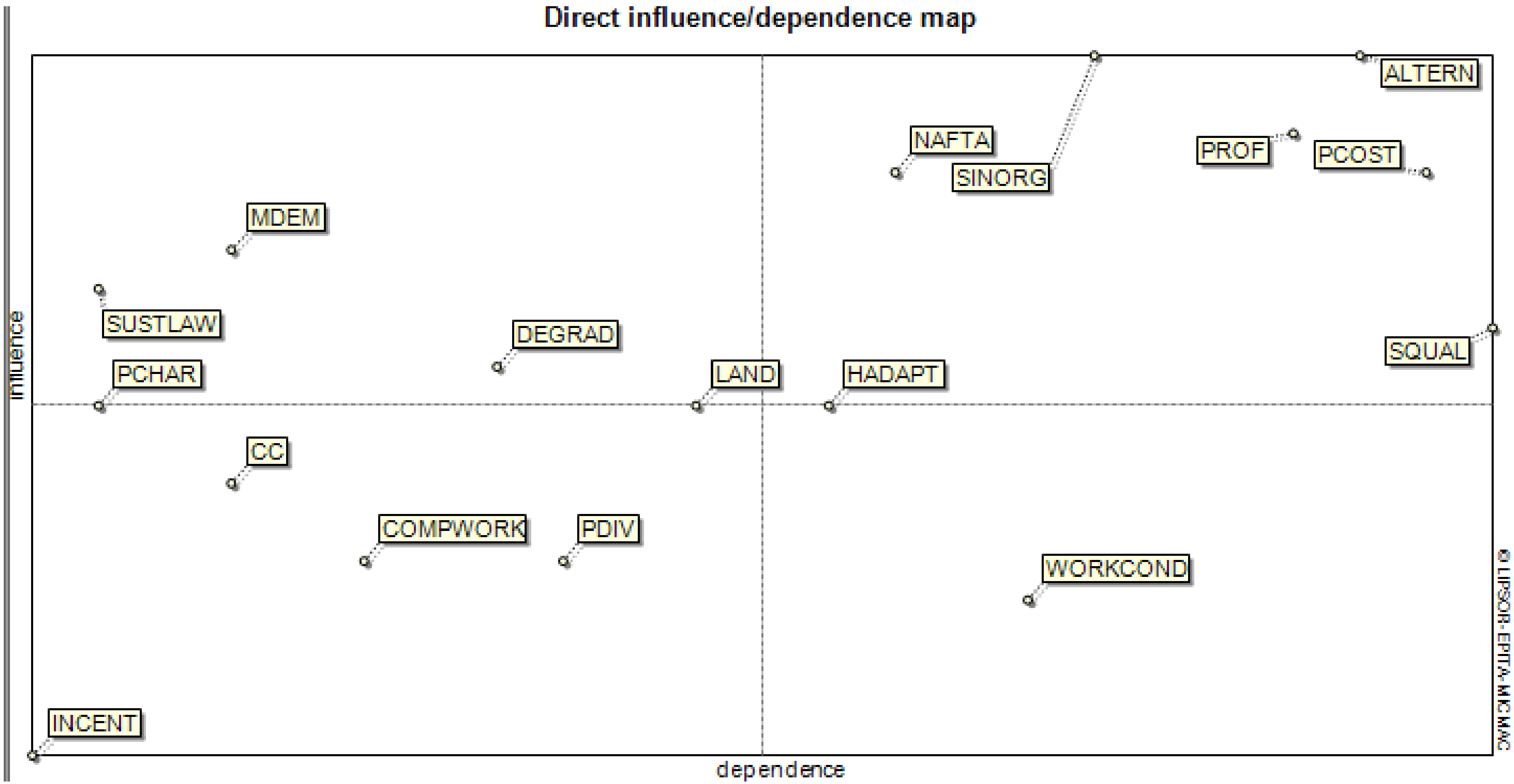


Figure 31. Tamasopo - Direct influence/dependence map
Own elaboration by using MICMAC software

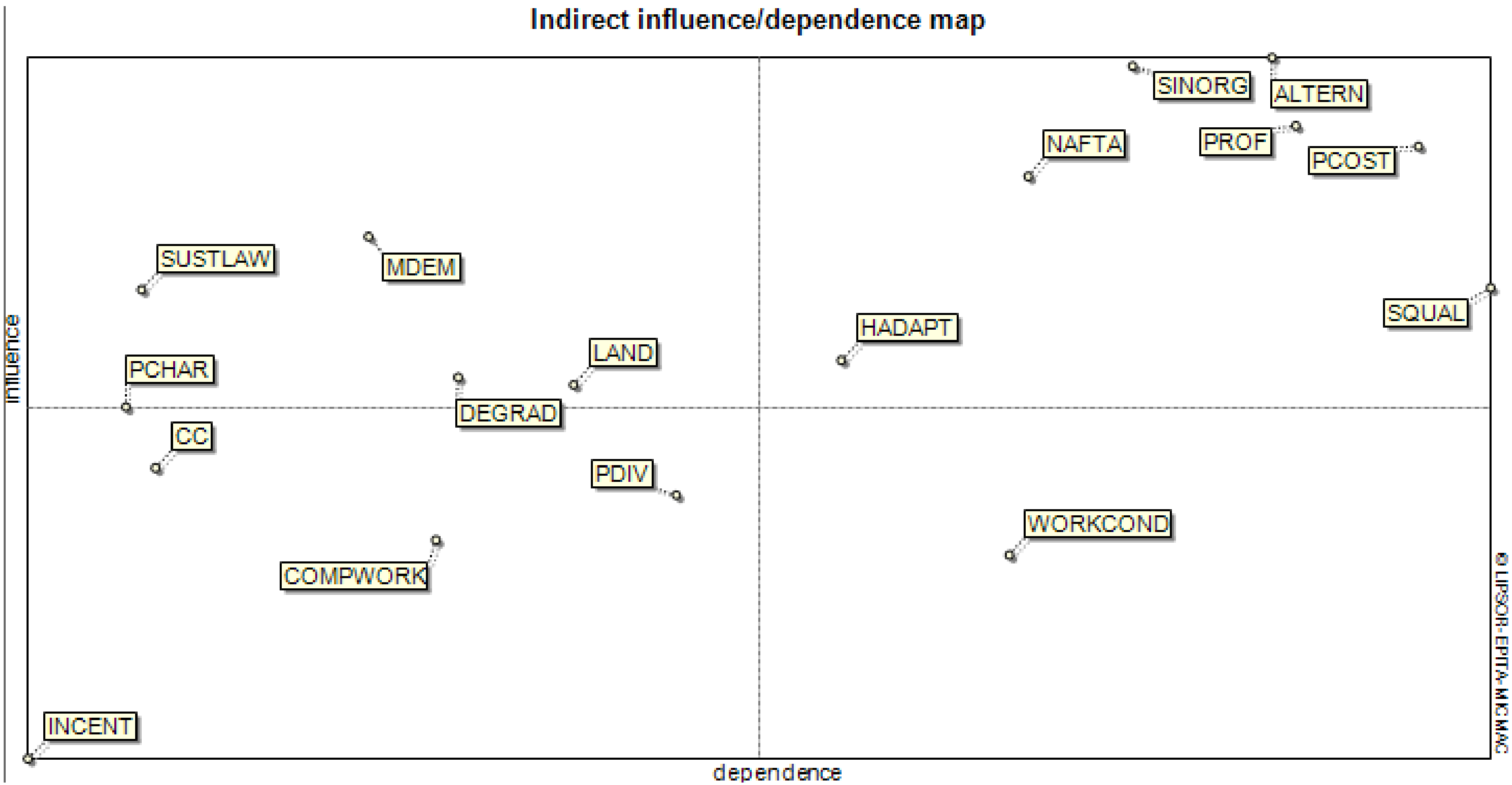


Figure 32. Tamasopo - Indirect influence/dependence map
Own elaboration by using MICMAC software

5.4 Comparative analysis

As can be seen in the preceding graphs (Figure 28, Figure 29, Figure 31 y Figure 32), the variables in Campos dos Goytacazes and Tamasopo are classified as follows:

Variables	Campos dos Goytacazes						Tamasopo					
	Direct analysis		Total	Indirect analysis		Total	Direct analysis		Total	Indirect analysis		Total
Autonomous	-Machinery (harvester) investment	Ec	4	-Machinery (harvester) investment	Ec	4	-Government incentives to producers	P	5	-Government incentives to producers	P	5
	-Cane transportation cost	Ec		-Cane transportation cost	Ec		-Competent workmanship for the use of machinery	S		-Competent workmanship for the use of machinery	S	
	-Arson	En		-Arson	En		-Producer's characteristics	S		-Producer's characteristics	S	
	-Pest incidence	En		-Pest incidence	En		-Products diversification	Ec		-Products diversification	Ec	
							-Climate change	En		-Climate change	En	
Dependent	-Production cost	Ec	11			8	-Cutters working conditions	S	2	-Cutters working conditions	S	1

	-Sugarcane profitability	Ec					-Harvester adaptability	T				
	-Financial solvency of COAGRO	Ec		-Financial solvency of COAGRO	Ec							
	-Labor migration	S		-Labor migration	S							
	-Unemployment	S		-Unemployment	S							
	-Labor and machinery outsourcing	T		-Labor and machinery outsourcing	T							
	-Competent workmanship for the use of machinery	S		-Competent workmanship for the use of machinery	S							
	-Employment diversity in the State	S		-Employment diversity in the State	S							
	-Availability of cutters	S		-Availability of cutters	S							
	-Association management	P		-Association management	P							

	-Soil, water, and air degradation	En			En							
Independent	-State environmental legislation (harvest)	P	3	-State environmental legislation (harvest)	P	4	-Sustainable sugarcane development law	P	4	-Sustainable sugarcane development law	P	4
	-Harvester availability in the market	T		-Harvester availability in the market	T		-Soil, water, and air degradation	En		-Soil, water, and air degradation	En	
	-Characteristics of the land	En		-Characteristics of the land	En		-Characteristics of the land	En		-Characteristics of the land	En	
				-Harvester adaptability	T		-Reduction in the demand for sugar	Ec		-Reduction in the demand for sugar	Ec	
Strategic	-Closure of sugar mills	Ec	6	-Closure of sugar mills	Ec	8	-Producers' organizations	P	6	-Producers' organizations	P	7
	-Research, development, and innovation of alternatives	T		-Research, development, and innovation of alternatives	T		-Production cost	Ec		-Production cost	Ec	
	-Diminution of the sugar cane producers	S		-Diminution of the sugar cane producers	S		-Profitability	Ec		-Profitability	Ec	

	-Discouragement of producers	S		-Discouragement of producers	S		-Sugarcane quality	Ec		-Sugarcane quality	Ec	
	-Climate change	En		-Climate change	En		-Research, development, and innovation of alternatives	T		-Research, development, and innovation of alternatives	T	
	-Harvester adaptability	T		-Production cost	Ec		-Free-trade agreement (USA)	P		-Free-trade agreement (USA)	P	
				-Sugarcane profitability	Ec					-Harvester adaptability	T	
				-Soil, water, and air degradation	En							
Total			24			24			17			17

Chart 8. Comparative Analysis

The autonomous variables in Tamasopo are not the same as in Campos dos Goytacazes. Moreover, the results do not vary between the direct and indirect analysis for each study site.

The dependent variables in Campos dos Goytacazes are 11 with the direct analysis and 8 with the indirect analysis, and mainly correspond to social and economic factors. While in Tamasopo there are 2 with the direct analysis and 1 with the indirect analysis, and they correspond to social and technological factors. Additionally, in Campos dos Goytacazes, as a result of the indirect analysis, the variables production cost, sugarcane profitability, and soil, water and air degradation, were relocated as strategic variables.

The independent variables in Campos dos Goytacazes correspond to politic, technological, and environmental factors. Besides that, in Tamasopo they correspond to politic, economic, and environmental factors. In both, legislation, and land characteristics match. On the other hand, in Campos, the variable harvester adaptability, which was a strategic variable, was relocated as an independent variable after the indirect analysis.

The strategic variables correspond to different factors, but in Tamasopo the environmental factor is not included. In both, in the direct analysis, the variables research, development, and innovation of alternatives coincide; and after the indirect analysis, the variables production cost and profitability coincide.

6 Chapter VI: Discussion

6.1 Green harvest an option towards sugarcane sustainability

According to the PESTEL impact analysis, green harvesting is the option with the highest positive valuation, considering that this practice favors compliance with international agreements to mitigate climate change, as eliminating burning reduces the emission of greenhouse gases and compounds (Mejía and Saldarriaga, 2013; Benítez, 2016; Cassou, 2018). In addition, it favors the compliance with social and environmental standards that may be considered in commercial agreements for sugarcane or its subproducts, thus improving its competitiveness in the market and increasing the profitability of the industry and its cultivation (Romero, Digonzelli and Scandaliaris, 2009). Additionally, green harvesting allows changing the perception of straw as waste, since it becomes a product that can be used to benefit their own crops or can be sold to the industry (Ronquim, 2010; Carvalho, Cerri and Karlen, 2019). It is for these reasons that countries such as Brazil have seen an advantage in its implementation, giving it interinstitutional support (Strachman and Milan-Pupin, 2011), which has made it possible to include the mandatory adoption of this practice in the legislation (Ronquim, 2010).

On the other hand, in relation to production costs, green harvesting has positive and negative impacts that result in a low valuation (Figure 25). As it is mechanized, it reduces the costs of hiring labor for burning, cutting and loading the trucks that transport it to the mills; but the costs of operating and maintaining the machinery arise (Vilaboa and Barroso, 2013; González, 2016; Biaggi, 2018). If it is manual, it implies the hiring of a greater number of people to be able to carry out the cutting at the required times, which is not always feasible due to the hard working conditions and the lack of personnel (Vilaboa and Barroso, 2013; González, 2016; Biaggi, 2018), so producers who wish to change to green harvesting prefer to invest in machinery (Mejía and Saldarriaga, 2013). It is important to consider that the investment amounts are generally high and not very accessible for small producers (Ronquim, 2010; Acosta, 2021); in addition, there is currently not a wide variety of harvesters available on the market that can be adapted to the different soil conditions (Valeiro and Biaggi, 2019). Therefore, green harvesting can promote technological innovation, generating positive impacts on sugarcane production and on the working conditions of the personnel who work on it (Strachman and Milan-Pupin, 2011; López and Gómez, 2015), even though the use of machinery could mean unemployment for cutters (Ronquim, 2010; Mejía and Saldarriaga, 2013; dos Santos and de Matos, 2017).

Although one of the main drivers of green harvesting is the reduction of emissions from burning, it should be considered that it has negative environmental impacts that reduce its valuation in the PESTEL analysis. These environmental impacts have been analyzed by Vilaboa and Barroso, 2013; González, 2016; Biaggi, 2018, highlighting the atmospheric emissions from machinery fuel, land modifications that can promote deforestation and affect local flora and fauna, and soil compaction due to the weight of the harvesters.

As mentioned above, green harvesting has multiple benefits compared to harvesting with burning (Mejía and Saldarriaga, 2013; Benítez, 2016; Cassou, 2018). However, a more detailed analysis of the environmental, social, economic, and political conditions of each sugarcane growing locality is required to conduct an adequate transition process towards green harvesting, seeking to mitigate the negative impacts that could occur (Temple *et al.*, 2011). Therefore, this work uses the structural analysis approach to understand the system through the identification of its components and their interrelationships, the results of which are presented below.

6.2 Towards a green harvest of sugarcane in Campos dos Goytacazes

In Campos dos Goytacazes, as was observed in the previous chapter, the influencing variables that are independent are the legislation, the soil, and the availability of the combine harvester. This finding coincides with the State Law 5990 which establishes the gradual elimination of burning sugarcane fields in Rio de Janeiro until 2024, making the mechanization of the harvest mandatory (Governo do Estado do Rio de Janeiro, 2011). But it must be considered that the characteristics of the terrain, such as the extension of the crops, are a limiting and highly influential in the sugarcane harvest (Acosta, 2021; Inojosa, 2021; Veiga, 2021). On the other hand, the size of the harvesters currently available on the Brazilian market does not fully meet the needs of sugarcane producers in Campos dos Goytacazes, since they are characterized by being large and heavy, which makes them difficult to maneuver in the small fields typical of this location (Veiga, 2021).

The strategic variables, in Campos dos Goytacazes, due to their high influence and dependence on the transition to mechanized harvesting are: 1) production cost, 2) sugarcane profitability, 3) closure of sugar mills, 4) diminution of sugar cane producers, 5) climate change, 6) research, development, and innovation of alternatives, 7) discouragement of producers, 8) soil, water and air degradation. The reason for this is that the changes required by legislation may imply the use of technology or the change of agricultural practices whose high costs are a constraint for producers, which raises their cost of production, thus reducing their profitability (Acosta, 2021; Inojosa, 2021). The impotence to adapt to mechanized harvesting, added to their low sugarcane production in comparison with other Brazilian municipalities (de Barros, 2006), generates discontent among producers, who prefer to dedicate themselves to other activities such as the oil industry or cattle raising (Silva and Miranda, 2019; Veiga, 2021). This is directly related to the closure of sugarcane mills (Veiga, Vieira and Ferreira, 2006; Gomes *et al.*, 2020), because when there is a decrease in the number of producers, the amount of raw material needed by the mills to produce sugar or ethanol profitably is also reduced.

Environmental factors such as climate change and the degradation of water, air and soil are perceived as a threat to sugarcane production, whose alterations could directly affect the quality of the crop and therefore generate negative effects on the profitability and well-being of producers. Consequently, stakeholders are interested in reducing GHG emissions and stopping the degradation of environmental components to maintain their production and favor the competitiveness of their products in the international market, especially ethanol, since it is an alternative source of energy (Berra, 2004; Ronquim, 2010). Consequently, research, development and innovation of alternatives is an essential factor for the continuity of sugarcane production, to achieve improvements in the production process, increasing its efficiency and reducing its environmental impacts.

On the other hand, the dependent variables with the highest valuation are unemployment and migration, since mechanizing the harvest reduces the labor required to cut sugarcane, generating unemployment and migration of this labor force (Acosta, 2021; Inojosa, 2021; Veiga, 2021); this is a serious social problem because the people who cut sugarcane generally have low levels of education and income (Ronquim, 2010; dos Santos and de Matos, 2017). However, with mechanization, the labor profile changes to one of greater specialization for the use and maintenance of the machinery (Moraes, 2007), which could encourage the study and training of the cutters.

In the case of the autonomous variables, contrary to what was initially assumed, it is interesting to note that the Machinery (harvester) investment variable has low values of influence and dependence. This confirms that the biggest problem faced by the producers of Campos dos Goytacazes to mechanize their harvest is not the cost of the machinery, but the lack of harvesters that are adapted to the conditions of their land (Inojosa, 2021; Veiga, 2021).

After the indirect analysis through the MICMAC software, the following is highlighted:

The adaptability of the harvester, although it is a strategic variable in the map of direct variables, in the map of indirect variables it moves to the quadrant of the independent variables as the conditions of the harvesters that are currently on the market, cannot be used by the producers of Campos dos Goytacazes, who have small extensions of land according to (Veiga, Vieira and Ferreira, 2006; Inojosa, 2021; Veiga, 2021). So, it becomes a limiting factor that does not depend directly on the actors of the system.

Likewise, soil, water, and air degradation, in the map of indirect variables, becomes a strategic variable because the producers' awareness of this factor leads them to take actions for the implementation of sustainable agricultural practices. Thus, the degradation of environmental factors, especially soil degradation, is directly related with the reduction of sugarcane production (Romero, Digonzelli and Scandaliaris, 2009; Leal *et al.*, 2013; Vilaboa and Barroso, 2013; Nunes *et al.*, 2017).

In addition, the cost of production also becomes a strategic variable in the map of indirect variables. As a result, an adequate balance between labor and mechanization influences the transition process from a harvest that uses burning to a green harvest (Romero, Digonzelli and Scandaliaris, 2009).

Based on the above, the variables soil, water and air degradation, and cost of production have a direct impact on crop profitability, which is evident in the map of indirect variables, as it becomes a strategic variable.

6.3 Towards a green harvest of sugarcane in Tamasopo

On the other hand, the results presented in Chapter V corresponding to Tamasopo, show that the variables: 1) Sustainable sugar development law, 2) soil, water, and air degradation, and 3) reduction in the sugar demand are influential variables, and, at the same time, they are independent. Although the Sustainable Sugar Development Law does not establish a definitive prohibition of burning in sugarcane harvesting, related government programs, such as the National Sugarcane Agroindustry Program, promote a progressive replacement towards green harvesting (CONADESUCA, 2019). The results obtained with MICMAC (Figure 31 and Figure 32) indicate that the motivation that influences this change is the mitigation of the environmental impacts related to this activity, since according to (Santiago, 2021) its degradation affects sugarcane quality and therefore profitability. Another factor of great influence is the reduction in the demand for sugar, as the continuity of sugarcane production and its modernization is directly related to the sale of sugar on the domestic and international markets (Mertens, 2008).

The strategic variables in Tamasopo, due to their high influence and dependence on the transition to mechanized harvesting are 1) production cost, 2) profitability, 3) research, development, and innovation of alternatives, 4) discouragement of producers, 5) soil, water, and air degradation. Sugarcane growers' organizations play a fundamental role in the transition to green harvesting because, in addition to being a communication bridge between growers, industry and government (CONADESUCA, 2004), they accompany growers during each stage of sugarcane cultivation to ensure the final quality of the product (Fortanelli, 2020; Santiago, 2021). The quality of the sugarcane is a relevant factor because the sugarcane mill and the organizations establish the amount to be paid to producers based on the percentage of sucrose obtained per harvest (Santiago, 2021), which directly influences their profitability. Consequently, the organizations not only control the sugarcane production process, but also, they have the power to exert pressure on decisions related to the sugar market to benefit sugarcane producers. Thus, they become a political force that can benefit or limit the implementation of agricultural practices such as mechanization of harvests, directly related to the sale of sugar in the national and international markets (Mertens, 2008; Vásquez, 2021).

On the other hand, Tamasopo requires the development of economically efficient alternatives that do not generate increases in production costs and that allow maintaining or increasing the profitability of the crop. In addition to this, it is necessary to add its capacity to adapt to the characteristics of the terrain, which constitutes a strong limitation due to its slopes of more than 12% and the reduced size of the cultivated areas (Salazar Gómez and López Rubio, 2021).

NAFTA must also be considered as an external factor of great importance, since it determines the production conditions of traded products, as well as establishing standards that take into account social and environmental factors in the production process (Mertens, 2008). In addition, NAFTA has generated internal and external competition between sugar produced in Mexico and high fructose syrup produced in the USA, which has had repercussions on the sugar market, directly affecting the profitability of sugarcane production (Mertens, 2008). Furthermore, Mexico's participation in this agreement may favor the availability of tax-free and more accessible machinery and spare parts for Tamasopo's producers (Vorley, 2002), which could promote the development and acquisition of machinery for the sugarcane fields.

The variable working conditions of the cutters is defined as dependent and is due to the fact that mechanizing the harvest reduces the labor required to cut the cane. It is important to emphasize that for this analysis in this study site, this variable also considers cutter unemployment. The loss of employment of the labor force in Mexico is a major constraint to the transition to green harvesting. For this reason, even when organizations or producers have machinery, manual cutting is preferred, relegating combine harvesters to a secondary role as a support to avoid shutdowns at the mill due to sugarcane shortages (Santiago, 2021).

In the case of the autonomous variables, the Incentives variable should be highlighted since there is a lack of government support to improve sugarcane production conditions (Salazar Gómez and López Rubio, 2021). Incentives in Tamasopo constitute a palliative to face the national crisis of the sugar agroindustry (Aguilar-Rivera, Galindo-Mendoza, et al., 2010).

After the indirect analysis through the MICMAC software, there are no major changes in the dependence-influence graph, but it is emphasized that the adaptability of the harvester becomes a strategic variable in the map of indirect variables, because technological improvements would be required for the harvesters to adapt to the land conditions, which is an important limiting factor in Tamasopo for green harvesting (Vilaboa and Barroso, 2013; Salazar Gómez and López Rubio, 2021). Additionally, it should be noted that, unlike what was found in the bibliographic references, the land conditions in Tamasopo, despite being a relevant factor that has limited mechanization, is at the limit between the independent variables and the autonomous variables in the direct analysis. Its role in the system is clarified after the indirect analysis in which it is defined as an independent variable.

6.4 Potential reduction of atmospheric emissions from sugarcane harvesting in Tamasopo and Campos dos Goytacazes

Each study site has a different political, economic, environmental, and social reality, which is defined by its history, government strategies and national and international market conditions for sugarcane subproducts. In Mexico, the sugar agroindustry is a deteriorated sector mainly due to the reduction in sugar consumption, as a result of competition with other sweeteners, and the inclusion of the Mexican sugar industry in NAFTA (2008) (Mertens, 2008; Aguilar-Rivera, Galindo-Mendoza, *et al.*, 2010). This corroborates the need to diversify the products obtained from sugarcane to encourage investment by producers and promote technological development in the agricultural field that favors the mitigation of the negative environmental impacts of this crop (Mertens, 2008; Aguilar-Rivera, 2011). For this reason, at the local level in Tamasopo, economic factors are more relevant in the process of transition to a green harvest. On the other hand, in Brazil, sugarcane production continues to grow, driven by the diversification of its industry, especially towards the production of ethanol as an alternative to fossil fuel (dos Santos and de Matos, 2017). However, sugarcane production in Campos dos Goytacazes, unlike other Brazilian municipalities, presents serious problems of solvency and adaptability to market requirements, as evidenced by the discouragement of producers to remain in this activity, leading to the continuous closure of mills (de Barros, 2006; Veiga, Vieira and Ferreira, 2006; Silva and Miranda, 2019) This problem has limited the capacity of sugarcane growers to modernize their agricultural practices, on a par with other sugarcane-producing municipalities nationwide.

Despite the challenges faced by the sugarcane industry in Tamasopo and Campos dos Goytacazes, according to MICMAC the legislation has influence on the mitigating of GHG emissions from this agricultural activity in both study cases. In Campos dos Goyatacazes, by having a law that specifically establishes the need to eliminate burning within a defined deadline, it is possible to observe further progress in the process of transition to green harvesting. In Tamasopo, since there is no mandatory provision regarding the elimination of burning, there is no immediate need to make this change.

Since Tamasopo and Campos dos Goytacazes have land conditions that make mechanization difficult, it is important to adapt the harvesters that are currently on the market (Veiga, Vieira and Ferreira, 2006; Vilaboa and Barroso, 2013; Salazar Gómez and López Rubio, 2021). For this reason, research, development, and innovation of alternatives is considered a strategic variable in both sites. In the case of Tamasopo, as mentioned by Salazar and López (pers. comm., 2021), research on alternatives to burning has focused its efforts on the advantages of straw as a source of nutrients and organic matter, but not on the management of machinery improvements, even though it is necessary. This may be because Mexico depends technologically on products developed in the USA due to the strong commercial relationship that exists between them. In Campos, a similar pattern is observed since the machinery available is that developed in other municipalities such as Sao Paulo, with other production characteristics (Veiga, 2021). However, in Campos, due to the obligation to eliminate burning, there is evidence of a process of collaboration between the different actors to manage the development of harvesters through agreements with the German government, highlighting the TRABBIO project (CLIENT II., 2020; Veiga, 2021) (Pereira. pers. comm., 2021).

Ethanol production in Brazil was a driver for the transition to mechanized harvesting, as it needs to comply with environmental requirements such as emissions mitigation within its production chain to be commercially attractive as an alternative to fossil fuels (dos Santos and de Matos, 2017; Oliveira *et al.*, 2021). Therefore the Brazilian government has focused its efforts through programs, incentives and laws to favor the sustainable development of the sugarcane industry (dos Santos and de Matos, 2017). In contrast, in Mexico, the almost non-existent ethanol industry, resulting from the lack of interest in substituting fossil fuels (Salazar Gómez and López Rubio, 2021), has hindered the implementation of practices that contribute to the reduction of GHG emissions. For this reason, in Tamasopo, environmental factors are important variables, but of little relevance in the process of transition to green harvesting, as contrasted with Campos dos Goytacazes, where they are strategic variables. For this reason, mechanization in Tamasopo is not conceived as an alternative for mitigating emissions from burning, nor is it perceived as a significant air pollution problem that could affect air quality or contribute to climate change (Santiago, 2021). For producers in Tamasopo, the greatest environmental effect related to burning is soil deterioration, which has been evidenced by changes in sugarcane quality over the years (Fortanelli, 2020). However, this has not fully justified a change to mechanization since mechanization also has negative impacts on the soil (Cabrera and Zuaznábar, 2010; Tolentino de Lima *et al.*, 2017).

Unemployment of sugarcane cutters emerges as a consequence of the mechanization of harvesting (Ronquim, 2010; Mejía and Saldarriaga, 2013; dos Santos and de Matos, 2017) However, this is a dependent variable with a weak influence on the system in both study sites. Therefore, if governments, supported by the industry and sugarcane organizations, decide to adopt mechanization as a mandatory practice, as is the case in Campos dos Goytacazes, cutters will hardly be able to limit the modernization process. Consequently, it would force them to be trained in the handling and maintenance of machinery to continue working in the sugarcane fields (Mertens, 2008; Verola *et al.*, 2010).

7 Chapter VIII: Conclusion

Mitigation and adaptation to climate change is a challenge that humanity is currently facing, so this study aimed to analyze the potential reduction of emissions from sugarcane burning. This was done based on the analysis of the impacts of burning and green harvesting, which allowed confirming the advantages of green harvesting as an alternative to reduce emissions into the atmosphere. On the other hand, a structural analysis, using the MICMAC method, in collaboration with the stakeholders, was used to understand the systemic complexity of the transition process towards green burning in two sites with similar production characteristics but developed in very different contexts. As a result, the relevant variables, their role, and their interrelationship in this technological transition process were identified, allowing to support stakeholders and decision makers in the process of eliminating crop burning, through the application of compatible technology in each specific area, ensuring its successful adoption and long-term permanence.

By conducting a holistic and systemic analysis through this research, it has been possible to identify the specific opportunities and limitations of each location. In Campos dos Goytacazes, although the process of transition to green harvesting has already begun, it has evolved slowly, mainly as a result of the crisis affecting sugarcane production in this municipality. On the other hand, in Tamasopo, the economic factors related to the sale of sugar in the market are the ones that guide the agricultural practices implemented. It is for this reason that, Tamasopo producers do not see a need for change either by the market or by legislation, so the transition to a non-burning crop has not been encouraged. However, a key variable for both study sites is research, development, and technological innovation, which is necessary mainly to adapt the machinery to the characteristics of the terrain and to the economic and social factors of both sites.

It is also recommended to promote research and innovation in the use of straw, to provide an incentive to the industry and producers for the adoption of green harvesting. Thus, there are few alternatives for its use, most of which require high technification and investment. It should be emphasized that sugarcane producers should be economically rewarded not only for the sucrose present in the cane, but also for the sale of the subproducts of the residues such as straw and bagasse, which would increase the profitability of the producers.

Also, given that the technological transition is an imminent step towards the elimination of burning, it is important to consider the unemployment and migration of cutters. These factors are consequences, which require immediate action by the government in collaboration with sugarcane organizations and the industry. In this way, they can support the evolution of this workforce towards a more technified one that can adapt to the new agricultural practices in the sugarcane fields.

It is important to emphasize that the information obtained from the different stakeholders involved in sugarcane production was of great value, since it allowed enriching the analysis based on their perspectives and interests to create a consensus on the process of eliminating sugarcane burning as a strategy for reducing atmospheric emissions. For this reason, it is recommended to promote the participation of all the actors included in any transition process from its planning to its achievement, especially in the case of future research and projects that imply the development of technological alternatives for the improvement of agricultural practices. However, in addition to the above, the limitations of this analysis should be considered, as a result of the COVID-19 pandemic, which did not allow the approach with a bigger number of participants for the conformation of the groups of experts and interviews. Therefore, it should be noted that this research work provides an overview of the variables and their interrelationship to allow a macro understanding of the system. It is recommended that future research in Campos dos Goytacazes and Tamasopo should deepen the evaluation of the socioeconomic aspects, which have a strategic role within the system.

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Annex 1: Interview Guideline

1. Interview technicians – experts

- Research work description
    a. Background of the research project

- Sugarcane burning in the region
    b. Have been taken measures to control burning at the regional and/or national level?
    c. What regulations are in place to reduce the burning of sugarcane fields?

- Harvest mechanization
    d. Is it feasible to carry out 100% green harvesting at the local level (Tamasopo / Campos dos Goytacazes)?
    e. Is the machinery accessible to small and medium producers?
    f. How has the use of harvesters influenced sugarcane production?
    g. What is the effect of reducing sugarcane straw burning and increasing the areas harvested with machines?
    h. How can be evaluated the impacts on the environment and people living in the region resulting from sugarcane burning?

2. Interview of representatives of associations/cooperatives

- Research work description
    a. Background of the research project

- Sugarcane harvest
    b. What is the role of the association during harvesting?
    c. What is the percentage of associated producers in the region?
    d. What is the average production of the association's producers?
    e. Do sugarcane producers have any additional legal benefits or subsidies?

- Sugarcane burning in the region
    f. What are the benefits of pre- and post-harvest burning?
    g. Are there any disadvantages to burning and what are they?

- Harvest mechanization
    h. Is it feasible to carry out 100% green harvesting at the local level (Tamasopo / Campos dos Goytacazes)?
    i. Is it possible to acquire or develop machinery that benefits all members of the association?
    j. How has the use of harvesters influenced sugarcane production?
    k. Is there any technical training for cutters on how to use the machinery?
    l. What are the advantages and disadvantages of green harvesting?
    m. How does the association manages the disadvantages of green harvesting for farmers?

3. Interview producers

- Research work description
    a. Background of the research project

- Sugarcane Harvest
    b. How is sugarcane harvesting performed on your property?

- Sugarcane burning in the region
    c. What are the benefits of pre- and post-harvest burning?
    d. How is this activity performed? Who are the responsible parties?
    e. Are there disadvantages of burning? What are they?

- Harvest mechanization
    f. Is it feasible to carry out 100% green harvesting at the local level (Tamasopo / Campos dos Goytacazes)?
    g. Is the machinery accessible?
    h. How has the use of harvesters influenced cane production?
    i. How is labor hiring done? Is there technical training in the use of harvesters?
    j. What are the advantages and disadvantages of green harvesting?

4. Mic-mac: Group of experts

To conduct the dynamics, and thus obtain the variables to build the matrix, the following questions are asked:

- Economic
    a. What economic conditions influence the reduction of sugarcane burning?
    b. Technological
    c. What factors, barriers or problems are present for its use and development?
- Political

d. Are there institutional and political conditions to support the reduction of sugarcane field burning? Which ones?
e. Are there institutional conditions and policies that hinder the reduction of sugarcane field burning? Which ones?

- Social
  f. Is the replacement of cane field burning by green harvesting a socially accepted option?
- Environmental
  g. Does the environment (topography, plant composition, soil) allow green harvesting?
  h. Does the burning of sugarcane have impacts on the environment?

Annex 2: Interview results

INTERVIEW No.	DATE	HOUR	SUBJECT	FORMAT
001	07/07/2020	11:30	Sugarcane harvest in Tamasopo	Presential

INTERVIEWED			
Name	**Company**	**Role**	**Country of origin**
Roberto Fortanelli	CNC organization -	President CNC Tamasopo Sugarcane producer	Mexico

No.	SUBJECT
1	**SUGARCANE HARVEST**

a) What is the role of the Association during the harvest? What is its function with the producers?

Alianza Popular is acquiring straw shredders. After the cane is cut, the straw is shredded in such a way that the layer is thin and then a tractor with a disk plow is used to incorporate it into the soil, thus avoiding burning and taking advantage of the organic matter. It will be used for the 2021 harvest.
Change is being adopted because the government is increasingly demanding it.

Owners (producers) with small properties with stony soil, where machinery cannot be used, do not burn sugarcane to improve their soil. Where it is already possible to cut with a tractor, the straw is incorporated into the soil with people who are dedicated to machining.

Some growers burn the straw to reduce costs as a first herbicide application.

b) What is the average production of the association's producers?

This changes with the harvest but is around 50 Mg/ha.

c) Do sugarcane producers have any additional legal benefits or subsidies?

No, only social insurance affiliation.

No.	SUBJECT
2	**SUGARCANE BURNING IN THE REGION**

d) What are the benefits of pre- and post-harvest burning?

Mainly, it is done to avoid snakes and to avoid hitting the stones with the machete. It is also by custom because it has been done for many years. Before, it was not burned because there was a lot of manual labor, it was a great source of manual labor. With time, it changed.

In the past, green harvesting was done (manually, with a lot of manual labor) but it was changing, modernizing, with the extension of the cultivation areas given by President Luis Echeverría Álvarez, who modified the sugarcane fields, they were modernizing, and new mills were built. There was a greater need for sugarcane, larger areas of sugarcane were planted, then the loaders arrived because they needed more speed. It was also decided to burn cane to supply the mills. Before, cutters did not want to cut burned cane because their hands were blackened.

e) Are there any disadvantages to burning and what are they?

Now with climate change, periods of very hot or very cold weather; even very windy. Therefore, the producer has seen the need to change practices such as reforestation. There was a very good project, approved by the 4 sugar mills in the country, to reforest, which was going to start in 2021, but so far it has not been implemented. These reforestation initiatives were planned through government institutions, sugarcane associations and the military. Now only private reforestation is being carried out.

No effects on workers' health are seen, only damage to the soil. The cutter cuts the burned cane. The cutters are protected.

No.	SUBJECT
3	HARVEST MECHANIZATION

f) Is it feasible to carry out 100% green harvesting at the local level (Tamasopo)?

Yes, but so far progress has been made between 20 and 25%.

g) Is it possible to acquire or develop machinery that benefits all members of the association?

Machinery is purchased through quotations; the decision is made as an organization. Not having a harvester means not entering into green harvesting and it needs to be promoted.

h) How has the use of harvesters influenced sugarcane production?

It influences in sugarcane quality. Field laboratory to determine the amount of sucrose and humidity to authorize the cut. The factory laboratory determines how much sugar is in the juice before it enters the process; at each mill, samples are taken at the mill and payment is determined according to the level of sugars.

i) Is there any technical training for cutters on how to use the machinery?

Talks and training are given constantly. The mill's and the group's technicians talk with the growers daily. The growers know that burning the straw causes damage to the soil. They know that over the years the soil becomes poorer (the organic matter is running out).
The farmers' children have already studied technical careers such as agroecology or agroindustrial engineering, and they are also taught technical subjects in high school.

j) What are the advantages and disadvantages of green harvesting?

The harvester can cut green, separating the trash from the cane. When the canes are very small to avoid high personnel costs, a harvester is used, but it is previously burned to prevent stones or irregularities in the terrain from damaging the machine.
Moreover, in green it is better for the sugar mill because the cane lasts longer because it is more hydrated. It can last up to 72 hours without spoiling. On the other hand, burned sugarcane begins to lose sucrose in 24 hours, creating starch.
When harvesting on a slope, there needs to be a guaranteed price for the cane, so that the cutter can be paid well and not fluctuate.
In the hillside, fire is used for harvesting, but once it is cut, the straw is left behind.

k) How does the association manage the disadvantages of green harvesting for farmers?

There is a need to increase the production of tons per hectare, taking advantage of water, making more fields with pressurized or drip irrigation, trying to avoid wasting water so that we can have more surfaces and, therefore, more tons per hectare.

The Association helps the producers to implement these irrigation systems, making the necessary arrangements with government institutions; the National Water Commission supports the producer, with the objective of taking care of the water. The Commission approves the project and may even provide financial support. The Association oversees the design of the project, in terms of form and costs, taking care not to damage the water in the rivers.

ADDITIONAL QUESTIONS	
No.	**SUBJECT**
4	**CNC ROLE**

l) How long ago was the CNC formed?

The CNC was formed when the Agua Buena sugar mill was located and was called Circulo Regional Cañero Número 25. When Agua Buena disappeared and the more modern Alianza Popular sugar mill was created, the Confederación Nacional Campesina (CNC) adopted the Circulo Regional Cañero Número 25 and became the Unión Nacional de Productores de Caña de la CNC (National Union of Sugarcane Producers of the CNC). In 2020 it is no longer CNC, it is now Unión Nacional de Productores de Caña de Azúcar AC del Ingenio Alianza Popular.

m) How do you interact or work together with the CNPR?

CNC and CNPR are independent in terms of producers and forms of administration, but together with the sugar mill a committee is formed, which is the Sugarcane Production and Quality Committee. They engage in dialogue and debate proposals for planting, cultivating, and harvesting sugarcane. They meet during the harvest every week and in the off season whenever necessary. In these meetings, issues such as green harvesting and mechanization have been discussed, especially at the beginning of the harvest; CONADESUCA, which is the national commission that regulates sugarcane producers, asks for data on harvesting and cultivation costs and also how much is green and how much is burned. There is a Technical Committee of CNC, CNPR and the sugar mill that meet to discuss all technical aspects.

INTERVIEW No.	DATE	HOUR	SUBJECT	FORMAT
002	03/06/2021	00:30	Sugarcane harvest in Tamasopo	Online (Zoom)

INTERVIEWED			
Name	**Company**	**Role**	**Country of origin**
Erika Santiago	CNC organization	Field Chemical Advisor	Mexico

No.	SUBJECT
1	**SUGARCANE BURNING IN THE REGION**

a) Have measures been taken to control burning at the regional and/or national level?

At the Tamasopo level, the only control measures regarding burning are found in a harvesting manual/regulation, where there are measures and schedules, at what time according to the temperature depending on cold or very hot weather.

b) What regulations exist that are related to reducing the burning of sugarcane fields?

I do not know. No institution regulates the burning of sugarcane, there is no regulation related to this practice; burning is done out of necessity. Cutting with a green harvester loses quality, besides, they pay less.

No.	SUBJECT
2	**HARVEST MECHANIZATION**

c) Is it feasible to carry out 100% green harvesting at the local level (Tamasopo)?

No. The less green cane is better.

d) Is the machinery accessible to small and medium-sized producers?

Machinery is accessible, but the topography of the soil prevents the use of machinery, so that, within the areas, on average 22,000 hectares, only 1000 hectares are cut with a harvester, so they opt for burning or manually, even though there are 7 harvesters, technology, and machinery. In addition, people refuse because it damages the field. The Alianza Popular sugar mill uses almost no harvesters.

When using a machine, the payment is cheaper: 108 pesos per ton in manual and 100 with a machine. Prices may vary per harvest. Prices are stipulated at the beginning of the harvest because agreements are made on how work will be done during each harvest.

e) How has the use of harvesting machines influenced sugarcane production?

The main advantage is the time in harvesting, but it generates more trash (impurities); this lowers the quality of the cane. To respond this effect, a strict quality control of the cane is carried out before it enters the factory, since, if chopped cane enters the factory, fermentation increases.

Machines can be used when the mill runs out of sugar cane. The entry of green cane per hour is regulated. Producers are paid for quality, not quantity.

f) Is the technical or technological capacity available for its development?

People are trained to use machinery; they use it, but not enough because quality is taken care. For this reason, harvest quotas are given.

g) What is the effect of reducing sugarcane straw burning and increasing machine harvested areas?

Payment to producers is reduced.

h) How can the impacts on the environment and people living in the region be assessed with the reduction of sugarcane straw burning?

With a record of accidental burns in sugarcane crops.

INTERVIEW No.	DATE	HOUR	SUBJECT	FORMAT
003	16/06/2021	12:45	Sugarcane harvest in Tamasopo	Email

INTERVIEWED			
Name	**Company**	**Role**	**Country of origin**
Nehemías Vásquez	Fideicomisos Instituidos en Relación con la Agricultura "FIRA"	-	Mexico

No.	SUBJECT
1	**SUGARCANE BURNING IN THE REGION**

a) What measures have been adopted at the regional and/or national level to control burning?

Some are considering that the product obtained from a green harvest can be differentiated, and certification opportunities for good harvesting practices have been identified.

b) What are the regulations related to the reduction of cane field burning?

I am particularly unaware of this part of the environmental policy or regulation. In Tamasopo, the reduction of available labor is beginning to be an element that has led to the transition to green cutting.

No.	SUBJECT
2	**HARVEST MECHANIZATION**

c) Is it feasible to carry out 100% green harvesting at the local level (Tamasopo)?

At the local level, it is feasible. For about 6 years, efforts have been made to move from harvesting by burning to green harvesting. The limitations have been cultural and economic. Cultural because the acquisition of such machinery is being acquired through producer organizations. Land tenure and the high dispersion of productive land means that there is not a compact area for mechanization. In the area, there is a high dependence on the activity, so it is even "normal" for burning to take place.

d) Is the machinery accessible to small and medium-sized producers?

No. The price of a piece of machinery is close to 8 MDP, which limits the acquisition by an individual. The machinery acquired has been through organizations that offer the service to their members. Far from depending on subsidies, producers do not have sufficient guarantees to access financing.

e) What is the effect of reducing sugarcane straw burning and increasing machine harvested areas?

Biomass will directly impact the tons of sugar produced, which will probably reduce the sucrose content.

f) How can the impacts on the environment and people living in the region be assessed with the reduction of sugarcane straw burning?

I will review this last point in more detail.

INTERVIEW No.	DATE	HOUR	SUBJECT	FORMAT
004	06/05/2021	14:00	Sugarcane harvest in Campos dos Goytacazes	Online (Zoom)

INTERVIEWED			
Name	**Company**	**Role**	**Country of origin**
Frederico Veiga	N/A	Sugarcane producer	Brazil

No.	SUBJECT
1	**SUGARCANE HARVEST**

a) How is sugarcane harvesting performed on your property?

Normally, what is pursued is manual harvesting, it is what exists, what is available. There is a labor legislation where workers must have all the security to work, they must be regularized. Normally, today the labor legislation allows the creation of service consortiums, it happens that the structure of the harvesting process depends on machines for shipping and transportation. As my property is a little larger than the average for the region, it would not be able to hire a small group of workers, because this structure would only be available for a short time, so what is done is that as there are greater volumes of harvest in certain periods, then the consortiums help with a larger number of workers because it concentrates the harvest in a shorter period of time in terms of transportation and shipping structure. So the harvest must be outsourced in terms of workers, in terms of machines, in terms of transportation, in spite of being of a medium size, for me it is difficult to have a large structure to harvest that volume of cane perhaps in periods of 2 or 3 months would be reasonable, so normally the consortia of workers are used for the manual cutting of the cane which must be regularized in terms of transportation of workers, during the period of work. In summary, harvesting is outsourced in terms of both manual labor and equipment.

No.	SUBJECT
2	**SUGARCANE BURNING IN THE REGION**

b) What are the benefits of pre- and post-harvest burning?

Benefits, perhaps only in terms of conditions for harvesting, because there is the issue of time, of the structure to be available.
Workers come from other regions of the country with higher yields, this week I had information of groups of workers coming from Minas Gerais that harvest more, they harvest more than double the capacity of the workers of this region. It is important to consider the yield of the harvest and the availability, because many times it is fine to harvest half of the production, but it costs the double. Even so, there is not that availability of workers for the small manual cutting of sugarcane without burning. There used to be manual harvesting without burning, but, what happens, the volume of plants (mills) was smaller, the system was different.

The current generation of manual sugarcane cutters are not accustomed to a cut without burning, in terms of yield, there is no such availability, unfortunately. They are looking for alternatives, through a partnership with TH Köln for harvesting without burning, there are some projects with COAGRO, with a system that allows manual harvesting without burning, they are trying to adapt this project, because the biggest problem is the straw. The yield drops when they try to cut the straw with a cutting tool, bought by COAGRO. The investment is already made, but they are adjusting and unfortunately the project is not working. It would be a faster option, even if there is not a good yield, because we would be using a volume of sugarcane with straw, it would allow harvesting without burning. It would be a more immediate solution. I think that the limitation in mechanical harvesting without burning are the small machines that are not viable, in terms of cost, the term of maintenance of machines, the yield falls to less than half of the harvests in other regions, there is wear of the machines with small useful life, unfortunately it is not profitable and also the market availability, we have tried through the association, to bring other machines, we have accompanied the process through the university, we are accompanying these attempts of harvesting without burning through the association, and also of the mills, but there is this limitation.
First alternative should be to have a small machine and immediately to have a manual cut without burning, taking straw to the plant (power plant), there is also another project of TH-Köln to produce bio-coal taking advantage of the charcoal coming from the straw and bagasse of the sugarcane.

c) How is this activity performed? Who are the responsible parties?

Scheduling the harvest is a challenge. In 2006: there were about 10,000 sugarcane growers. Today, the small growers are close to 4,000, it has decreased a lot.

People are always thinking about the organization of bringing technology to small producers. It is necessary to have a greater approximation, although it is difficult to reconcile this approximation. It is not only complicated to bring the harvesters closer together, but also to bring technology. In the region, there are only two plants (mills), but it is difficult to reconcile, to have the loyalty of the producers and that would make this approach difficult.

So, normally an authorization must be obtained from the environmental agency to burn the cane to harvest it, and this authorization is communicated to the plant (mill), so the mill must be previously informed when receiving the cane that there is an environmental authorization for the cane to be harvested by burning, whether it is programmed or accidental, as can often happen.

No.	SUBJECT
2	**SUGARCANE BURNING IN THE REGION**

d) Is it feasible to carry out 100% green harvesting at the local level (Campos dos Goytacazes)?

Yes, the fastest way would be if the mills to be able to receive the cane with straw or to have small harvesters to harvest all the cane without burning. This is the most sustainable solution, it is urgent.

e) Is the machinery accessible?

The large sugarcane harvesters have been an aspect that made it difficult, due to maneuvers. Not having the land prepared for the large harvesters, and their use caused damage to production. I tried to make a type of double harvest plantations, but, as there is not a good direction in the region. Specially the operators of the machines themselves. Then the effort to adapt my production to these machines was worse, it was directed in a different line, due to the lack of having a culture of mechanized harvesting.
In large regions of Brazil, it was also a gradual work, they had and still have problems, this technique has been adapting over time, but it has its availability in large areas, different from our region. There must be a training, a preparation because there may be other consequences, there is a smaller volume of cane, a smaller weight with a lot of straw that will impact on the cost of transportation and this is worthwhile, but there must be an adaptation, because there is a loss in terms of yield, but there is better productivity, better use of soil.

f) How has the use of harvesters influenced cane production?

In other regions, they had projects to train personnel in the use of machines. In our region there is a need for people, even if it is outside the field training, to work in manual sugarcane harvesting, not only in harvesting but also in cultural treatments. That change, I would say that today the cane harvesters in our region do not have that very rural vocation, that diversification in their training, could be in other areas other than the rural area. We see many people who do not have any skill in harvesting sugarcane, and this is reflected in the low yield. They are in the field (agriculture) for lack of choice, but they have no vocation. The direction for their occupation or training could be in other areas, other than the rural area.

g) What are the advantages and disadvantages of green harvesting?

I believe that there would be more advantages, especially in regions with an aggravating semi-arid climate, similar to that of northeastern Brazil, in terms of rainfall distribution. Benefits: preservation of humidity, soil organic matter reflecting in productivity.
Disadvantages: perhaps what is happening in other regions, emergence of soil pests (root weevil), difficulty in controlling harmful pests, these are situations that depend on the adaptation as it happened and is happening in other regions.

The benefits are greater. Regarding FREST, there must be a control, it is quite backward in our region, there should be debated and consolidated points, we must look for those ways out, those adaptations to have benefits and have a greater sustainability of the sector, this management not only in the type of soil I have, there are other consequences of organic soils in the region that lost their production capacity, today there is no more organic horizon in soils and this reflects not only in productivity, but also in the sustainability of the sector.

INTERVIEW No.	DATE	HOUR	SUBJECT	FORMAT
005	18/05/2021	14:30	Sugarcane harvest in Campos dos Goytacazes	Online (Zoom)

INTERVIEWED			
Name	**Company**	**Role**	**Country of origin**
Tito Inojosa	ASFLUCAN	President ASFLUCAN Campos dos Goytacazes	Brazil

No.	SUBJECT
1	**SUGARCANE HARVEST**

a) What is the role of the association during harvesting?

In terms of harvesting, we have a record of burns carried out by our association. And, within that, we have producers, who joined in consortiums to hire cutters to do their harvesting.

Several producers joined together in a consortium and hired cane cutters to do the manual cutting. From 100 hectares of surface until 2024, you can continue in the burning process law. The area above 100 hectares can no longer burn cane, the last year was last year. Unless it is, now I don't remember the slope of the property, a greater slope, in a larger part, it is also still allowed until 2024, within this part of the harvest. Most of the harvesting is done by the mills. Those that have the consortiums and those that do not have the consortiums are the mills that hire the cane cutters, that hire the machines to harvest. The raw cane harvesters, who have the big harvesters, are the mills, who harvest the raw cane, and the people who harvest the burnt cane of these small producers; the trucks are all hired by the mills, most of them hired by the mills. Most of the trucks are contracted by the mills. TQC, as they call it in São Paulo.

b) What is the average production of the association's producers in Campos?

55, 50 tons per hectare.

c) Do sugarcane producers have any legal benefits or subsidies?

The only benefit he has is the rural pension, which is for him. If he contributes cane in his name, in his wife's name, in his son's name, then he has the number of years, which is thirty years, contributing he would be entitled to the rural retirement, which I think is around a minimum salary, a small minimum salary. The minimum salary is around 1,100 or 1,150 reais.

They do not have one here. Until three years ago they had a tax that they contributed to the sugarcane cutters' hospital, which was made to attend the rural producer. The sugarcane producer, his family, and his workers, but over the years the hospital could no longer support itself. Now, if you do something private there, we give a 15% discount to the rural producer, the sugarcane producer, any member of his family, any employee of yours. We give a 15% discount. I am also part of the hospital's board of directors. But today the hospital lives with public funding. It does not sustain itself. In the past, it was self-sustaining. Because there was money from the Federal Government in the Sugar and Alcohol Institute (IAA), so it could allocate funds to the social area of the sugar mills and the social area of the sugarcane cutters. through the sugar mills there was social assistance with ambulances, with doctors, with dentists, there was money to pay for the university, there was a lot of things that with the closing of the IAA ended. When the price became free market, the government no longer interferes in the price, it is the market, it ended.

No.	SUBJECT
2	**SUGARCANE BURNING IN THE REGION**

d) What are the benefits of pre- and post-harvest burning?

I think the practice of burning cane is a very bad practice for our region, but we cannot get machines for small farmers, and that is our great difficulty. We are not going to have machines. That is the challenge of the association. We managed to bring sugarcane planters, we have a very good planter there, it is even with me, it is mine, it reduces a lot the foundation cost of the crop, but the harvesting part we did not get. Our planter was developed by people who manufacture machines for planting cassava, so they were able to adapt a planter for planting sugar cane. Now for the harvesting part we have to see one more machine in São Paulo. We are waiting for the pandemic issue to subside, then we will look at a smaller machine to see if it works here. For now, we cannot. We have already tried several machines and we have not been able to get it, even a big machine, from a big manufacturer which is Keyes. We tried to get a smaller machine for four thousand dollars through COAGRO and it is lying in the scrapyard of COAGRO because it didn't work.

e) Are there any disadvantages to burning and what are they?

The biggest problem is the acquisition of machinery, because they do not produce machines for small producers, the factory has no interest because the sales volume is very small.

People are still burning. There are environmental laws near the power grid, near the city, something near a forest, near a natural reserve that you can't burn. So, there are some limitations. Now, there is also a lot of burning. There has been a very dry August-September and the incidence of fires is very high. Whether it is sugarcane or pasture, the incidence of fires is very high.

No.	SUBJECT
3	**SUGARCANE BURNING IN THE REGION**

f) Is it feasible to carry out 100% green harvesting at the local level (Campos dos Goytacazes)?

In 2024, it will be. I don't know how, but it must be. It is a law. If there are no changes, it will have to be done. The Public Prosecutor's Office is all over this. The problem is getting the technology we don't have.

g) Is it possible to acquire or develop machinery that benefits all members of the association?

No, as I explained before.

h) How has the use of harvesters influenced sugarcane production?

Look, what happens with big machines. The producers' property is very small, one is glued to the other. The machine doesn't even have room to maneuver properly, so the machine maneuvers a lot and doesn't produce. The production drops. Therefore, it increases the cost a lot and makes harvesting economically unviable.

i) Is there any technical training for cutters on how to use the machinery?

Yes, there are. All the operators of the big machines, some were even former sugarcane cutters, were trained. At the beginning, people went to São Paulo for training in São Paulo, and then these people trained the others here. But they are big machines, they are not suitable for the small farmer.

j) How does the association manage the disadvantages of green harvesting for farmers?

We are trying. We live researching, trying to find out, trying some machine and we don't get it. We tried some machines, and we didn't get it. We have already tried four or five different manufacturers and none of them have worked. Even last year we brought a machine and returned it in January, because it was not producing well. When I got a cane with higher productivity, it would push or cut the cane with a very high stalk. The German machine worked well in a demonstration; this machine is stopped at COAGRO. It worked well in a demonstration, but then the project stopped. Do you understand? Unfortunately, it stopped.

ADDITIONAL QUESTIONS	
No.	**SUBJECT**
4	**ASFLUCAN ROLE**

k) What is the difference between association (ASFLUCAN) and cooperative (COAGRO)? How do they work together?

Well, the association. Every sugarcane producer in Brazil is obliged to be linked to some association of sugarcane producers. What we do is to see the price of the producers. We get the information from the sugarcane mills, and we process the information of sugar and alcohol prices, the volume of sugar and alcohol production of each industrial unit with the price of each one, and in this volume, we have a formula, which is copied from the CONSECANA system in São Paulo, where the association makes the price of sugarcane. We also do the burning register. We do all the registration, all with the area located in the GPS and we pass it to the environmental agency. Law enforcement is the obligation of the environmental agency. We participate in the cleanup of the lowland canals. Our region has the highest rate, the largest area of canals in Latin America. We have about 1500 kilometers (KM) of canal areas and our association participates in that, in these cleanups with machines, bank water collection with pumps, with people working.

We take care of the rural retirement of these producers. All the rural registry to pass to INSS, which is the retirement agency in Brazil. The information is ours; we have files there, they check it. And another one, several works that provide new technologies with machines, with other things. This is the work of the association. The mill is already industrializing, processing, trying to make and help the producer in some way with the plantation, with the harvest. Thus, the role of the cooperative, COAGRO, is trying to do all the work, you could say collective. It is a collective work to process this sugarcane. That is the objective of the cooperative. And, on the other hand, the association to defend the interests of the producers, in a general way, both COAGRO and Canabrava.

l) Does the association have a record of how many people work in the harvest?

That depends on the mills. This data has to do with the mills. The association does not harvest. The harvesting is done by the COAGRO and Canabrava. I think it is about three thousand people, who do this harvest. It is decreasing with the mechanization, with these machines that the mills bought, this number is decreasing. And the big difficulty, if you look at the diagnosis that was made, at that time the average age of the cutters was 57 or 58 years old, I don't remember well, you know? So, these people today, even the biggest group of cutters are older people, who don't know how to do anything else, who didn't adapt to do anything else. The bulk of those people. And lately cane cutters have arrived from other regions of Brazil, mainly from Minas Gerais.

m) Do you know how many workers come from other regions? Do you have data?

I believe there are about 500 cutters, the rest are from the region. This labor force of cutters works in the period between harvests, planting cane. In the plantation, in the areas that have something to clean, in the cultivation and planting.

n) What is the percentage of associated producers in the region?

No percentage. There is no percentage in the association. Here in the association, there are 4,000 producers, but before there were 40,000. Today there are about 4,000 producers. 100% of the sugarcane producers must be associated. It is a federal law that comes from the time of the Sugarcane and Alcohol Institute, and they pay 1% of the value of the cane for the association's contribution. The factories deduct it from the supplier and pass it on to the association.

o) How many of producers of the region are small, medium and large?

80% have less than one rural unit of the Brazilian association, which is 500 hectares. Then there is an intermediate group and a large group. This other large group is 5% or less, they are the large suppliers in our region. The rest are medium-sized suppliers. In terms of Brazil, everything is small. Even our large ones, in terms of Brazil, are all small.
Now, with the prospect of the return of the Paraíso mill, there are many people returning to cut cane, thus the problem of the lack of water in the canals appeared. We bought a machine, which is a large hydraulic excavator to clean these canals. This machine arrived on 25 January, and we have already cleaned more than 25 kilometers (km) of canals to

try to bring water to these farmers so that they can go back to cutting cane. Because we have the problem of serious weeds. I think you could drive around the region later to get an idea.

INTERVIEW No.	DATE	HOUR	SUBJECT	FORMAT
006	18/05/2021	19:30	Sugarcane harvest in Campos dos Goytacazes	Online (Zoom)

INTERVIEWED			
Name	**Company**	**Role**	**Country of origin**
Luiz Acosta	N/A	Sugarcane Producer	Brazil

No.	SUBJECT
1	**SUGARCANE HARVEST**

a) How is sugarcane harvesting performed on your property?

We are already finishing the burning cycle, we are starting to remove the burnt, but with the use of harvesters. The cooperative ordered the use of harvesters to do the removal. We are harvesting a lot of sugarcane for cattle and livestock, it is done naturally, it is not burned

We are in the process to change burning. We have not yet reached the goal of this process, but we are moving forward to harvesting everything without burning.

b) What are the benefits of pre- and post-harvest burning?

The only benefit of burning would be ease of cutting, other people may think differently or see differently, but I won't say anything. It makes cutting easier, mainly when you have a cane crop with a very large productivity. The cane grows very close together, stuck together and makes it difficult to cut, and burning makes it easier.

No.	SUBJECT
2	**SUGARCANE BURNING IN THE REGION**

c) How is this activity performed? Who are the responsible parties?

Burning is complex. Burning has become more complex because, in my opinion, there is a lack of discipline for burning. I will give you some easy examples to understand: if you burn a cane that is already ripe, prepared at 7 hours in the morning or maximum 8 hours, it will have a behavior, the straw will be burned, but there will not be a very big heating in relation to the release of oxygen and other things, there are people who have already detected this in practice. The cane is going to be burned and removed from the straw almost in its entirety, it does not become uncomfortable, there is a damage, but it is not very big. Now if it is at midday or 1 o'clock in the afternoon, and it causes a strong fire, thus destruction. You can feel the heat at a distance, you can see everything disappearing. If a stricter discipline is created, I believe that the burning of the cane could have more time, but currently it is over, it had to be over and people never understood, some people, because in my region some people did that, most of them did not do it and we realized that it reached where it had to reach.

d) Are there disadvantages of burning? What are they?

First of all, the loss of nitrogen from the soil, the formation of CO_2 in the atmosphere, at the field level. The people who work with burnt cane end up breathing the smoke, dust and when they arrive at the sugarcane mill, in the manufacturing part, it is difficult to clarify the broth from burnt cane. So, they end up using more products, clarifiers, which they would not use if the cane was unburnt.

Certainly, the stop of burning initially caused some problems, such as labor, because people are culturally accustomed to that kind of cane cutting. Cutting cane with straw is more expensive for the producer, but now the use of harvesters has begun and is an irreversible situation, even medium-sized producers are beginning to acquire harvesters, so it is felt that there is no way back. The state legislation stipulated for 2021 or 2022 or complete cycle of cane cutting with straw and that is what is happening.

No.	SUBJECT
3	**HARVEST MECHANIZATION**

e) Is it feasible to carry out 100% green harvesting at the local level (Campos dos Goytacazes)?

It is possible, we are on the way, we are well advanced, I would say that not for this harvest, but in one or two more harvests we will have the complete elimination of the burns.

f) Is machinery accessible to all producers?

What is happening here now, factories are trying to produce machines that cover or serve all levels of producers, because if you acquire a big machine, you must have a lot of cane that compensates the use of the machine, or smaller producer can join another producer, or can acquire a smaller machine, but we are realizing that there are factories that are concerned in selling equipment accessible to the size of producer. It is possible that in the next few years, several producers will buy machines according to their production.
Exactly, for example the price of a new tractor would be around 150 thousand reais (30 thousand dollars), so a machine should not cost much more than this value, but it can cost more. If they create more compatible machines, I believe that many producers would buy the machine, it would be compensated, it is a trend that is growing, because people are believing that the burning is going to end and people start to worry about another alternative. Because the alternative of harvesting without burning but manually, that is not a very viable alternative, because it makes the cost of sugarcane production too expensive.

g) How has the use of harvesters influenced cane production?

Visibly, it is a situation that is developing a lot. I cited a case that smaller machines are appearing in the market, to attract the smaller producers. I am going to make an observation: the small producers are going to disappear from the region, the producers that will remain are the medium and large producers. The situation as it is projected in the region, the small producers is going to disappear. We had a payroll some 15 or 20 years ago, through the producers' association, which consisted of 8 thousand producers where there were 200, 300 or 400 tons of cane, today that ended, those suppliers disappeared, there are no more, at present I do not know how many there are in the payroll, but I can guarantee you that it fell to 1000 suppliers or less. One was buying from another one, another one could not pay, and only the biggest ones were left, and we no longer have small suppliers. This region has a centennial tradition of small suppliers, but now, no more. The change came fast, in the last years, this change was already coming but slowly, but at a certain point, the change came fast, and we will have no more small suppliers.

h) How is labor hiring done? Is there technical training in the use of harvesters?

The contracting is as follows: the laws are basically made by the laws of the sugarcane mills, of the cooperative, basically speaking. It is not that there are not some outsiders who form a group, hire some people to work, but, in general, the COAGRO hires the personnel and distributes the people for the sugarcane cultivation, that is basically how it is. We have some different cases, but they are not so representative.

i) What are the advantages and disadvantages of green harvesting?

Advantages. In the first place it goes directly to the quality of life. Even the cutter of the cane without burning, will have a home, a better moment in his work a lot. Now, as a disadvantage, in terms of profit for him to have a compatible remuneration, he will have to charge a higher value to the owner of the cane, the owner will have to pay much more, I will risk with some precision that it is a ratio of 3 to 1, as soon as he cuts 3 quantities (tons) of burnt cane, he can cut 1 ton of cane with straw, this would be economically a disadvantage.

Other advantage, with the cane without burning, the permanence of the worker in the workplace, it would be a much more humanized place where it would not be necessary to breathe dust, smoke of the burned cane. Also, the treatment of the cane to produce sugar would not use many of the clarifying products that it receives at the plant (mill).So we are seeing that there is a very big advantage, as economically, that is why we are thinking about the issue of the machines, because if we think of placing only labor (worker) we would have problems, "the account does not close", we would have welfare of the people, the environment, the quality of sugar, but the production cost (economy) would be very high, expensive.

ADDITIONAL QUESTIONS	
No.	**SUBJECT**
4	**INFLUENCE ON THE HARVEST LABOR**

j) Is the type of harvesting a decision of the producer or is it influenced by the mill or the association?

This is a difficult question. There are no definitive criteria. First of all, here there are many accidental burnings, when I say in quotation marks, it means that people who cause burnings and make it look as if it were an accident, that still happens. Now, we have some cases, a few cases that are the decision of the supplier and sometimes the decision of the power plant, I can affirm that this part, who was responsible or who ordered the burning or not is very small, these accidents in the region still amaze us, this accident story may make us think that it is an isolated case, but it is not, this happens in many cases. This issue is regulated, but at the time of the decision the person may say that it was an accident, but we know that it was not true, that he was the one who caused the accident.

k) In the case of reducing harvesting with manual labor by using machinery, could personnel be trained to operate the machinery?

The truth is the following, we have in the region, as there is in the whole country, high unemployment, statistics show it, only that the labor force for sugarcane cutting in the last few years has not been very attractive, people are not very attracted, they come many times out of necessity, because of unemployment. So, the exit of the people who would lose their jobs because of the machines will not be very dramatic, I believe that they will be used, a part of them in the crop itself, in the producer's place, in the mechanized work, and the other part will go to look for another activity, because the number of people who work in sugarcane cutting is very large, a very expressive number. Only if the person works in one harvest, the following year he/she remains unemployed, because the cane cutting does not give the worker a livelihood for the whole year, this is something negative. It is an issue that must be considered, observed calmly, because the cane cutting is a palliative, for example, now we are beginning the harvest and those who commit themselves to the cane cutting now will not pass or will not reach the month of October and from then on, there will be no more cane cutting for the person.

Annex 3: Campos dos Goytacazes variables and matrix

The variables identified by the stakeholders are shown in Chart 9.

TYPE	GROUP NAME	ITEM	SYMBOLOGY	DESCRIPTION
INTERNAL	Politic	1	LEG	State environmental legislation (harvest)
		2	LIC	Environmental licenses (harvesting)
		3	ASSOC	Association management
	Economic	4	PCOST	Production cost (labor, machinery, operational)
		5	MINV	Machinery (harvester) investment
		6	PROF	Sugarcane profitability
		7	DUR	Harvest duration
		8	PRED	Production reduction
		9	BPROF	Profit for bagasse and straw
		10	PSIZE	Property size
		11	TCOST	Cane transportation cost
		12	FSCOAGRO	Financial solvency of COAGRO
	Technological	13	CHEMS	Reduction of chemicals in industrial processes (Mills)
		14	MO	Machinery outsourcing (consortiums)
		15	ALTERN	Research, development, and innovation of alternatives
		16	HADAPT	Harvester adaptability
		17	HPERF	Harvester performance
		18	HSIZE	Harvester size

		19	HAC	Harvester accuracy of the cutting
		20	HAVAIL	Harvester availability in the market
		21	HL	Harvester Lifetime
		22	ES	Efficient separation of bagasse and straw
	Social	23	LO	Labor outsourcing (consortiums)
		24	CAVAIL	Availability of cutters
		25	HSCHED	Harvest scheduling
		26	COMPWORK	Competent workmanship for the use of machinery
		27	AMO	Availability of machine operators
		28	DPROD	Diminution of sugarcane producers
		29	TPROD	Type of producer (small, medium, and large)
		30	UNEMPL	Unemployment
		31	DISCP	Discouragement of producers
		32	LMIG	Labor migration
	Environmental	33	VAR	Varietal selection for mechanized harvesting
		34	SS	Size of stalks
		35	LAND	Characteristics of the land (size, location, slope)
		36	LC	Local climate
		37	DEGRAD	Soil, water and air degradation
		38	FIRE	Arson (fire outside of planning)
		39	PEST	Pest incidence
		40	HERB	Herbicide application
EXTERNAL	Politic	41	NLL	National Labor Legislation

	Economic	43	EMPDIV	Employment diversity in the State
		44	CLOSMILL	Closure of sugar mills
	Social	45	COORDPP	Coordination between plant and producers
	Environmental	46	CC	Climate change

Chart 9. Campos dos Goytacazes harvest variables
Own elaboration

From the list of variables in Chart 9, 24 variables were selected to create the matrix below according to the experts' criteria (Chart 10).

FACTORS OF CHANGE		State environmental legislation (harvest)	Production cost (labor, machinery, operational)	Machinery (harvester) investment	Sugarcane profitability	Cane transportation cost	Labor and machinery outsourcing (consortiums)	Financial solvency of COAGRO	Employment diversity in the State	Closure of sugar mills	Research, development, and innovation of alternatives	Harvester adaptability	Harvester availability in the market	Availability of cutters	Competent workmanship for the use of machinery	Diminution of sugarcane producers	Unemployment	Discouragement of producers	Labor migration	Association management	Characteristics of the land (size, location, slope)	Soil, water and air degradation	Arson (fire outside of planning)	Pest incidence	Climate change
		LEG	PCOST	MINV	PROF	TCOST	LMO	FSCOAGRO	EMPDIV	CLOSMILL	ALTERN	HADAPT	HAVAIL	CAVAIL	COMPWORK	DPROD	UNEMPL	DPROD	LMIG	ASSOC	LAND	DEGRAD	FIRE	PEST	CC
State environmental legislation (harvest)	LEG		3	2	2	2	2	2	1	1	3	3	0	3	3	1	3	2	2	0	2	3	3	3	2
Production cost (labor, machinery, operational)	PCOST	0		0	3	1	3	2	0	2	2	2	0	2	1	2	3	2	3	1	1	2	0	0	0
Machinery (harvester) investment	MINV	0	0		2	0	2	1	0	0	2	0	2	1	1	1	1	1	1	0	0	2	0	1	1
Sugarcane profitability	PROF	0	2	0		0	1	3	1	3	2	0	1	1	1	3	3	3	2	2	0	1	1	1	1
Cane transportation cost	TCOST	0	0	0	2		1	2	1	2	2	0	0	0	0	2	1	2	1	1	0	0	0	0	0
Labor and machinery outsourcing (consortiums)	LMO	0	3	0	2	1		2	1	1	0	0	0	2	1	0	3	1	2	0	0	0	0	0	0
Financial solvency of COAGRO	FSCOAGRO	0	1	0	2	0	1		2	3	2	1	1	1	2	3	3	3	2	1	0	1	1	0	1
Employment diversity in the State	EMPDIV	0	2	0	1	1	1	1		1	2	0	0	1	2	1	1	1	2	1	0	1	0	0	0
Closure of sugar mills	CLOSMILL	0	1	0	2	1	1	3	3		3	1	2	3	2	3	3	3	3	2	0	1	0	0	1
Research, development and innovation of alternatives	ALTERN	0	2	1	2	1	1	1	2	2		3	3	1	2	2	2	2	2	1	0	3	0	2	2
Harvester adaptability	HADAPT	0	1	1	2	2	3	2	1	2	3		2	2	2	2	2	2	3	2	0	2	1	1	2
Harvester availability in the market	HAVAIL	0	1	3	2	2	3	1	2	2	3	2		2	2	2	3	2	2	1	0	2	1	1	2

Availability of cutters	CAVAIL	0	3	0	2	1	2	1	1	2	1	1	0		1	2	3	2	3	1	0	1	2	1	1
Competent workmanship for the use of machinery	COMPWORK	0	2	0	1	1	1	1	2	1	1	1	1	1		1	1	1	1	1	0	1	1	0	2
Diminution of sugarcane producers	DPROD	0	2	0	1	1	2	3	1	3	2	1	2	3	2		3	3	3	3	0	2	2	1	2
Unemployment	UNEMPL	0	3	0	1	0	3	1	2	1	1	1	0	3	1	1		1	3	1	0	1	2	0	0
Discouragement of producers	DPROD	0	2	0	1	1	2	3	2	3	1	1	0	3	2	3	3		3	2	0	2	1	1	2
Labor migration	LMIG	0	3	0	2	0	2	2	1	1	1	1	1	3	2	2	2	2		1	0	1	1	0	1
Association management	ASSOC	2	1	0	2	1	1	1	1	1	2	2	1	1	2	2	1	2	1		0	2	1	0	1
Characteristics of the land (size, location, slope)	LAND	2	3	1	2	3	1	1	1	2	3	3	2	1	2	3	1	2	2	1		2	2	2	1
Soil, water and air degradation	DEGRAD	3	1	0	1	0	0	1	2	2	3	1	1	0	2	2	2	2	1	1	1		0	2	3
Arson (fire outside of planning)	FIRE	1	2	0	2	1	1	1	0	1	1	0	0	1	0	1	0	2	1	1	0	2		1	2
Pest incidence	PEST	1	1	0	2	0	0	1	1	1	3	1	0	1	1	1	1	2	0	1	0	1	0		2
Climate change	CC	3	1	0	3	1	1	3	2	2	3	1	1	2	1	2	2	3	2	1	0	3	1	2	

Chart 10. Campos dos Goytacazes matrix with expert rating
Own elaboration

Annex 4. Tamasopo variables and matrix

The variables identified by the stakeholders are shown in Chart 11.

Type	Group name	Item	Symbology	Description
Internal	Politic	1	SUSTLAW	Sustainable sugarcane development law
		2	SINORG	Producer's organizations
		3	INCENT	Government incentives to producers
	Economic	4	PCOST	Production cost (labor, machinery, operational)
		5	MINV	Machinery (harvester) investment
		6	PROF	Profitability
		7	INCOME	Producers income
		8	LOWGC	Less payment for green cane
		9	CDAM	Crop damages
		10	SQUAL	Sugarcane quality
		11	PSIZE	Property size
		12	TCOST	Transportation cost
	Technological	13	ALTERN	Research, development and innovation of alternatives
		14	HAVAIL	Harvester availability in the market
		15	HADAPT	Harvester adaptability
		16	MAINT	Machinery maintenance
	Social	17	WORKCOND	Cutters working conditions
		18	CPOV	Cutters poverty
		19	PCHAR	Producers characteristics (age, education)

		20	UNEMPL	Unemployment
		21	LOPAYC	Low pay for cutters
		22	COMPWORK	Competent workmanship for the use of machinery
		23	DPROD	Discouragement of producers
		24	LMIG	Labor migration
	Environmental	25	LAND	Characteristics of the land (size, location, slope, quality)
		26	DEGRAD	Soil, water, and air degradation
		27	FIRE	Arson (fire outside of planning)
		28	PEST	Pest incidence
External	Politic	29	NAFTA	Free-trade agreement (USA)
		30	PDIV	Products diversification
		31	MDEM	Reduction in the demand for sugar (competition with other sweeteners)
	Environmental	32	CC	Climate change

Chart 11. Tamasopo harvest variables
Own elaboration

From the list of variables in Chart 11, 17 variables were selected to create the matrix below according to the experts' criteria (Chart 12).

FACTORS OF CHANGE		Sustainable sugarcane development law	Sindical organizations	Government incentives to producers	Free-trade agreement (USA)	Production cost (labor, machinery, operational)	Profitability	Sugarcane quality	Products diversification	Reduction in the demand for sugar (competition with other sweeteners)	Research, development, and innovation of alternatives	Harvester adaptability	Cutters working conditions	Producers characteristics (Age, education)	Competent workmanship for the use of machinery	Characteristics of the land (size, location, slope)	Soil, water and air degradation	Climate change
		SUSTLAW	SINORG	INCENT	NAFTA	PCOST	PROF	SQUAL	PDIV	MDEM	ALTERN	HADAPT	WORKCOND	PCHAR	COMPWORK	LAND	DEGRAD	CC
Sustainable sugarcane development law	SUSTLAW		3	3	3	2	2	2	3	1	3	1	2	0	2	1	1	1
Producers' organizations	SINORG	3		2	3	3	3	3	1	1	2	2	3	1	3	2	3	1
Government incentives to producers	INCENT	1	1		0	2	1	0	0	0	2	2	1	2	1	2	2	1
Free-trade agreement (USA)	NAFTA	2	3	2		3	3	3	2	3	0	2	2	1	2	2	2	1
Production cost (labor, machinery, operational)	PCOST	0	3	1	3		3	3	3	3	3	3	3	2	2	0	1	0
Profitability	PROF	1	3	2	3	2		3	2	3	3	2	3	2	2	1	2	0

Sugarcane quality	SQUAL	1	3	2	3	3	3		3	2	3	2	1	1	2	0	0	0
Products diversification	PDIV	2	2	1	3	2	3	3		3	2	0	0	0	0	0	0	2
Reduction in the demand for sugar (competition with other sweeteners)	MDEM	1	3	2	1	3	3	3	3		3	0	3	1	1	2	1	1
Research, development and innovation of alternatives	ALTERN	3	2	0	3	3	2	3	3	0		2	3	2	1	3	3	3
Harvester adaptability	HADAPT	1	2	0	1	3	2	3	1	1	3		1	2	1	3	2	1
Cutters working conditions	WORKCOND	0	2	0	2	3	2	2	1	1	2	2		0	1	2	0	2
Producers characteristics (Age, education)	PCHAR	1	2	2	1	2	2	3	0	1	2	2	3		0	2	2	2
Competent workmanship for the use of machinery	COMPWORK	0	2	0	1	2	2	2	1	0	2	3	2	1		2	2	1

Characteristics of the land (size, location, slope)	LAND	1	1	0	1	3	2	2	1	1	3	3	2	1	2		2	2
Soil, water and air degradation	DEGRAD	1	1	1	2	2	2	3	1	0	2	2	2	1	2	3		3
Climate change	CC	1	1	0	1	1	2	2	1	1	3	2	2	2	1	3	2	

Chart 12. Tamasopo matrix with expert rating
Own elaboration