University of St.Gallen
Master of Arts in International Affairs and Governance
Master Thesis

Environmental Policies after the Paris Agreement

Innovative cement production and CO_2 emissions in the case of Colombia

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Abstract

Growing urbanization and increased infrastructure demands will augment cement production considerably. By 2050, cement production will reach 6 billion tonnes, which will also be translated into a serious increase in CO_2 emissions. Cement is currently responsible for 7% of total global greenhouse gases. Therefore, the business as usual scenario of cement production is not a sustainable solution. The not yet well-known Limestone Calcined Clay Cement, shortly LC3, is an alternative cement that reduces CO_2 emissions by 30%. While the technical and economic feasibility of LC3 has already been proven, the next step consists of promoting LC3 and making it a main-stream alternative cement production.

This thesis focuses on the implementation of LC3 in Colombia, a mega-biodiverse country that is especially vulnerable to climate change and where the construction sector is growing fast. This thesis shows that LC3 can contribute considerably to Colombia's goal to reduce its CO_2 emissions by 20% by 2030. Further, the given environmental policy framework of Colombia with various policies that seek to reduce CO_2 emissions is in favor of the wide-spread dissemination of LC3. This thesis tackles pull factors that incentivize the private sector to implement the alternative cement production. The existing financial incentives that push firms to adopt more green technologies and environmental sound production methods should be embraced. Demand for LC3 can be created through the voluntary carbon market. Firms could support the construction of social houses built with LC3 and compensate their emissions through the CO_2 savings achieved with the alternative cement production. Strong marketing of LC3 is needed to promote LC3 amongst the government of Medellin, which pursues a green development path of the Smart City. Finally, this thesis concludes that in order to make LC3 a wide-spread alternative cement production, it is necessary to extend the focus from energy efficiency that is tackled widely in Colombia to embodied energy, which focuses on the efficiency of the construction material itself.

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List of Abbreviations

BAU	Business as Usual
CCCS	Colombian Sustainability Construction Council
CONPES	National Economic and Social Policy Council
CO2	Carbon Dioxide
COP21	21st Conference of Parties
CSI	Cement Sustainability Initiative
ECDBC	Colombian Low Carbon Development Strategy
EPFL	Swiss Federal Institute of Technology
DANE	Administrative National statistic department
GEF	Global Environmental Facility
GDP	Gross Domestic Product
GNR	Getting the Numbers Right
IDB	Inter-American Development Bank
IEA	International Energy Agency
IDEAM	Institute of Hydrology, Meteorology and Environmental Studies
IIT	Indian Institutes of Technology
LAC	Latin American and Caribbean Countries
LC3	Limestone Calcined Clay Cement
m tonnes	M tonnes / mega tonnes
NDC	Nationally determined contributions
OECD	Organization of Economic Cooperation and Development
PAS	Sectorial Mitigation Action Plan
PNACC	National Adaption Plan on Climate Change
REDD+	Reducing Emissions from Deforestation and Forest Degradation
SDC	Swiss Development Cooperation
SDG	Sustainable Development Goal
SINA	General National System of the Environment SINA
SIP	Sustainable Infrastructure Program
SISCLIMA	National System of Climate Change
UN	United Nations
UNEP	United Nation Environmental Program
UNFCCC	United Nations Framework Convention on Climate Change
USD	United States Dollar
VAT	Value added tax
VIS	Social housing
WBCSD	World Business Council for Sustainable Developmen

I Introduction

The year 2015 was a historic year. On the one hand, it was the hottest year since climate was first recorded in 1880. The global average temperatures were one degree above the late 19th century levels, largely driven by carbon dioxide emissions. (Northon, 2016). On the other hand, it was the year, in which the Paris Agreement on Climate Change was adopted by 197 countries and where every country declared its own nationally determined contributions (NDCs). After many years of failed discussions, this agreement represents a big opportunity to halt climate change.

However, despite the global commitments made at Paris and a constant CO_2 emission level in the last years, it is estimated that CO_2 emissions increased in 2017 by approximately 2%, mainly driven by China and by little to no reduction in emissions in the United States (Hausfather, 2017).

Currently, the industry sector accounts for 7% of total CO_2 anthropogenic emissions. The cement sector contributes considerably to these emissions. One released ton of ordinary cement is approximately equal to one ton of CO_2. These numbers are particularly alarming as the global demand for cement is steadily increasing. It is estimated that CO_2 emissions will increase massively by 2050 due to the growing urbanization in developing countries and the increasing demand for adequate housing. In a business as usual scenario, emissions will have increased by almost five times by 2050 compared to 1990. (Imbabi et al, 2013, p.202). In order to fight against climate change, it is of considerable importance to find low carbon substitutes to ordinary cement.

What if there were a cement that is not only emits substantially less CO_2 emitting, but were also technically feasible and economically interesting without hurting cement quality? What if this cement could contribute considerably to the nationally determined contributions of the governments made at the Paris Agreement? What if this cement could be the solution for the tradeoff of increasing CO_2 emissions and the human right for adequate housing and elaborated infrastructure?

There is a sustainable solution: Limestone Calcined Clay Cement (LC3) seems to make all this possible. LC3 is a highly promising cement alternative that reduces CO_2 emissions by 30% without hurting cement quality and without increasing performance costs. The technical feasibility of LC3 has been proven, but now a major work has to be done to raise awareness of the huge potential of this cement that could revolutionize the cement industry.

1.1 Research question & Relevance

The focus of this thesis lies on Colombia, one of the world's megadiverse countries, which is especially vulnerable to climate change. The weather phenomena La Niña in 2010 and 2011, which was responsible for considerable asset losses highlighted the impact of climate change on the country. With the implementation of the Paris Agreement, Colombia has made the most recent internationally stated environmental contribution. The country has the goal to reduce its emission by 20% by 2030. With the growing demand for housing and large infrastructure projects, the cement sector plays a considerable role in Colombia's economy. Therefore, LC3 could contribute considerably to Colombia's NDC.

This thesis provides answers to the following research questions:

- » How can the LC3 cement production contribute to the NDCs of Colombia?
- » Which environmental policy framework in Colombia favors or restricts the wide-spread dissemination of LC3?
- » Which pull factors are necessary to convince the construction sector in Colombia to adopt LC3?

This thesis shows that the implementation of LC3 is not only interesting at national level but also at sectorial, local and entrepreneurial level. The Colombian city Medellin, which represents itself as a Smart City is pursuing a green development path and should therefore be interested in implementing sustainable infrastructure measures.
This thesis analyzes Colombia's environmental policy framework and shows which policies should be embraced to implement LC3. Furthermore, this thesis discusses different pull factors, including financial and non-financial incentives. The goal is to show which pull factors should be embraced to incentivize firms to implement the alternative cement production and how the government could contribute to these pull factors.

1.2 Methodology

This thesis consists of five main parts and begins with background information about the cement industry. After discussing the negative externality of the cement sector, the next part is dedicated to the Paris Climate Agreement and the NDCs of Colombia.

Then, this thesis discusses the LC3 project and its considerable potential for the cement industry to reduce CO_2 emissions. After having discussed the advantages of LC3, the direct impact of LC3 in Colombia is analyzed. The contribution of LC3 to the national and sectorial reduction goal of Colombia is shown. This is followed by a series of construction examples, which compare the emissions to Ordinary Portland Cement. The last part is dedicated to the implementation of LC3 in Colombia. The general environmental policy framework is briefly discussed, followed with theoretical financial and non-financial pull factors and practical pull factors in Colombia that incentivize the cement industry and the government to support LC3.

This thesis is based on different types of sources and information derived from literature. Furthermore, part of the information was obtained during a field trip to Medellin, Colombia between December 2017 and January 2018. The information was obtained through personal communications with the cement enterprise Argos, with civil society, and with the NGO Colombian Sustainable Construction Council (CCCS). The aim of the field trip was to obtain information about climate change management and incentives driving the environmental performance of companies in Colombia as well as information about sustainable construction measures. Presentations to Argos about the LC3 project aimed to raise awareness about the potential of the alternative cement production. Additionally, part of the information was obtained during meetings with the international team of the LC3 project. These meetings also helped to do the comparison calculations between LC3 and Ordinary Portland Cement.

II Background Cement sector

2. Global cement

2.1 Definition of Concrete and Cement

Concrete plays a vital role for our modern environment. It is the largest manufactured product on earth by mass and the second most consumed material on earth after water. Nearly three tonnes of concrete are annually used for each man, woman and child (WBCSDa). Concrete consists in cement, water, and in aggregates such as gravel, crushed stones and sand (Schweizer Zement). A paste made by mixing cement and water hardens and gains strength through a chemical reaction, becoming concrete.

A key ingredient of concrete is cement, which was used even by ancient Egyptians, Romans and Macedonians in ancient Greece (Imbabi, 2013, p.197). Today, cement-based materials represent more than one-third of the total materials extracted from earth each year (Scrivener, John, Gartner, 2016, p.v).

Cement is the glue in concrete as it acts as a hydraulic binder. The special binding properties of cement make concrete a very resilient, durable building material. Cement provides our society with mobility and living room. It is used for all types of infrastructure: housing, innovative skyscrapers, architecturally impressive buildings, roads and railways, bridges, hospitals, and so on, none of these would be possible without cement (SDC Global Programme Climate Change and Environment, 2017).

2.2 Common Cement Production

Cement production begins with the quarrying of raw materials, mainly limestone, and clay. Most cement plants are located near limestone-abundant areas to minimize the transportation costs of the raw material. The huge rocks are then crushed into small chunks. The pre-homogenization phase consists of the proportion mix of the different types of clay, limestone, and other required material. The silos are used to separate each of the raw material which will be later added in specific amounts according to the particular cement type produced. In the calcination process, the quarried materials are burnt at 1450° Celsius and provoke a chemical reaction called calcination. The product of this reaction is clinker, the main raw material used in cement manufacturing. After a quick cooling, the clinker together with limestone and gypsum, are grinded into cement. There are different types of cement, but the most common is Ordinary Portland Cement (OPC). It accounts for 70% of total consumption (Schweizer Zement). The illustration below shows the OPC production.

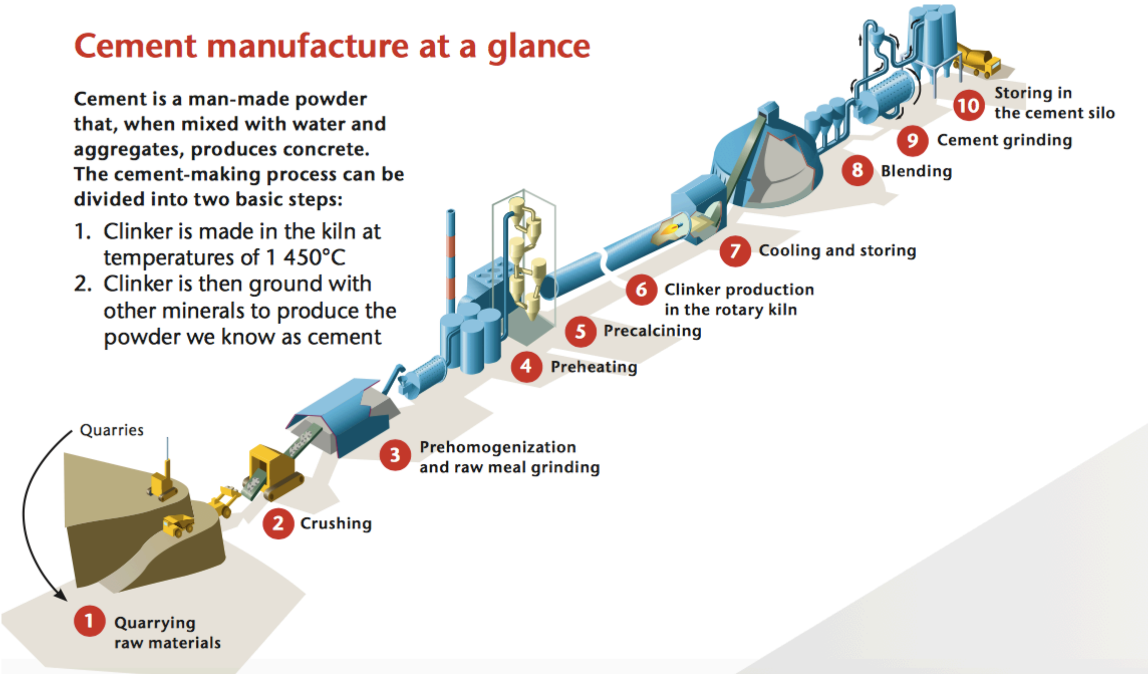


Figure 1:Cement production. Source: IEA, 2010, p. 4.

OPC, also widely known as grey cement, consists of more than 90% clinker. The remaining part consists of gypsum. Clinker production is the most energy-intensive component of the cement production (Scrivener, John, Gartner, 2016, p.20).

An alternative cement is Portland Pozzolana Cement (PPC), accounting for 18% of total consumption. It is a blended cement and is produced by grinding OPC clinker with gypsum and pozzolanic materials, or by grinding the OPC clinker, gypsum, and Pozzolanic material separately. Producing PPC is less energy-intensive than producing OPC, as it involves less heat to perform the calcination process. PPC consists of 80% clinker, of 15% pozzolanic materials such as volcanic ash, calcined clay, fly ash, and silica fumes, and of 5% gypsum (Sagar Cement). Compared to OPC, the reduced clinker-content in the PPC production results in fewer environmental impacts.

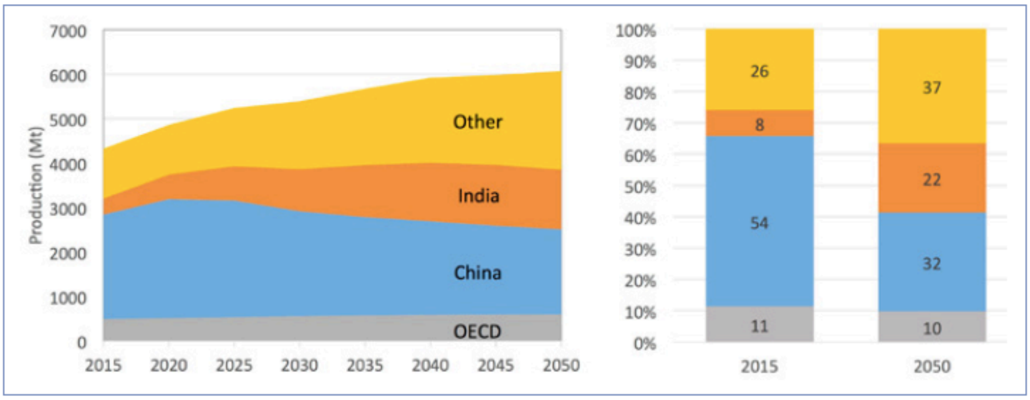
2.3 Increasing demand

In 2015, 4.6 billion tonnes of cement were produced and the quantity of cement produced is rising fast. According to the United Nations Environmental Program (UNEP), in the last 65 years, the cement production increased by 34-fold, whereas the population has increased less than three-fold (Scrivener, John, Gartner, 2016, p.2).

Today 828 million people live in slums. Many of them are especially vulnerable to the effects of climate change, as their housing is not resistant against stronger winds, heavier rains, and inundations. About 90% of cement production is outside of OECD countries, as 95% of urban expansion will take place in developing countries in the next decades (Scrivener, John, Gartner, 2016, p.3) and as cement takes over natural materials like mud brick, timber, and bamboo. According to the UN, by 2050, 2.5 billion more people will live in cities, which is a 66% increase compared to 2014 (UN, 2014). Therefore, with the increasing demand for buildings, higher living standard, and an elaborated infrastructure in developing and emerging countries the demand for cement will double by 2050. Hence, in 2050 about 6 billion tonnes of cement will need to be produced.

China used to be the largest cement consumer but is expected to diminish by 2050 (from 50% to 30%) as cement production has already peaked. (Scrivener, John, Gartner, 2016, p.3)

The graphic below shows the cement production in different countries. It shows that OECD countries only account for 10% of global cement production. Whereas cement production in China is decreasing, in developing countries cement production tends to increase by 2050.



Graph 1: Global cement production. Source:Scrivener, John, Gartner,2016,p.3.

2.4 Negative externality

2.4.1 Definition

A negative externality, also known as an external cost, is a cost that is not suffered by the consumer or the producer, but by a third party. In the case of cement, the external cost arises from the CO_2 emissions in the cement production. The marginal private cost of the cement enterprise is smaller than the marginal social cost. As firms do not have to pay for their released CO_2 emissions, a considerable environmental cost arises with which society has to contend. This negative externality provokes a market failure, as the market does not balance the social costs on its own.

There are different market-based solutions to compensate the market failure, such as taxing polluters or selling permits to pollute. These market-based environmental policies are discussed further in chapter 8.1.

2.4.2 CO_2 emissions

The basic human right to a decent shelter and sophisticated infrastructure comes at the expense of environmental resources. Whereas in 1970 total anthropogenic greenhouse gases, such as CO_2, F-Gases, N_20, and CH_4, accounted for 27 Giga tonnes (Gt), they increased to 49 Gt by 2010. CO_2 accounted for 65% of these total greenhouse gases, without including the CO_2 released from forestry and other land use. The use of fossil fuel and industry processes, which includes cement production, are the main sources of CO_2 emissions (EPA).

In 2014, 4.2 billion tonnes of cement were produced globally and accounted for approximately 2.7 Gt of CO_2 emissions worldwide, which constitutes 7% of total global anthropogenic CO_2 emissions[1]. Cement is the second largest CO_2 contributor in industry after power plants. (Kumar, 2017).

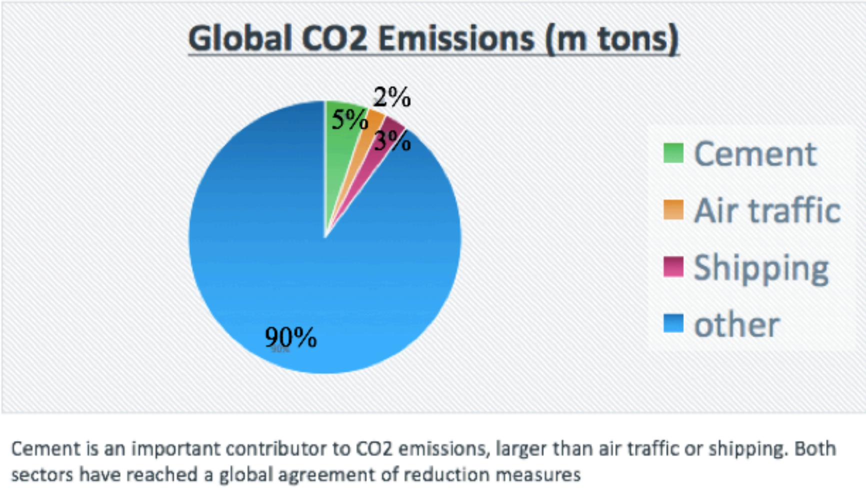
Depending on the efficiency of the process, the fuels used, and the specific type of cement product, the current production of one ton of cement commonly releases 0.65 to 0.95 tonnes of CO_2 (Müller, Harnisch, p.7).

Significant CO_2 emissions are created through two main sources:

1.) About 60% of the emissions are created through the raw materials used in the manufacturing process of cement. The chemical breakdown of limestone into lime releases CO_2.

2.) About 40% are created through the energy used to heat the materials to a temperature of 1450° C. (WBCSD, CSI, 2015, p.1)

[1] According to the CSI and WBCSD, the CSI member countries released 563 m tonnes CO_2 representing 21% of world production. As these companies tend to be the best environmental performers, 2.7 Gt CO_2 is likely an underestimate



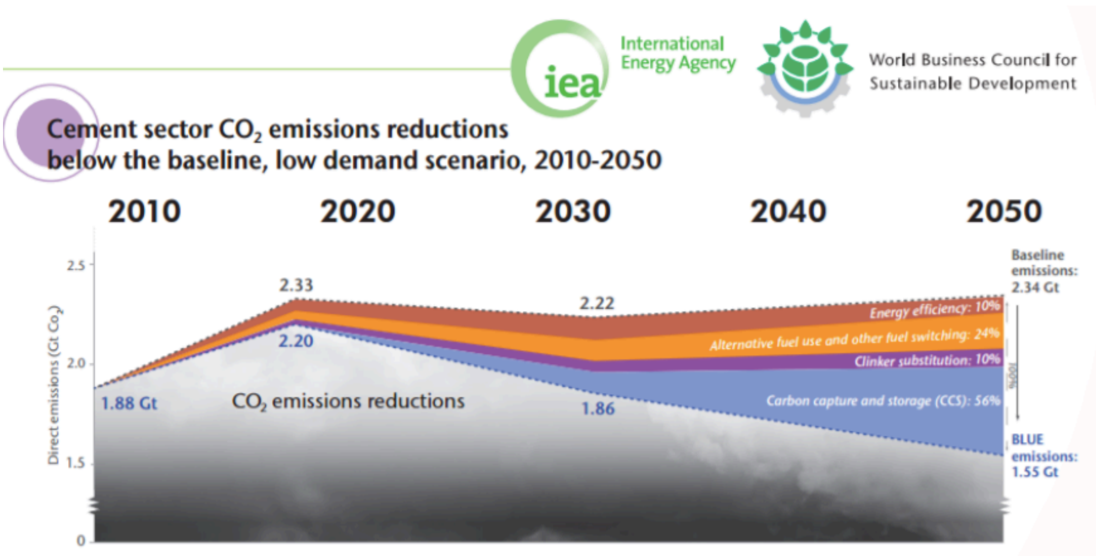
Graph 2: Cement contribution to global CO_2 emissions. Source: LC3 Project.

2.4.3 Mitigation measures

Aware of the huge emissions that cement produces, the cement industry has been pursuing strategies long before global warming became a priority. In 1999, the Cement Sustainability Initiative (CSI), a CEO-led project, has been created to reduce CO_2 emissions. Since 2002, the cement enterprises have made significant progress in reporting and mitigating their CO_2 emissions and shared this progress with other cement firms. A common energy- and CO_2-reporting protocol for the cement sector and a common technology roadmap has been created together with the International Energy Agency (IEA). (WBCSD, CSI, 2015, p.1)

The CSI aims to reduce CO_2 emissions in the range of 20 to 25% by 2030 compared to the business as usual (BAU) scenario. (WBCSD, CSI, 2015, p.2) This means a reduction from 2.34 Gt to 1.55 Gt of CO_2 emissions.

The IEA Cement Roadmap of 2009 proposed four different CO_2 reduction measures, which are shown in the graphic below. The main strategy to reduce CO_2 consists of the Carbon Capture and Storage (CSS) strategy.



Graph 3:Cement roadmap to reduce CO_2 emissions. Source: IEA. 2010.

The graphic of the Cement Roadmap shows that the proposed CO_2 reduction is achieved through energy efficiency (10%), alternative fuel use and other fuel switching (24%), clinker substitution (10%), and through Carbon Capture and Storage (56%).

1. **Energy efficiency**

CO_2 emission reduction is achieved through the deployment of innovative technologies, which increases the energy efficiency of the cement in the manufacturing process.

2. **Alternative fuels and biomass**

Less carbon intensive and alternative fossil fuels and biomass in the cement production process also help to achieve a CO_2 reduction.

3. **Carbon Capture and Storage**

The CSS strategy captures and stores CO_2 emissions of the cement production.
However, this strategy is highly cost-intensive and results into a two to three times increase of the marginal cost of clinker production. This is mainly due to a large amount of energy required to implement the CCS strategy. Furthermore, implementing cost-effective transport and safe disposal remain problematic for CCS (Scrivener, John, Gartner, 2016, p.6).

4. **Clinker substitution**

The substitution of clinker, which is the most energy-intensive part in the production, leads to a considerable CO_2 emission reduction and is therefore a highly promising way to reduce CO_2 emissions in the cement production.
Until now, the most used clinker substitutes are fine limestone, granulated blast furnace slag, and fly ash (Scrivener, John, Gartner, 2016, p.5). There has been a

stagnation of substitutes, and fly ash as well as slags are globally not abundant and availability will decrease by 2050 (Scrivener, John, Gartner, 2016, p.x). The only constantly available alternative material is limestone.

Additionally, while slag and fly ash reduce CO_2 in the clinker production process, they generally require more energy for grinding cement finely. (IEA, 2009, p.7)

2.5 Cement in Colombia

Cement production in Colombia has a long history. It dates back to 1909, when the first cement plant was installed by the firm Samper. Since the 1930s, several companies entered the cement market, but today the cement industry in Colombia is rather oligarchic (Latorre Canon, 2008, p.9). The cement market is dominated by mainly three international firms: the Colombian firm Argos Cementos, which has seven plants in Colombia, the global company Holcim, which has one plant in Colombia, and the Mexican firm Cemex, which has five plants in Colombia. (Argos, 2016, p.3). The Colombian cement market is the third biggest in Latin America after Brazil and Mexico. In 2015, cement production reached 12 million tonnes (m tonnes) and is expected to reach 20 m tonnes by 2030 (Granados, 2017).

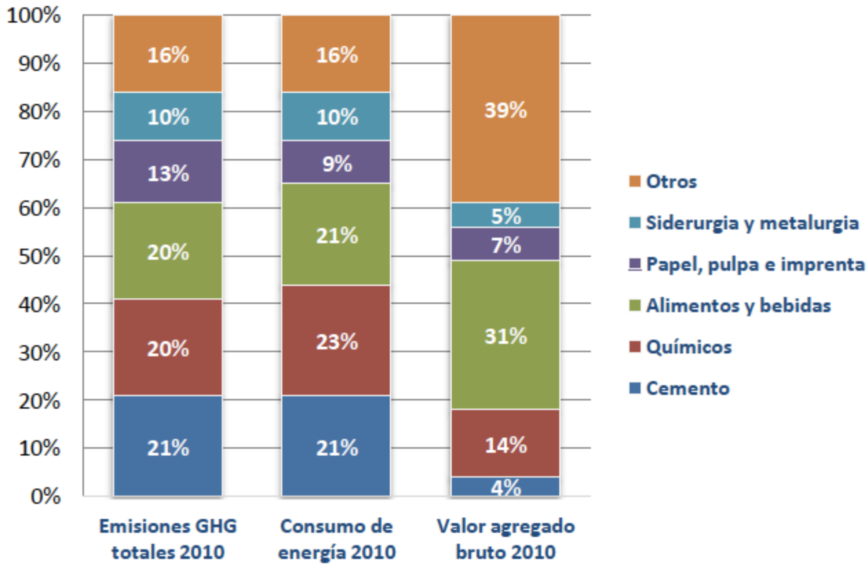
According to the National Administrative Statistics Department (DANE), Portland Cement is the most produced cement in Colombia. (2018a, p.25). National demand comes mainly from concrete manufacturers and constructors. Cement consumption is concentrated in Bogota, Medellin, and Cali. The main demand comes from the department of Antioquia, representing almost one fifth of Colombia. (DANE, 2018a, pp.11, 17).

2.5.1 CO_2 emissions

The industry sector is the fourth sector that is a major contributor to Colombia's GDP; it accounts for 11,3% of total GDP (MinCIT, 2015). This economic contribution is also perceptible in the CO_2 emissions of the industry sector. According to the scientific environmental institution of Colombia (IDEAM), the industry sector released 22 013 m tonnes of CO_2 in 2010. Without mitigating action, it is estimated that the CO_2 emissions will increase to 46 389 m tonnes of CO_2 in 2030. (IDEAM et al., 2017, p.65)

The CO_2 emissions of the industrial sector can be split into two groups: emissions generated due to energy consumption, in which the cement production belongs, and emissions generated due to the development of productive processes. Cement,

chemicals, food and beverage, paper and printing, and iron and steel represent 84% of the total emissions generated by the Colombian industry (MinCIT, 2015, p.6).
The following graph shows that 21% of total greenhouse gas emissions in 2010 were attributed to the cement sector. (MinCIT, 2015, p.7)



Graph 4: Cement contribution to total greenhouse gases released by industry. Source: MinCIT, 2015, p.7

As already mentioned above, clinker is the costliest and most CO_2-intensive material in the cement production process. In Colombia, cement contains on average approximately 72% clinker (Argos, 2016a, p.5). This is slightly under the global average of 74.5%, according to figures of the GNR (Getting the Numbers Right) report of the WBCSD. (WBCSDa).

2.6 Interim summary

- The most common cement is Ordinary Portland Cement (OPC), which consists of up to 95% clinker. Clinker is the most energy-intensive component of the cement production.
- Cement demand is going to increase, and most of the demand comes from developing and emerging countries. Growing urbanization, which increases demand for buildings, housing, and infrastructure, boost cement production.
- In 2014, cement production accounted for 7% of total anthropogenic CO_2 emissions worldwide. Cement is the second largest CO_2 contributor in industry after power plants. The CO_2 emissions are created through the

chemical breakdown of limestone into lime and through the energy to heat the materials.

- The Cement Roadmap of 2009 seeks to reduce CO_2 emissions through energy efficiency, alternative fuels and biomass, carbon capture and storage, and clinker substitution. Pozzolan is globally not abundant and, therefore, limestone is the only consistently available alternative material.
- The Colombian cement industry is the third biggest in Latin America after Brazil and Mexico. In 2010, 21% of the industry's CO_2 emissions came from the cement sector.

III Paris Climate Agreement and the NDCs

3. Paris Climate Agreement

The Paris Agreement is a clear sign of hope to halt climate change, after the disappointing and unsuccessful Kyoto Protocol. On 12 December 2015, the multilateral, legally-binding Paris Agreement was officially adopted by 195 parties at COP 21.

3.1 Defined goals

With the objective to hold the increase in the global average temperature to below 2°C above pre-industrial levels, and to pursue efforts to limit the temperature increase to 1.5°C above these levels, a complete decarbonization of the economy by the end of the 21st Century is foreseen.

Contrary to the Kyoto Protocol, the Paris Agreement does not differentiate between developed and developing countries concerning greenhouse gas reduction efforts. Every country has defined its own NDCs and has adopted action and mitigation plans to achieve these goals. The NDCs presented in Paris are the minimum of contributions. Each country should increase its contributions over time. There are no legal sanctions; the Paris Agreement relies on a “naming and shaming” mechanism. Every five years, the countries must report their development of the NDCs and foster their efforts (Obergassel et al., 2016, pp.14-17).

Differentiation between developed and developing countries is much more attenuated in the Paris Agreement compared to the Kyoto Protocol. Developed countries should undertake economy-wide absolute emission reduction targets, while developing countries should continue enhancing over time economy-wide emission reductions with the support of developed countries. (Obergassel et al., 2016, pp.29-31).

Despite the hope to enhance emission reductions by all member parties,
the declared contributions are not sufficient. Even if the Paris Agreement were fully implemented, global average temperature are likely to increase by between 2.7°C and 3.5°C (Obergassel et al., 2016, p.3). For this reason, it is highly important that the countries take action now to implement their NDCs and to foster their ambitions every five years to reach the goal of the Agreement. Additionally, it is of considerable importance that developing countries get support from developed countries.

3.2 Cement sector at COP21

n 2009, the WBCSD and the IEA developed the Low Carbon Technology Roadmap to remain within the 2°C temperature increase above the preindustrial level. The CSI members stated in the preparation of the COP21 the ambition to reduce CO_2 emissions by 20 to 25% by 2030 compared to the BAU scenario.

In order to achieve this goal, the CSI enhances overall energy efficiency of the cement manufacturing process, good quality alternative fuels and raw materials, a further reduction of the clinker content in cement, and the development of new cements that use less CO_2. Furthermore, the CSI calls for the development and implementation of international standards for energy efficiency and CO_2 emission reductions in the cement industry (Fonta, 2016, pp.23-24).

4. Colombia

4.1 Environmental vulnerability

Colombia, with its exceptional flora and fauna, is one of the richest countries in terms of biodiversity. Although Colombia only covers 0.8% of the world's land surface, it is home to some 15% of all plant species in the world. It has a biodiversity of fauna unrivalled by any other country and possesses 311 different types of ecosystems.

To preserve this impressive biodiversity, the Colombian government's environmental management efforts date back to the National Code on Renewable Natural Resources and Protection of the Environment, which was adopted in 1974.

Despite the efforts to adopt different policies on environmental protection, the effects of climate change do not leave Colombian cities and regions untouched. The water and air pollution, deforestation, global greenhouse gas emissions, and the growing vulnerability to natural disasters all pose big challenges to Colombia (World Bank Colombia, 2014). Notably, the serious effects due to "La Niña" in 2010 and 2011 showed the negative impact of climate change in Colombia. More than 3.2 million people were affected, associated costs added up to 6000 million USD $, 3.5 million hectares were flooded, and 845 primary and secondary routes were closed, all of which affected the country economically and socially (Gobierno de Colombia, 2015, pp.4-5).

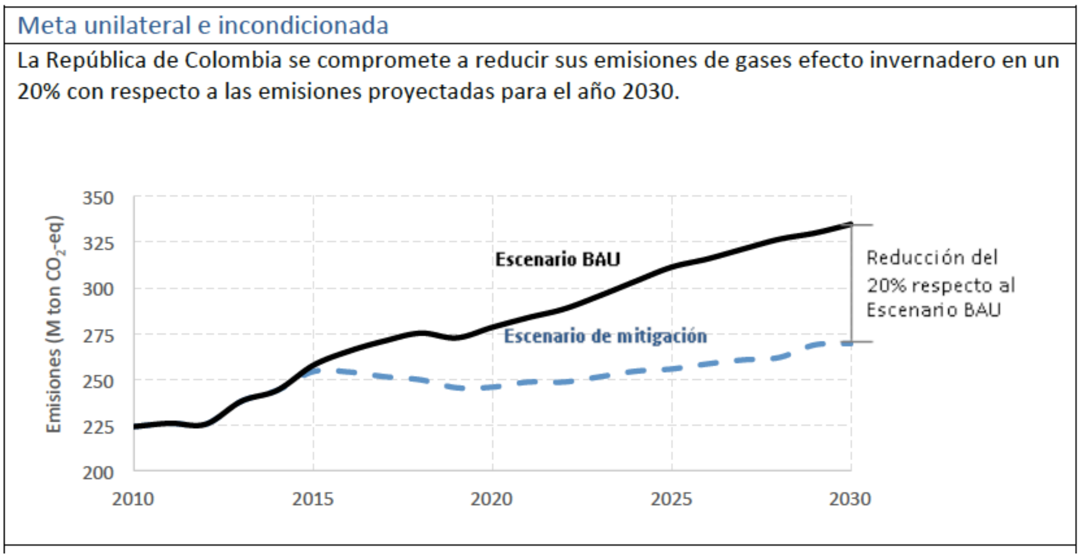
Colombia's economy is highly dependent on climate and on the use of natural resources. If the country does not undertake adaption measures to climate change, Colombia's economy would document an annual loss of 5.2% by 2030 of GDP (Jaramillo, 2014, p. 2).

In the following sections, the NDC of Colombia, the CO_2 reduction goals of the different economic sectors and the Sectorial Mitigation Action Plans of the Industry and Housing sector, which are relevant for LC3, are discussed.

4.2 Nationally Determined Contributions Colombia

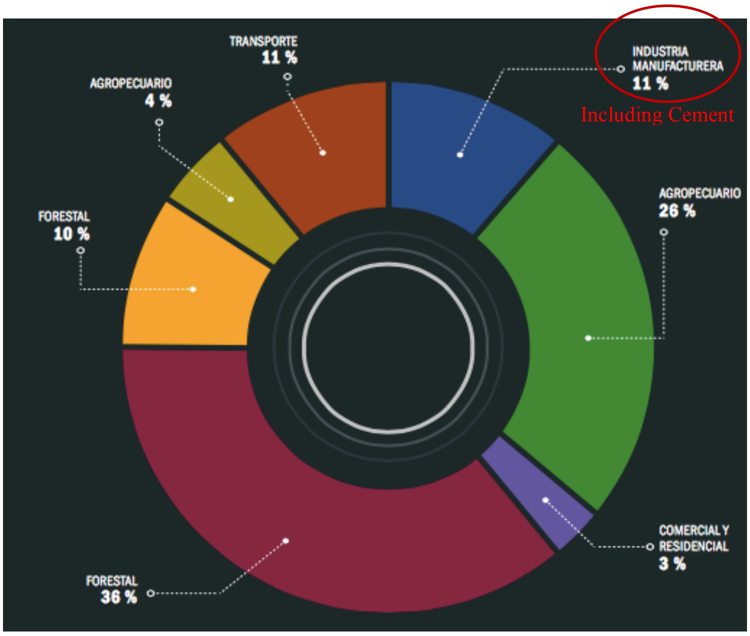
According to the Institute of Hydrology, Meteorology, and Environmental Studies (IDEAM), Colombia issued 224 m tonnes of CO_2 in 2010, which accounts for 0.46% of all global greenhouse gas emissions (Gobierno de Colombia, 2015). This comparably small share of greenhouse gas emissions is largely due to Colombia's low energy and clean electricity consumption compared to other Latin American countries (Calderon et al., 2015, p. 575). However, if Colombia follows the BAU scenario, its emissions could increase by 50% by 2030, as the country has experienced steady growth during the past decade. (Gobierno de Colombia, 2015).

In order to fight against the BAU scenario and to avoid major impacts on Colombia's environment, Colombia expressed in 2015 in Paris its willingness to actively address climate change and to foster a green development path.



Graph 5: Nationally determined contributions: 20% reduction. Source: Gobierno de Colombia, 2015, p.2

With the declared NDCs, Colombia has the ambition to reduce greenhouse gas emissions by 20%, and with international support by 30%, until 2030 relative to the BAU scenario. A 20% emission reduction means a reduction from 335 m tonnes CO_2 (BAU) to 268 m tonnes of CO_2 in 2030. In other words, a reduction of 67 m tonnes CO_2 by 2030. (Dirección de Segmentos Empresas y Gobierno Bancolombia, 2016).



Graph 6: Sectorial greenhouse gas distribution. Source: IDEAM et al., 2017, p.17

According to the third national communication of the IDEAM in 2016, changes in the use of land (deforestation and farming) contribute the most to the greenhouse gas emissions in Colombia (62%), followed by transport (11%) and the industry sector (11%). (IDEAM et al., 2017, p.17). In Colombia the forest sector consists of two sectors: silviculture (36%) and manufacture (10%). The first refers to the exploitation of forest and the second one refers to the transformation of wood including paper and wood furniture, for example (Olarte Villanueva et al., 2008, pp.229-230).

From 1990 to 2012, the manufacturing sector recorded a massive increase of 94% of its emissions. It passed from 14 to 28 m tonnes of CO_2. Antioquia, the department in which is located, is the most emitting department. (IDEAM et al., 2017).

4.2.1 Sectorial Reduction goals

CARTERA ASOCIADA	LÍNEA BASE EN 2030	REDUCCIÓN ESPERADA
MINISTERIO DE MINAS Y ENERGÍA	54.112	10.822
MINISTERIO DE COMERCIO, INDUSTRIA Y TURISMO	46.389	9.278
MINISTERIO DE AGRICULTURA Y DESARROLLO RURAL	67.287	13.457
MINISTERIO DE VIVIENDA, CIUDAD Y TERRITORIO	26.913	5.383
MINISTERIO DE TRANSPORTE	48.613	9.723
MINISTERIO DE AMBIENTE Y DESARROLLO SOSTENIBLE	2.264	453
BOLSA COMERCIAL INSTITUCIONAL	3.407	681
EMISIONES POR DEFORESTACIÓN	83.435	16.687

Table 1: CO_2 Reduction goal by sectors. Source: IDEAM et al.,2017, p.45

The graph shows the CO_2 reduction goals until 2030 of the different ministries in mega tonnes. The commerce, industry, and tourism sectors aim to reduce CO_2 emissions by 19%, equivalent to 9 278 m tonnes of CO_2. The housing and territory sector aims to reduce CO_2 emissions by 20%, or 5 383 m tonnes of CO_2. (IDEAM et al., 2017, p. 45).

4.2.2 Implementation strategy

To implement the NDCs, Colombia has adopted ten priority mitigation, adaption and implementation mechanisms until 2030. The ten concrete adaption measures are based on the National Adaption Plan on Climate Change (PNACC), which was formulated in 2011 (Gobierno de Colombia, 2015, p.5).The action plans concern the whole national economy, territory, and all the sectors that are responsible for greenhouse gas emissions, and seek to engage as many actors as possible at different governmental levels. Furthermore, eight Sectorial Mitigation Action Plans (PAS) have been formulated. These PAS have been elaborated within the Colombian Low Carbon Development Strategy (ECDBC) and have been approved by the different sectorial ministries (Gobierno de Colombia, 2015). The PAS of Industry and the PAS of Housing, which are relevant for the LC3 implementation, are discussed in detail in chapters 7.2.2 and 7.2.3, respectively.

4.3 Interim summary

- At the Paris Climate Agreement in 2015, each country defined its own nationally determined contribution which should be increased over time.
- Colombia aims to reduce its CO_2 emissions by 20% by 2030. This means a national CO2 reduction of 67 m tonnes, from 335 m tonnes to 268 m tonnes by 2030. Each sector, including the industry and housing sector, defined its own reduction goals by 2030. The industry sector has the goal to reduce the emissions by approximately 19% until 2030 and the housing sector by approximately 20% by 2030.
- Sectorial Mitigation Action Plans (PAS) aim at defining how the different sectors achieve the reduction goals.

IV Alternative Cement production LC3 and its impact in Colombia

As shown above, the cement production is highly CO_2 emitting. Colombia's goal to reduce its emissions by 20% by 2030 and the industry reduction goal could be reached partly through the implementation of LC3. The following chapters discuss the LC3 project and its advantages.

5. The LC3 project

The Limestone Calcined Clay Cement (LC3) project has been established by a partnership between the EPFL, the Universidad de las Villas in Cuba, and, since 2012, Indian scientists of the Indian Institutes of Technology (IIT) Delhi, Bombay and Madras as well as by contributors of the NGO Development Alternatives. The project has been financed by the Swiss Agency for Development and Cooperation (SDC Global Programme Climate Change and Environment, 2017).

From 2013 on, the international team investigated the combination of calcined clay, the only material really potentially available in viable quantities and abundant limestone. LC3 is a new type of cement based on a blend of limestone and calcined clay. It is environmental sustainable, as it allows producers to reduce the clinker content and can be processed with calcined clay and gypsum. The lower the amount of clinker, the lower are the CO_2 emissions. In other words, it is possible to produce with one bag of clinker two bags of LC3 cement (SDC Global Programme Climate Change and Environment, 2017).

The main components of LC3 are:

The major innovation in LC3 lies in combining the use of the abundantly available kaolinite clay with limestone, which does not lead to a reduction in mechanical performance (LC3 project).

5.1 Environmental considerations

It is estimated that LC3 allows a 30% CO_2 reduction. This reduction of CO_2 emissions is achieved in two ways:

1.) A reduction of fuel consumption is achieved as calcined clay can be processed at much lower temperatures (800°C instead of 1400°C).
2.) A reduction of CO_2 which is produced during the breakdown of limestone in cement manufacture ($CaCO_3 \rightarrow CaO + CO2$).

The LC3 process allows a reduction of clinker by 50% without compromising cement quality. The current clinker production facilities allow an increase in cement production twofold without increasing CO_2 emissions.
Normally, a cement plant has a clay deposit and is located close to a limestone quarry. Hence, transportation costs would not increase.
Additionally, the implementation of LC3 does only leads to marginally increased investments in calcining equipment. The LC3 production does not require significant modifications to the existing machinery, so the production can be integrated into an existing production plant.

Advantages of LC3

- 50% less clinker
- 30% less CO2
- similar strength than OPC
- availability of materials
- existing equipment can be used
- lower production costs
- better chloride resistance

Moreover, LC3 can be implemented with lower production costs. The reduced clinker content, decreased fuel consumption for calcination compared to clinker, and the fact that limestone does not need to be heated lead to lower production costs (LC3 project).
Pilot projects in India and Cuba, where buildings were constructed with LC3, proved the promising characteristics of LC3. In Cuba, LC3 was exposed to aggressive conditions to test the resistance of LC3. It resulted that LC3 has a better chloride resistance than OPC and has a very strong refinement of porosity (LC3, 2016).
In 2016, the Indian cement firm JK Lakshmi was the first cement company in the world that introduced a full-scale plant trial production to produce LC3. Trial applications of the cement have shown that it can reduce 30% of CO_2 emissions and 20% of energy

consumption. The illustrations below show the Swiss Embassy in India, which was constructed with LC3 by the Indian cement firm JK Lakshmi (LC3 project, 2017).

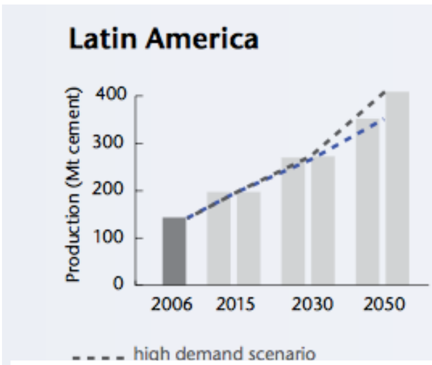
Figure 2: Indian Cement Firm constructs LC3 blocks for the Swiss Embassy in India. Source: Saxena

Figure 3: Swiss embassy in India made with LC3. Source: Kumar, 2017

The implementation of LC3 comes with a highly promising positive environmental impact. The alternative cement saves 400 m tonnes of CO_2 per year. This equates to 1% of global greenhouse gases, or similar to the annually emissions of France (SDC Global Programme Climate Change and Environment, 2017). The following chapters discuss the impact of LC3 in Colombia.

6. Potential of LC3 for Colombia

According to the WBCSD it is estimated that cement production will reach 400 m tonnes by 2050 in Latin America in a high demand scenario. In a low demand scenario cement production will reach approximately 325 m tonnes in Latin America by 2050 (WBCSD, IEA, 2010). This is an increase of 200% and 162.5%, respectively, compared to 2015.



Graph 7: High and low cement demand scenario for Latin America. Source: WBCSD, IEA.

There is no official cement production projection in Colombia, but various factors led to the conclusion that the production will considerably increase by 2050.

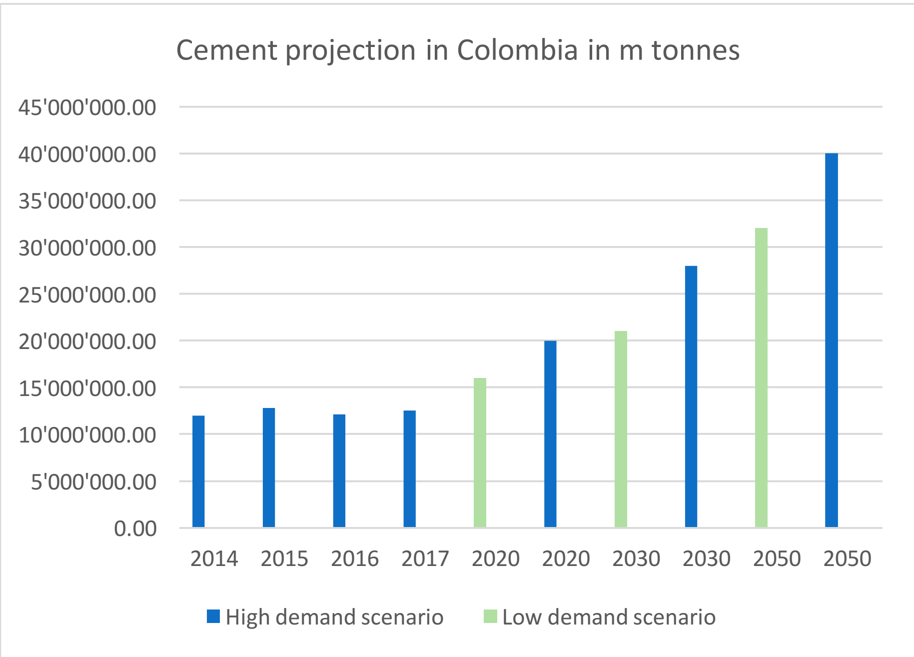
First, the current cement ratio per capita is low; it accounts for 250 kg per habitant per year (Universidad Nacional de Colombia, 2017). China, which has already reached the peak of cement demand has a cement ratio per habitant of 2 tonnes per year. Hence, in Colombia, the peak of cement demand seems far away from being reached.

Second, global players, such as Cemex and Holcim are present in Colombia. The cement market has expanded as new enterprises entered the market, such as EcoCementos in 2015, which was founded through the cooperation between Corona and Cemento Molins (Global Cement, 2017).

Third, cement production is tightly correlated with infrastructure. Unfinished and postponed infrastructure projects, such as in the metro of Bogota, the permanent housing deficit, and governmental subsidies for social housing drive demand for cement in the coming years. Additionally, the fourth generation (4G) project, which seeks to expand massively roads in Colombia in the next six years, also positively affects the cement production. It is estimated that 5 m tonnes of cement will be required for the project (Hernández, 2017).

Fourth, the cement market in Colombia is the third biggest in Latin America after Brazil and Mexico.

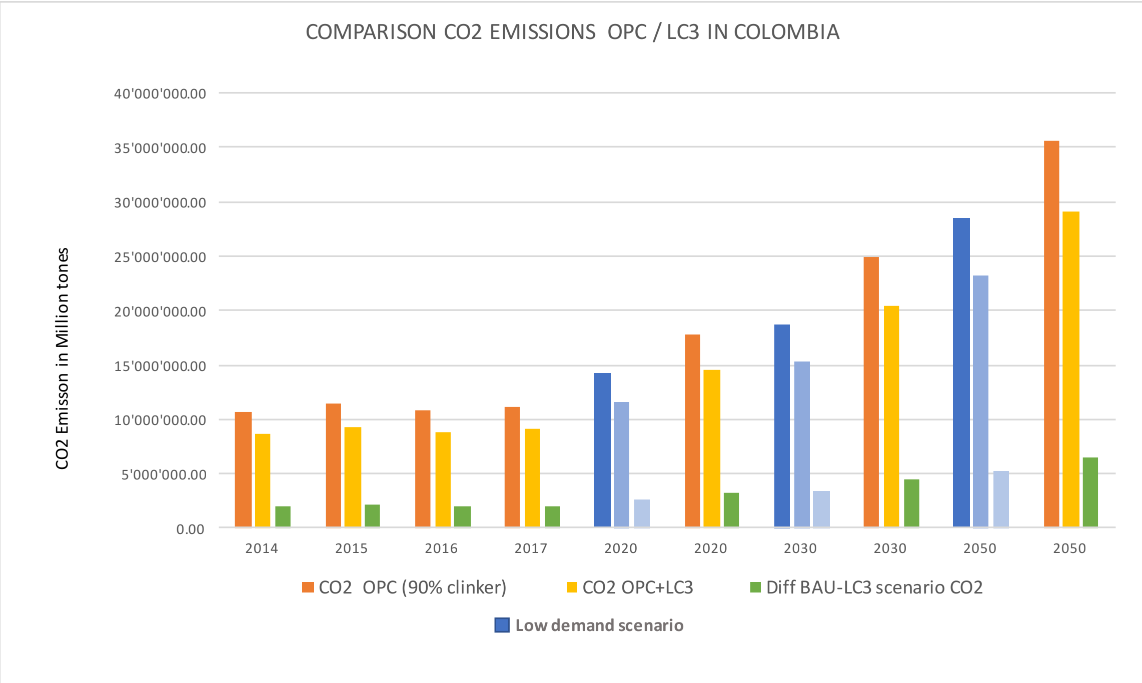
For these reasons and the official projection of cement production in the coming years in Latin America released by the WBCSD and the IEA, this thesis estimates that cement production will reach 40 m tonnes by 2050 under a high demand scenario, which is shown by the blue graph below. A low demand scenario estimates that the production will reach 32 m tonnes by 2050, which is shown by the green graph below. This stagnation in 2016 can be explained by the lack of environmental licenses and a lack of financing plans (Granados, 2017).



Graph 8: Cement Projection in Colombia in m tonnes. Source: Own estimation.

The graph below shows the future cement projection in Colombia with LC3 and OPC and the associated CO_2 emission scenarios.

The graph consists of a high demand cement scenario in orange and yellow, and a low cement demand scenario in dark and light blue for the years 2020, 2030 and 2050. The graph in orange (high cement demand) and dark blue (low cement demand) show the CO_2 emissions if the cement industry produces 100% Ordinary Portland Cement. The yellow graph (high cement demand) and blue (low cement demand) show the CO_2 emissions if the cement industry would produce 50% OPC and 50% LC3. The green (high cement demand) and the light blue (low cement demand) graph show the difference between the 100% OPC production and the 50% OPC and 50% LC3 production. In 2050, under a high cement demand scenario of 40 m tonnes, 6 524 600 m tonnes of CO_2 could be saved with 50% LC3 of total production. Under a low cement demand scenario, in 2050, 5 219 840 m tonnes of CO_2 could be saved with 50% LC3 of total production[2].



Graph 9: CO_2 emissions of LC3 and OPC in Colombia in m tonnes. Source: own illustration.

[2] All the calculations are based on 890.63 CO_2/t OPC and 564.39 CO_2/LC3
All cement production numbers are attached in the annex

6.1 National and Sectorial benefits

As already mentioned, Colombia's goal is to achieve a greenhouse gas reduction of 20% by 2030 and to reduce CO_2 emissions from 335 m tonnes (BAU scenario) to 268 m tonnes by 2030. The table below shows the potential contribution of LC3 to this goal.

Colombia in 2030	**m tonnes**
Total CO_2 emissions with BAU scenario	335
Total CO_2 emissions with NDC scenario	268
Total CO_2 reduction goal of Colombia	-67
100% LC3 cement production m tonnes	28
CO_2 savings with LC3 if 100 % LC3 production	9
50% LC3 Cement production m tonnes	14
CO_2 savings with LC3 if 50 % LC3 production	4.5
Contribution to NDCs (67 m tonnes)	**6.7%**
Industry Reduction goal contribution (9 278 m tonnes)	**48.5%!**

Table 2: NDC contribution through LC3. Source: Own Illustration

If Colombia produces 28 m tonnes of cement in 2030 and all production were with LC3, the reduction would be a bit more than 9 m tonnes of CO_2. However, it is rather unlikely, that all production would be produced with LC3. Therefore, the table shows a second scenario, where half of the total production, 14 m tonnes, were produced with LC3. This would result in a reduction of a bit more 4.5 m tonnes of CO_2 compared to Portland Cement.[3]

A reduction of 4.5 m tonnes CO_2 would mean a 6.7% contribution to the NDC reduction goal of 67 m tonnes and a considerable 48.5% contribution to the industry sectorial reduction goal of 9 278 m tonnes.

6.2 Local benefits: Examples in Medellin

The implementation of LC3 can not only benefit at national and sectorial levels, but also at a local level. The following construction examples aim to illustrate the local

[3] All the calculations are based on 890.63 CO_2/t OPC and 564.39 CO_2/LC3

benefits of the implementation of LC3 in Medellin. The constructions are shown with Portland Cement and with LC3 in order to compare the CO_2 emissions.

» The Bridge Madre Laure

Figure 4: Bridge Madre Laura in Medellin. Source: edu, 2008.

The Bridge Madre Laura in Medellin is a megaproject that connects the north-oriental and north-occidental zones of Medellin, and is at 786 meters the longest bridge in Colombia. It directly benefits two communities and indirectly four communities. It is also called a social bridge, as the people that were affected by the construction have the possibility to obtain new housing close to the bridge Madre Laura (edu).

Comparison of CO_2 emission to OPC and LC3		
	OPC	LC3
Concrete used	70 000 m^3	70 000 m^3
Cement used (0.4 t / m^3)	28 000 tonnes	28 000 tonnes
Average clinker factor	0.89	0.56
CO_2 emissions	24 920 t of CO_2	15 680 t of CO_2
CO_2 savings		**9 240 tonnes of CO_2**

Table 3: Comparison CO_2 emissions with LC3 and OPC for a bridge in Medellin. Source: Own illustration

The table above shows that with LC3 instead of OPC, 9 240 tonnes of CO_2 could have been saved.

» The Metro in Medellin

Figure 5: Metro in Medellin. Source: Metro de Medellin.

The metro system in Medellin was first introduced in 1995, with a first line between Niquia and Poblado. Since then, the metro system has been massively extended, with the goal to replace old, high carbon-emitting buses. For its construction, approximately 582 000 m^3 of concrete was used. The metro system today has 27 trains and 6 cable cars, which connect particularly the poor from the upper neighborhoods with the city center. (Metro de Medellin).

Comparison of CO_2 emission to OPC and LC3		
	OPC	LC3
Concrete used	582 000 m^3	582 000 m^3
Cement used (0.4 t / m^3)	232 800 tonnes	232 800 tonnes
Average clinker factor	0.89	0.56
CO_2 emissions	206 480 t CO_2	130 368 t CO_2
CO_2 savings		**76 112 tonnes of CO_2**

Table 4: Comparison of CO_2 emissions to LC3 and OPC for the Metro in Medellin. Source: Own illustration.

The table above shows that with LC3 instead of OPC 76 112 tonnes of CO_2 could have been saved.

» Bancolombia headquarters in Medellin

Figure 6: Bancolombia Headquarter in Medellin. Source: Argos.

The Bancolombia Headquarters Building in Medellin became the 4th Latin American building to receive LEED Gold status in the category Operation and Maintenance for Existing Buildings (Argos).

Comparison of CO_2 emission to OPC and LC3		
	OPC	LC3
Concrete used	55 240 m^3	55 240 m^3
Cement used (0.4 t / m^3)	22 096 tonnes	22 096 tonnes
Average clinker factor	0.89	0.56
CO_2 emissions	19 665 t CO_2	12 374 t CO_2
CO_2 savings		**7 291 tonnes of CO_2**

Table 5: Comparison of CO_2 emissions to LC3 and OPC for the Bancolombia headquarters. Source: Own Illustration

The table above shows that with LC3 instead of OPC, 7 291 tonnes of $CO_{2,}$ could have been saved.

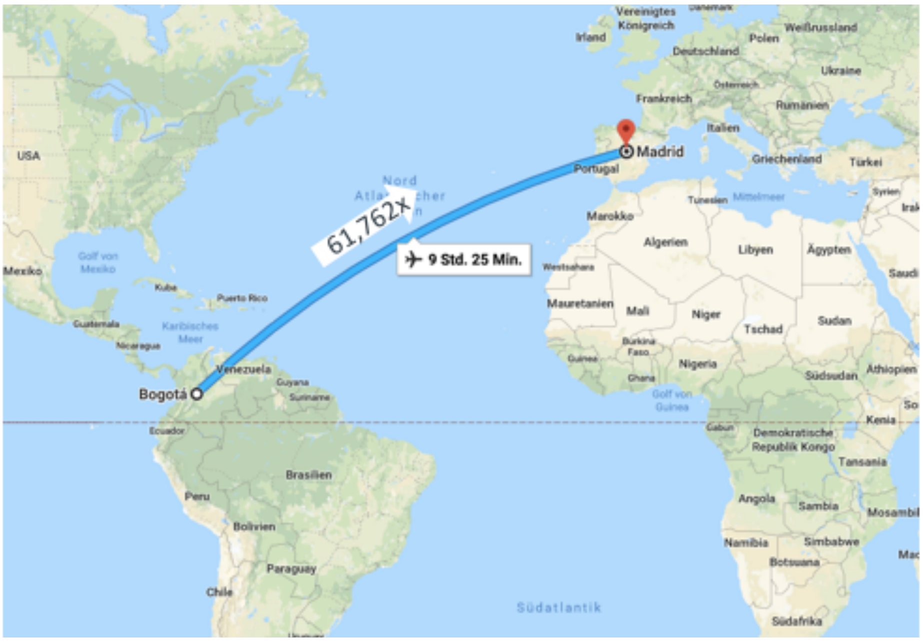


Figure 7: Achieved CO_2 savings through LC3 illustrated with flights from Bogota to Madrid. Source: Google Maps and own Illustration

This figure aims to illustrate the potential CO_2 savings through LC3 of the mentioned construction examples above. In total, with only three LC3 projects **92 643 tonnes of CO_2** could be saved which is equal to **61 762 one way flights** from Bogota to Madrid. One way from Bogota to Madrid equals 1.5 ton of CO_2 (MyClimate).

6.3 Entrepreneurial benefits

The enterprise Cementos Argos dominates the sector, with a 46% share of the cement market in Colombia. It has the capacity to produce 9.5 m tonnes of cement, which represents 45% of Argos total international cement production capacity. With the long-term aspiration to perform more sustainably, Argos aims to reduce its emissions by 35% by 2025. In 2016, Argos CO_2 emissions in Colombia accounted for almost four m tonnes. A 35% reduction of the CO_2 emissions in Colombia would mean a decrease of 1.4 m tonnes of CO_2**.** (Argos, 2016b). LC3 can contribute to this reduction goal.
A new cement plant can produce approximately 500 000 tonnes of calcined clay per year, which means a production of 1.7 m tonnes of LC3 per year. (30% of LC3 consists of calcined clay).

LC3 cement plant		
	OPC	LC3
1.7 m tonnes LC3	1.51 m tonnes of CO_2	0.96 m tonnes of CO_2
CO_2 savings		**0.55 m tonnes of CO_2**

Table 6: Comparison of CO_2 emissions to LC3 and OPC for Argos cement production. Source: Own Illustration.

The graph above shows that Argos could save 0.55 m tonnes of CO_2 with the implementation of one LC3 cement plant. Hence, with LC3, Argos could already reach with LC3 more than one third of its reduction goal of 1.4 m tonnes of CO_2.[4]
In financial terms, the saving of 0.55 m tonnes of CO_2 is also interesting. With a potential carbon tax of 5 USD per CO_2 ton released, would mean a saving of 2.75 million USD.

6.4 Interim summary

- Limestone Calcined Clay Cement (LC3) is a promising alternative cement production as the production reduces CO_2 emissions by 30% without hurting cement quality.
- It is estimated that cement production in Colombia will reach 28 m tonnes by 2050 under a high demand scenario. With a 50% LC3 and a 50% OPC cement production, approximately 4.5 m tonnes CO_2 can be saved. This is a 6.7% contribution to Colombia's NDCs of 20%. The contribution to the industry's reduction goal is even higher; if half of the cement were produced with LC3, the contribution would account for 48.5% of the industry's goal.
- The implementation of LC3 is not only interesting at national and sectorial levels but also at a local level. The infrastructure examples in Medellin aimed at showing that already with a few construction projects that are made with LC3 instead of OPC, the CO_2 savings are considerable. LC3 hold significant potential for future infrastructure projects.
- At the entrepreneurial level, LC3 is also highly interesting. As the members of the Cement Sustainability Initiative (CSI) permanently seek to find more environmental sound production methods and set their own CO_2 reduction goals, LC3 can contribute considerably to these goals. In financial terms, LC3 is also interesting. A potential carbon tax would result in considerable cost savings with the substitution of OPC by LC3. The annual savings of 0.55 m tonnes CO_2 through LC3 would result in cost savings of 2.75 million USD if the carbon tax were 5 USD per CO_2 ton.

[4] Given that 890.63 CO_2/t OPC and 564.39 CO_2/LC3

V Implementation of LC3 in Colombia

7. Policy Framework Colombia

After showing the potential of LC3, the next chapters contend with the implementation of LC3 in Colombia. For this purpose, the given environmental policy framework in Colombia is discussed and relevant policies for the LC3 implementation are analyzed.

7.1 General Environmental Policy Framework

Environmental policies are not new in Colombia. Already in 1974, Colombia created the Code of natural renewable resources and environmental protection which seeks to preserve and manage natural resources in a sustainable manner. Since then, various environmental policies have been defined by the National Economic and Social Policy Council (Conpes). It is not the purpose of this paper to discuss in detail all the environmental policies, but rather to give an abstract about the most relevant policies.

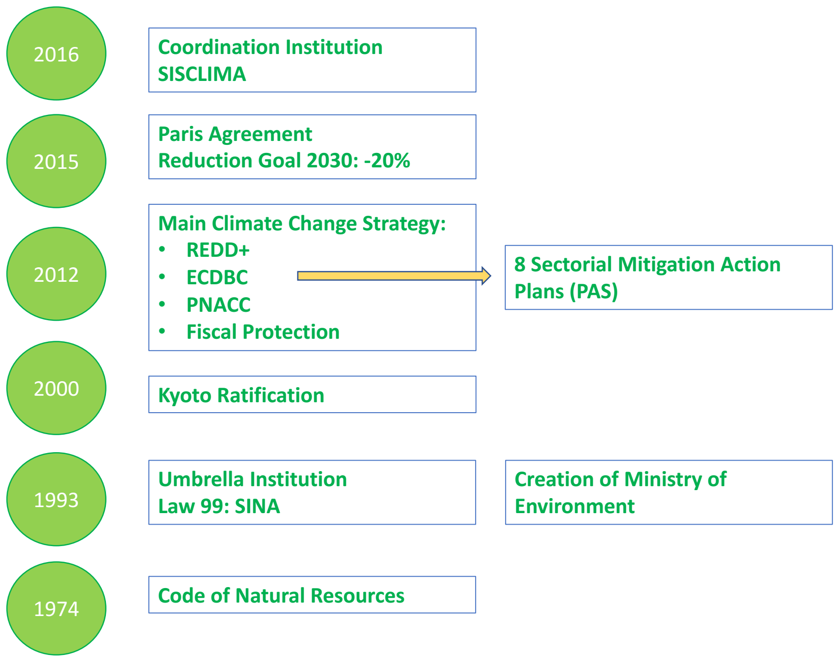


Figure 8: General Environmental Policy Framework Colombia. Source: Own Illustration.

» Law 99 / 1993

The General National System of the Environment SINA is the umbrella institution of all orientations, norms, activities, programs and institutions that are related to the environment. It was created with law 99 in 1993. The goal of SINA is to manage and preserve the environment and to focus on renewable natural resources.

Another important entity that was created with law 99 is the Ministry of Environment.

The Ministry defines the politics and regulations that aim to preserve, protect, and manage the use of the environment and renewable natural resources.

The autonomous regional corporations (CAR), departments, and the municipalities, and districts are subordinated to the Ministry of the Environment. CARs have the objective to administrate the environment in the whole national territory by executing politics, plans and national programs. Each region has a proper CAR. CORANTIOQUIA is responsible for the department of Antioquia (Conpes, DNP, 2011).

Since the implementation of SINA, Colombia has adopted various environmental initiatives and mitigation plans. When it comes to climate change, four major strategies in particular can be identified. After shortly discussing these major strategies, policies which concern the construction sector more specifically are discussed.

» Major Climate Change Strategies

The purpose of the SISCLIMA is to implement and coordinate the four major climate strategies, namely the National Climate Change Adaption Plan (PNACC), the Colombian Strategy of low-carbon development (ECDBC), the National Strategy of Reduction due to Deforestation in development countries (REDD+) and the Strategy for Fiscal protection against natural disasters represent the four major strategies on climate change in Colombia (Conpes, DNP, 2011, p.21).

» National Climate Change Adaption Plan (PNACC)

The PNACC was adopted in 2012 with the objective to increase knowledge of the potential risks and opportunities associated with climate change. The plan seeks to formulate priority programs and projects to reduce greenhouse gas emissions. The members of the PNACC are communities, private actors, governmental actors at all level and actors, who have an interest in Colombia.

The Coordinating Committee exchanges information and orientation documents about adaption measures with the aim to generate major knowledge about potential risk and opportunities (DNP, Gobierno de Colombia, 2017).

» Colombian Low Carbon Development Strategy (ECDBC)

In 2012, the low-carbon strategy was adopted, which is Colombia’s main mitigation strategy. It aims to reduce greenhouse gas emission by identifying actions, developing mitigation plans in each productive sector, and implementing monitoring and reporting mechanisms. The participating sectors are: Industry, Energy, Mine, Transport, Housing, Waste and Agriculture. Eight different Sectorial Mitigation Action Plans (PAS), which initiated in 2013, have been implemented. The different PAS contain

action programs and policies to mitigate greenhouse gases. They are governed by the different ministries, the Department of National Planning (DNP), and the ministry of environment and sustainable development (MinAmbiente, 2010). The PAS of housing and the PAS of Industry are discussed in chapters 7.2.2 and 7.2.3.
From 2016 on, the main focus of the ECDBC lies on the implementation of the NDCs made at the Paris Agreement and on the identification of the sectorial responsibilities to comply with the NDCs.

» Reducing Emissions from Deforestation and Forest Degradation (REDD+)

From 1990 until 2010 Colombia lost 6.2 million hectares of forest due to deforestation. The Reducing Emissions from Deforestation and Forest Degradation initiative, REDD+, identifies strategies to halt deforestation and to protect indigenous people, who have often been subject to displacement. The plan provides information about sustainable use of natural resources and protection as well as restoration of forest ecosystems (MinAmbiente).

» Strategy for Fiscal protection against natural disasters

Each year Colombia faces fiscal losses due to natural disasters. This Financial Protection Strategy has been created to reduce Colombia's financial vulnerability and to improve the capacity to respond to natural disasters.
The strategy focuses on the identification of financial risk of disasters, the financial management of disasters, and to assure the protection of governmental assets. (World Bank, p.8).

» National Climate Change System (SISCLIMA)

The National Economic and Social Policy Council formulated within the document 3700 in 2011, entailed the creation of an official national institution. In 2016, the National Climate Change System (SISCLIMA) was created by decree 298 with the goal to coordinate the four main strategies of climate change management in Colombia. It coordinates, articulates, formulates, and evaluates the politics, norms, strategies, plans, programs, projects, and actions that have been implemented so far (IDEAM et al., 2017, p.34).

7.2 Sustainable Construction Policies

This section focuses on policies that directly concern the construction sector and which are relevant for the implementation of LC3.

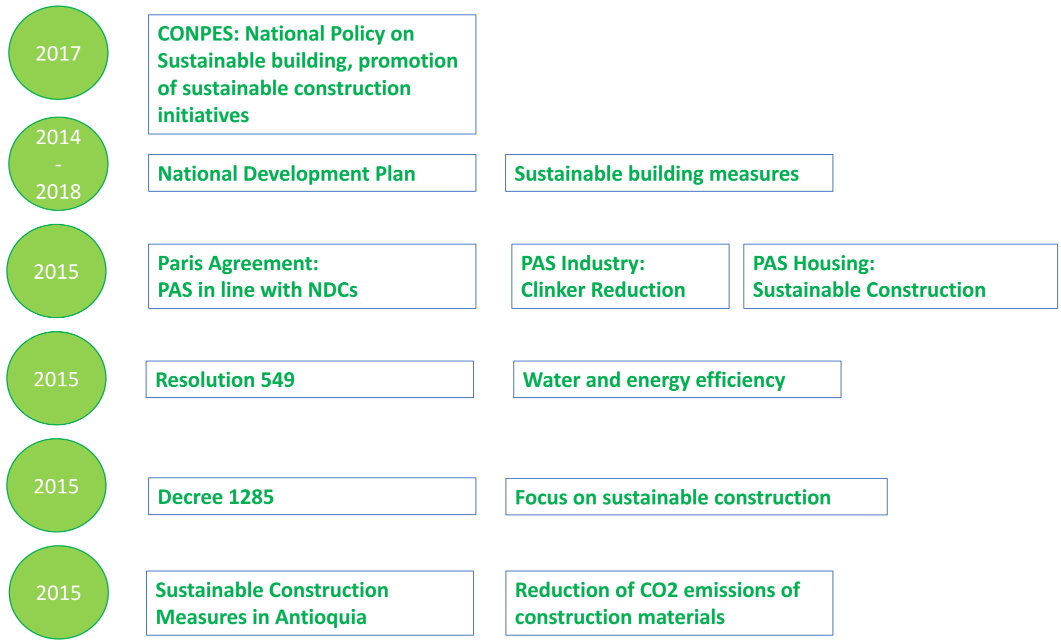


Figure 9: Sustainable Construction Norms. Source: Own Illustration.

7.2.1 National Development Plan 2014-2018

The National Development plans represent the basic strategy of the different presidencies in Colombia and have been in force for four years.

The actual National Development Plan contains in point X strategies for a green growth path, which focuses on a low carbon strategy. Within the listed goals are specific actions for buildings listed, such as information systems, construction guidance to save water and energy and sustainable building compliance measures. Negative externalities should be mitigated through the whole planning, design, construction and use of building. However, the focus lies mainly in energy and in water efficiency (DNP). These actions are incorporated in the Sectorial Action Plans (PAS) of the low carbon strategy (ECDBC). Within this strategy, propositions to foster sustainable construction are mentioned.

7.2.2 Industry Sectorial Action Plan

The Sectorial Action Plan (PAS) of the industry established different strategies with the goal to contribute to Colombia's NDCs by reducing the CO_2 emissions.

The first strategy seeks more efficient energy and water use, based on law 1715 of 2014. Through financial incentives, enterprises should adopt low energy mechanisms. The second line focuses on the optimization of logistics and transports. The third line, which is especially relevant for the cement sector relevant, seeks a clinker reduction

in the final product and the capture of CO_2. Furthermore, it promotes carbon substitution measures by biomass (MinCit, 2015).
An alternative production of cement, such as the LC3, is not yet known and not discussed in the PAS of the Industry, but is likely to implement the third measure, which seeks a clinker reduction. As shown in chapter 6.1, LC3 would contribute with 48.5% considerably to the sectorial reduction goal of 9 278 m tonnes.

7.2.3 Housing Sectorial Action Plan

As the PAS of the Industry, the housing sectorial action plan aims to contribute to Colombia's NDCs with the adoption of mitigation measures. The PAS of the housing sector shows that the implementation of LC3 would contribute to the mitigation measures. The following strategies have been listed in the PAS of housing:

- The PAS contains construction norms that aim to reduce energy.
- The plan aims to adopt financial incentives for the implementation of eco-technologies. Furthermore, the plan mentions in point 5.1 incentives of sustainable construction (MinVivienda, 2014).
- The PAS aims to develop instruments and studies to use carbon-efficient materials.
- The PAS promotes innovative technologies and fabrication processes of the construction material.

With these mitigation measures, as shown in chapter 4.2.1 the target is to reduce CO_2 emissions from 26 913 m tonnes of CO_2 to 21 530 m tonnes of CO_2. This is a CO_2 reduction of 5 383 m tonnes. (IDEAM et al., 2017, p.68). Implementing LC3 would be a big potential to reduce CO2 emissions in the housing sector. This potential is further discussed in chapter 9.1.2.

- Operational and Embodied energy

In addition to the Sectorial Action plans of the industry and the housing sector are different norms that foster sustainable construction and provide financial incentives. However, these norms focus particularly on operational energy inside buildings and do not focus on embodied energy Nonetheless, it is worthwhile to analyze the existing norms in order to embrace existing regulations that opt for an environmentally sound use of resources. Embedding LC3 in the sustainable construction debate and in the existing norms is highly important to further reduce CO_2 emissions.

Operational energy refers to the energy consumption in the use phase such as the energy needed for air-conditioning, lightning, hot water systems and refridgeration. The primary energy that is used for the construction materials, products, and processes, along with the related transportation, administration, and services is known as embodied energy (Dixit, 2017, p.390).

Until recently, embodied energy has been considered as insignificantly in contrast to the operational energy in the total life cycle energy use. However, this was also due to the difficulty to quantify embodied energy as it depends a lot on geographic location and climate. According to Dixit, embodied energy accounts approximately for 2-38% of total life cycle energy use and in low-energy buildings it accounts for 9-46% (2017, p.390). Given the current efforts of low energy buildings, the share of embodied energy is increasingly important.

7.2.4 Sustainable construction norms

» Resolution 549 of 2015

The focus of this regulation is energy and water efficiency. It sets an obligatory percentage of energy and water saving in buildings. (Conpes et al., 2017, p.13).

» Decree 1285 of 2015

Decree 1285 stipulates that construction must comply with an environmentally responsible use of natural resources and take into account the environment. This responsibility has to be considered through all the construction and design phases. Article 2.2.7.1.2 focuses on energy- and water-saving mechanisms and also mentions the promotion of local incentives for a sustainable construction. (MinCit, 2015)

» National policy on sustainable buildings

The Conpes adopted a draft version on sustainable buildings. The policy fosters sustainable construction initiatives with action plans and financing with a time horizon until 2030. The policy is linked to Colombia's NDC goals.

Furthermore, the plan gives effect to the National Action Plan 2014-2018 and the Colombian Strategy of low carbon development.

The draft version states that despite the existing norms, such as the Resolution 549 of 2015, the focus has been particularly on water and energy savings in new buildings which excludes social housing and governmental buildings. (Conpes et al., 2017, p.11). The Conpes also states a lack of economic incentives to implement sustainable strategies. The advice aims to develop a program of economic incentives for

sustainable construction projects, such as Hipoteca Verde, which is discussed further in chapter 8.2.5, and to implement a preferential tax rate if the building has a green certification (Conpes et al., 2017, p.49).
However, the focus of the Conpes draft version lies again more on operational energy in buildings and not on embodied energy.

» Sustainable Construction Measures in Antioquia

At the regional and local level, the given policies also promote sustainable construction and are therefore, favorable to the implementation of LC3.
At the regional level, the politics of sustainable Construction in the Aburrá Valley was released in 2015 with the aim to foster a sustainable planning, construction, operation and maintenance of the construction sector in this region. The Aburrá Valley is located in Antioquia, with an area of 1 152km^2 and 4 million inhabitants. The regional capital is Medellin, where the main commercial and financial services and activities can be found. Within the adopted goals, the plan mentions the need to reduce CO_2 emissions which are released the construction process. (Área Metropolitana del Valle de Aburrá, 2015, p. 151).

Figure 10: Aburra valley. Source: Wikimedia commons, 2014.

The territorial legislation plan of Medellin stipulates the implementation of alternative energy saving systems in the housing sector (Alcaldia de Medellin, 2014, p.11). Furthermore, the plan's aim is to turn Medellin into an environmentally sustainable city by 2030 (Alcaldia de Medellin, 2014, p.9).
Since then, several enterprises, including Argos, have adopted more clean production and sustainable consumption measures. Some 600 enterprises are investing considerably in clean technologies and in environmentally friendly processes. However, whereas the investment in more energy and water efficient processes is a large part of the plan, there are few initiatives involving sustainable construction materials are rather small in the Aburrá Valley. (Área Metropolitana del Valle de

Aburrá, 2017). Therefore, LC3 is a great potential to focus also on embodied energy, given the importance of the housing construction.

After showing that the policy framework at national, regional, and local levels clearly foster a sustainable development path and favor hence the implementation of LC3, financial incentives and other pull factors are analyzed. First, theoretical market-based environmental policies are discussed. Then, the market-based environmental policies in Colombia, which can incentivize cement firms are examined, and finally this thesis discusses demand creation for LC3.

7.3 Interim summary

- These chapters aimed at presenting an overview of the given environmental policy framework in Colombia. Colombia clearly seeks a green development path at national, regional and local levels.
- The Sectorial Mitigation Action Plan of the Industry within the Low Carbon Development Strategy mentions the cement sector explicitly and seeks a clinker reduction. Clear strategies are not presented, and policymakers do not yet know of LC3. Therefore, policymakers should be aware of LC3 and its potential to reach the aforementioned clinker reduction.
- The aforementioned policies involved different financial incentives for the implementation of more environmentally sound technologies and production methods. The Sectorial Mitigation Action Plan of the Housing sector, for example, mentions financial incentives of sustainable construction. These financial incentives should be fully embraced to boost the demand for LC3.
- The policies on national buildings in particular seek operational energy in the use of buildings. The focus should be extended to embodied energy, in order to raise awareness of the huge potential of already saving CO_2 emissions in the construction activities prior to building use.

8. Financial Incentives and other Pull Factors

8.1 Theory: Market based environmental policies

Market-based instruments are regulations based on market signals. They come with the advantage of cost-effectiveness and technology innovation, as well as diffusion incentives. Contrary to command and control regulations, market-based instruments do not equalize regulations among firms, but incentivize those firms that are able to adopt the cheapest pollution-control methods. (Stavins, 2000, p.33).

Market-based instruments can be divided into four major categories: charge systems, tradable permits, market barrier reductions and information programs.

8.1.1 Charge systems

Negative externalities leave society with an external cost, such as pollution, for example, without making the polluter pay for it. The British economist Pigou developed the concept of the Pigouvian tax, which calls for public intervention to correct the market failure of a negative externality. Ideally, a Pigouvian tax costs the producer of the pollution the amount equivalent to the harm it causes to society. Hence, governments can tax on the amount of pollution that a firm generates.

Another form of pollution charges, is the deposit-refund system, which demands consumers to pay a surcharge purchasing a potentially polluting product, such as a bottle, for example. When they return the bottle, they get the refund. Tax differentiation is another instrument to incentivize firms to adopt more sustainable products.

The primary justification for environmental taxes should be environmental benefits and hence, the revenue should be invested in environmental protection and not in reforming the tax system per se (Stavins, 2000, pp. 34-35).

8.1.2 Tradable permits

Within a trading system, an overall allowable level of pollution is set and permits among firms are allocated. Firms that emit less than the pollution level can sell their surplus permits to other firms that area above the allowable level (Stavins, 2000, p.34).

The EU Emission Trading System (ETS), launched in 2005, is the world's biggest carbon market involving 31 countries. The ETS sets an overall cap of admissive emissions, which should be reduced over time. At the end of the year, each firm must show enough certificates to compensate for their emissions. For every metric ton of CO_2 released, emitters have to submit one emission permit. If they are not able to do so, they must pay a fine of 100 € per ton. If a firm does not need all of the acquired certificates, it can use them for future operations or sell them to other firms. The certificate sales incentivize firms to improve their environmental performance (Zetterberg et al., 2014).

The target of the ETS is to reduce Europe's emissions of at least 40% of CO_2 by 2030. Germany and Poland are the highest emitting member states under the ETS. This is due to their reliance on coal in their power and heat sectors. Coal power still accounts for 39% of total EU ETS emissions. (Buckley, 2017).

However, the ETS is highly criticized for its adoption of free allowances which do not lead to a CO_2 reduction. The cement sector received between 2008 and 2014 a significant number of free allowances due to a potential risk of carbon leakage (MacDonald, 2016). Carbon leakage happens when companies move outside Europe where they don't have to pay for their pollution. However, the current low carbon price in Europe does not lead to carbon leakage. Therefore, the free allowances are not justified.

As a result, the adverse ETS has increased the emissions of the cement sector by more than 15 m tonnes of CO_2. Sandbag asserted that if cement companies had been outside the ETS, their emissions would have been lower (MacDonald, 2016).

8.1.3 Market barrier reductions

This instrument seeks to remove existing barriers to market activity through market creation, liability rules encouraging firms to consider the potential environmental harm of their operations and information programs providing consumers with certain information. (Stavins, 2000, p.51). Within information programs, available information may help to foster market-oriented solutions to environmental problems. Product-labeling inform the consumers about a product's energy efficiency, for example. Another information program is the requirement of reports by firms. Firms must release information about the use, storage, and release of hazardous chemicals, for example. Reports help to foster compliance as well as enforcement and increase public's awareness of firms' actions. (Stavins, 2000, p.54).

8.1.4 Government subsidy reduction

Governmental subsidies may help to address environmental problems through incentives. However, in practice, many subsidies turned out to be economically inefficient and environmentally unsound practices. (Stavins, 2000, p.33)

During the oil crisis, which started in 1973, many governments were concerned about energy supply and promoted domestic energy sources with government subsidies. These subsidies favored energy supply over energy efficiency and did not address climate change (Stavins, 2000, p.56).

» Resistance of market-based instruments

Although the promotion of market-based instruments has increased in the last years, there is still resistance. Whereas firms see a limit to their flexibility and a reduction of cost savings due to environmental standards, some environmentalists see the increased flexibility in environmental regulation as an overall reduction of environmental protection. (Stavins, 2000, p.57).

8.2 Market-based environmental policies in Colombia

The Colombian government introduced a variety of fiscal benefits to incentivize firms to adopt cleaner products and production methods, as already shown in chapter 7. The fiscal benefits involve exemption or deduction of the VAT and reductions of the interest rate. The reductions may account to up to 20% (Rodriguez Cely, 2015, p.51).
However, it should be noted that despite the fiscal benefits that are listed below, tax incentives mainly concern operational energy and not embodied energy.

Charge System

8.2.1 Tax incentives of sustainable construction

Law 210 of 2016 has the goal to establish guiding principles to formulate the National Politics of Sustainable Construction, and defines economic benefits, and financial incentives and other types of stimulation to foster sustainable construction in Colombia. Article 6 in this law contains tax incentives or financing support for the owners and developers of sustainable constructions if certain requirements are proven, such as the incorporation of alternate materials and efficient energy use, for example. (Congreso de la República de Colombia, 2016, pp.2-3)

8.2.2 Carbon tax

Law 1819 of 2016 created a carbon tax on fossil fuels. The law stipulates a tax of 5 USD for each released ton of CO_2. According to Zambrano from the CCCS, it might be possible that the carbon tax will be extended to other sectors, such as the cement sector (Personal communication, January 2018).

Decree 926 of 2017 allows enterprises to avoid the tax payment if they compensate their CO_2 emissions through the acquisition of carbon bonds, which are invested in sustainable projects and compensate the released emissions. (MinAmbiente, 2018). This is further discussed in chapter 8.2.4.

In the first year, the financial revenue of the carbon tax reached 167 million USD. Although the revenue was intended to be invested in environmental initiatives, the major part of the revenue went to peace process initiatives. The carbon tax was supposed to finance 85% of the bonds destined to the environmental sector in 2018. (Correa, 2018).

8.2.3 Mine Royalties

A very interesting incentive could result from an exemption of the mining royalties for calcined clay. In order to reach the raw materials which are necessary to produce OPC, the top layer, called waste material or overburden, of a quarry must be removed. This process is time-, cost-, and energy-consuming as hundreds of trucks must deposit this waste material in a landfill. Contrary to OPC, the properties of the so-called waste material is suitable to produce calcined clay and hence, suitable for the production of LC3. The waste material can be converted into useful material. This means not only a reduction of the cost and time that arise from the trucks needed to excavate the waste material, but also a potential exemption of mine royalties as waste material should not be taxed. This can be a tax exemption of up to 3 USD per ton.

However, mine prospecting is a highly sensitive topic in Colombia. Mining firms face strong resistance from environmentalists, farmers and locals. Therefore, avoiding mine royalties, which are intended to benefit local residents and are destined for social funds, is a controversial issue. Mine royalties are primarily intended to finance social services such as health, education, drinkable water and child mortality reduction. Yet, it should be noted that the revenue of the royalties has not lead to the expected prosperity in the main receiving departments such as La Guajira and Cordoba (MinMinas, pp.48,50).

Furthermore, unclear politics about mining and incoordination between mine authorities and environmentalists have lead in the past years to social disputes, legal insecurity, illicit extracting, and a high level of informality. Therefore, the National

Development Plan 2014-2018 aims to establish a clear and a unique National Mine Policy which manages naturals resources according to social and environmental standards (MinMinas, 2016, p.7).

Market creation

8.2.4 Carbon Compensations

A possibility to link the carbon tax to LC3 is the voluntary carbon market. Voluntary carbon compensation mechanisms have become increasingly popular in the last years. In Colombia, especially since the introduction of the carbon tax in 2016, several enterprises provide firms with the opportunity to avoid the carbon tax by compensating their emissions. These enterprises are part of the voluntary carbon market, which was launched in 2016 and was co-financed by the Global Environmental Facility (GEF). The market is a voluntary platform for different purchasers and sellers of carbon credits. It is not restricted to enterprises that are concerned by the carbon tax, all firms have the possibility to voluntary compensate their released emissions. The goal of the voluntary carbon market is to reduce 500 000 tonnes of CO_2 in the first two years. One carbon bond is equal to one released CO_2 ton (Gonzalez, 2015). Besides the financial support of environmental projects, the participating enterprises are required to adopt mitigation strategies in the medium- and long-term, which reduce the negative environmental impact of their economic performance (Ordóñez Jiménez). Until now, the financed projects concern areas of agroforestry, ecological restoration, and energy efficiency.

The flight company Avianca, for example, released 743 509 tonnes of CO_2 between January and August 2017 on flights within Colombia. They bought carbon bonds, which support two projects in Colombia and two in greater Latin America that involve renewable energy, reforestation, restoration and conversation of forest (HSB Noticias, 2017).

However, according to the enterprise CO2CERO, the carbon market is presently inactive, due to the required approval of the financial regulating authority (Personal communication, 2018). Independently from the inactiveness of the carbon market, CO2CERO fights against deforestation with the offer of carbon certificates to enterprises that support forest projects. Four trees capture one ton of CO_2 (Ordóñez Jiménez, p.24). The price for voluntary carbon certificates range between 3 USD and 12 USD (Ordóñez Jiménez, p.21).

According to CO2CERO, the enterprise seeks to amplify the projects related to renewable energy (Personal communication, 2018). The extension of the financed projects to infrastructure projects built with LC3 may be an interesting incentive, especially in a context of an increasing demand for social houses. This demand creation is further discussed in chapter 9.1.2.

8.2.5 Incentives from private sector

The finance of sustainable housing is gaining attention. The Colombian bank Bancolombia and its project *hipoteca verde* plays a pioneer role.

Since 2016, constructors of sustainable buildings and persons that acquire housing of sustainable projects financed by Bancolombia, can obtain benefits from the financing rate. Instead of paying 11.95% of the mortgage tax annually, the beneficiaries pay 11.30% annually. In other words, this is a saving of approximately 20 USD per month. (Bancolombia, 2016)

In order to obtain a preferential financing rate, a certification of the sustainable building by EDGE or LEED has to be shown. LC3 should be included in the criteria that must be fulfilled to get a preferential financing rate.

8.3 Interim summary

These chapters aimed at showing the financial incentives of implementing LC3.

- In theory, there are different environmental incentives.
  - The Pigouvian tax is a tax that governments adopt in order to tax the amount of pollution that a firm generates.
  - Tradable permits aim at setting a maximum level of CO_2 emissions permitted. Firms that cannot stay within this emission level have to pay a fine or can buy surplus permits of other firms that stayed below the maximum level.
  - Other incentives consist of tax differentiation, deposit-refund systems, liability rules and information programs providing consumers of information about the product and its environmental performance.
  - Governments can provide further incentives by no longer subsidizing industries that have a negative environmental impact.

- In Colombia, there are different financial incentives
  - The National Politics of Sustainable Construction promotes the incorporation of alternate materials by providing tax incentives.
  - In 2016, Colombia adopted a carbon tax of 5 USD per CO_2 ton on fossil fuels. By acquiring carbon bonds, firms have the possibility to compensate their emissions and thus, circumvent the carbon tax. It might be possible that the carbon tax will be extended to other sectors, such as the cement sector, in the coming years.
  - Mine royalties may be another interesting incentive. Calcined clay which is necessary for LC3 is defined as waste material. The waste material which cannot be used for OPC might be exempted from mine royalties.
  - The voluntary carbon market has the potential to represent another interesting incentive. Firms can buy carbon bonds to compensate their emissions and thereby support with the carbon bonds environmentally-sound projects. Until now, the supported projects in particular concern energy efficiency and forest projects. The offered projects might be extended to constructions that are built with LC3.
  - The Colombian bank Bancolombia offers its clients a preferential financing rate for sustainable buildings. A certificate has to be shown to profit from the benefits. LC3 should be included in the criteria that must be fulfilled to get a preferential financing rate.

9. Non-financial incentives

9.1 Demand creation

The promotion of sustainable production measures within cities is increasingly important. The 21st century has been named the urban century, not only because of the increased urbanization, but also because of strategic importance of cities in relation with sustainable development. While the world's cities only account for 3% of the Earth's land, they are responsible for 60-80% of energy consumption and 75% of carbon emissions (UN, 2017).

According to the third national communication of the IDEAM, Antioquia, the department of Medellin, is with a contribution of 22.94% the most emitting department (IDEAM et al., 2017, p.16). Nonetheless, it is also one of the leading departments when it comes to enterprise innovation and the pursuit of a green development path. Therefore, a strong marketing of LC3 is needed in order to raise awareness amongst governmental authorities about the environmental potential of LC3.

9.1.1 Smart City: Medellín

Cities play an important role in the achievement of the UN Sustainable Development Goals (SDGs). Smart Cities are cities that are networked in an intelligent way and are characterized by an increasing quality of life with a minimal use of resources. One of the so-called Smart Cities is Medellin, the capital of Antioquia.

Medellin has turned out to be Colombia's innovation capital. The city was named in 2012 the "most innovative city" for its modern transport system, environmental policies and cultural offerings. This award has fostered Medellin's ambition to boost innovation. By 2021, Medellin wants to be the capital of innovation in Latin America. The Medellin Innovation District initiative is an urban and economic transformation project transforming the North of Medellin into an innovation cluster of entrepreneurs, companies and institutions. The project aims to increase investment in innovation with the purpose of generating a sustainable economy. The Medellin Smart City Program comprises citizen participation, open government, and social innovation, the promotion of sustainable projects and the reduction of CO_2 (IEEE).

However, tackling individual and voluntary behavior changes is a big challenge. Only with existing incentives are people willing to participate in CO_2 reduction projects, such as the environmentally sound *encicla* project in Medellin, where the residents can freely use communal bicycles. When it comes to cement production, a strong cooperation between the Medellin government, the cement and the construction sector is needed. Once the government is informed about the benefits of LC3 and its support of the Medellin Smart City vision, it should provide incentives to the private sector. One way could be the exemption of mine royalties for the waste material that is used for LC3 as already discussed in chapter 8.2.3. Another way to incentivize cement firms could result from governmental support of social housing (VIS) projects that are constructed with LC3. The next chapter discusses the demand creation of LC3 through the housing sector.

9.1.2 Social Housing

In the last years, the construction sector has increased considerably. Annually, 280 000 houses are constructed which makes housing the major stimulation of the construction sector (Hernandez et al., 2017, p.9). In the last 16 years, the aggregated value of the housing sector increased annually by 6.8% and accounted for 3.1 of national GDP. (Conpes et al., 2017, p.10). This increase is also due to the construction of VIS, which benefits from governmental subsidies. VIS sales account for 36% of total housing sales. According to Argos, 400 000 social houses were constructed between 2014 and 2018. (Argos, 2016c, p.19). The housing sector will tend to increase in the near future, as Colombia still faces a 20% qualitative and quantitative housing deficit on average. (Pulido Patron, 2017). 600 000 houses have a quantitative deficit and 1.6 million houses are in precarious situation and need to be improved. (Hernández, 2017, p.11). A quantitative housing deficit means that there are more people in need of a housing than houses are available. If more than five persons live in one room, then the house is also considered to have a quantitative housing deficit. A qualitative deficit means that the constructed houses do not meet minimal housing requirements, such as adequate construction materials, accessibility of public services and minimal required space to live (VIVA, 2014, p. 55). A lot of Colombians live in poor neighborhoods that were constructed illegally. The houses were constructed by the residents themselves with no official authorization, little money and with little constructing experience (Swisscontact).

Medellin, with its vast neighborhoods, is especially plagued by this precarious housing situation. Antioquia faces a total housing deficit of 364 238, where 28 794 houses have a quantitative deficit and 335 444 have a qualitative deficit. The sub regions Bajo Cauca and Uraba face the highest rate of deficits. The Antioquia region is also characterized by much displacement, due to the violent past of the armed conflict. (Acevedo Agudelo, 2017, p.5.18).

» Social housing enterprise VIVA

The industrial enterprise *Vivienda de Antioquia* VIVA was constructed in 2001 by the government of Antioquia, with the goal to manage social houses for habitants in the lowest social class. The development plan of the department mentions a development strategy that includes the environment in the territory management and fosters a sustainable infrastructure.

Antioquia is characterized by significant social, cultural, racial, environmental and economic diversity. VIVA divided rural houses into isolated and integrated houses and the urban houses into collective and in scattered houses (Acevedo Agudelo, 2017, pp.5.21, 5.24). Within this division are six different types of rural housing, including indigenous houses and wood houses, and six different types of urban housing in order to respond to the cultural diversity and to the different climate regions of Antioquia (VIVA, 2015, pp.69-71). The majority of social houses are constructed with concrete (Acevedo Agudelo, 2017, p.6.82). The average area of social houses varies between 39m^2 and 44m^2. (Acevedo Agudelo, 2017, p.6.75).

Figure 11: Free urban housing in Concordia, Antioquia. Source: VIVA, 2014, pp.244-245

» CO_2 emissions of the housing sector

The required increase in the housing sector comes also with large CO_2 emissions. At the moment, the housing sector is responsible for 10.5% of the total emitted greenhouse gases in Colombia. The government promoted a green and sustainable Antioquia and one of the main principle of VIVA is to construct sustainable communities. However, there was no incorporation of eco technologies or eco materials in the construction of social houses (Acevedo Agudelo, 2017, p.6.78).

For these reasons, LC3 represents a huge potential to respond in a sustainable way to the qualitative and quantitative housing deficit and to contribute to the Smart City goals of Medellin. According to the DANE, housing accounted for more than 50.4% of the concrete consumption in 2017, followed by buildings (26.6%) (DANE, 2018b). As the increasing housing constructions make up a significant part of the cement industry's revenues, the focus on social housing projects could be an interesting demand creation for LC3.

According to a study, 118.22 kg of grey cement per square meter is needed for a social housing that is built with concrete (Salazar Jaramillo, 2012, p.65). Thus, it follows deduction that for a social housing of 40m^2, a total of approximately 4 729 kg grey cement is used.

Figure 12: Constructed Social Housing, Indigenous Community La Palma. Source: Acevedo Agudelo, 2017, p.5.49

Comparison CO_2 emission OPC / LC3 for VIS		
	OPC	LC3
Total Area of VIS	40m^2	40m^2
Cement used	4 729 kg	4 729 kg
CO_2 / kg	0.89	0.56
CO_2 emissions	4 208 kg CO_2	2 648 CO_2
CO_2 savings per 40m^2 house		**1 560 kg CO_2**
CO_2 savings for 400 000 VIS		**624 000 tonnes CO_2**

Table 7: Comparison of CO_2 Emission to OPC and LC3 for social housing. Source: Own Illustration.

The table above shows that with LC3 instead of OPC 1 560 kg CO_2 for one social housing could be saved. If all of the 400 000 social houses that were constructed between 2014 and 2018, were constructed with LC3, considerable 624 000 tonnes of CO_2 could have been saved.

It would be interesting to analyze the whole life cycle assessment of energy and CO_2 emissions for housing and comparing different housing material. However, this goes beyond this thesis. A study released by Zea Escamilla and Habert compared different materials for houses and analyzed the environmental impact. They concluded that bamboo is the material with the lowest environmental impact (2015). However, bamboo tends to be associated with poverty in Colombia and therefore, it is socially rather unaccepted. Additionally, the transportation of the material to the building site might increase the proportion of embodied energy.

» Link to the Voluntary Carbon market

As already mentioned in chapter 8.2.4, there are already various carbon compensation mechanisms in Colombia. Companies have the possibility to become carbon neutral by compensating their CO_2 emissions with the purchase of carbon bonds which are invested in sustainable projects. The enterprise CO2CERO, for example, provides firms with the opportunity to support projects fighting against deforestation. As already mentioned, the enterprise seeks to diversify the sustainable projects where the carbon bonds are invested in. It would be interesting to link social houses which are built with LC3 to the carbon compensation market. A firm could purchase carbon bonds in order to compensate the released CO_2 emissions, which are then invested in the construction of social houses made with LC3.

9.1.3 Eco-Labeling

As discussed in chapter 8.1.3 about environmental based policies, information programs, such as product labeling, raise the awareness of sustainability to consumers. In the case of housing in Colombia, different initiatives involving sustainability standards are used. The most common are LEED and CASA.

The Leadership of Energy and Environmental Design (LEED) is a voluntary certification system for the implementation of sustainable construction criteria and is globally the most used certification. CASA is a local initiative launched by the CCCS in 2016. CASA Colombia focuses on seven different categories including the efficient use of materials that promotes sustainable products (CCCS, 2016).

These certificates express a clear willingness to foster sustainable houses in Colombia. However, although the efficient use of materials is mentioned, the focus on the requirements to get a certification lies again more on energy efficiency and not on the construction process itself. It could be interesting to promote LC3 at the CCCS which is headquartered in Medellin. LC3 should be considered as a standard for sustainable infrastructure projects.

9.1.4 UN Sustainable Development Goals

In 2015, 17 Sustainable Development Goals have been adopted with the aim to end poverty, protect the planet, and ensure prosperity for all. Each of the 17 Goals contains specific targets that have to be achieved by 2030. Not only governments, but also the private sector and civil society are called on to take action to achieve these goals. Firms can foster their corporate responsibility and demonstrate their role as an important actor when it comes to overcome global challenges by contributing to the SDGs. The implementation of LC3 contributes to the Goals 9, 11, 12. These Goals are discussed in detail below.

» SDG 9:

"Build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation"

Sustainable Development Goal 9 fosters infrastructure, industrialization, and innovation. It has long been recognized that investment in infrastructure is positively related to growth productivity and income, and improvement in health and in education. Point 9.4 of SDG 9 has the objective to upgrade and retrofit infrastructure to make them sustainable by 2030. Resource-use efficiency and greater adoption of clean and environmentally sound technologies and industrial processes should be promoted (UN, SDG9).

» SDG 11:

"Make cities and human settlements inclusive, safe, resilient and sustainable"

As already mentioned by 2030 almost 60% of the world's population will live in urban areas, and 95% of urban expansion in the next decades will take place in developing countries. Currently 828 million people live in slums, today and the number keeps rising.

A major challenge concerning cities consists in creating prosperity and jobs while not straining land and resources. Many cities face congestion, lack of funds to provide basic services, housing shortage, and declining infrastructure. SDG 11 aims at improving resource use and at reducing pollution and poverty.

Within SDG 11, the objective is to ensure by 2030 access for all to adequate, safe and affordable housing (UN, SDG11).

» SDG 12:

"*Ensure sustainable consumption and production patterns"*

Sustainable consumption and production aims to reduce resource use, degradation and pollution while increasing welfare gains from economic activities.

Point 12.6 within SDG 12 encourages companies to adopt sustainable practices and point 12.A fosters the support of developing countries to strengthen their scientific and technological capacity to move towards more sustainable patterns of consumption and production. (UN, SDG12).

10. Financial support

In light of the increasing urbanization, investment in climate resilient and low-emission infrastructure is crucial in order to promote economic, social and environmental growth. It is estimated that from 2015 to 2030, the global requirement for new infrastructure assets is 90 trillion USD. (Mercer, IDB, 2017, p.i). Two thirds of these assets are needed in the global South. (Mercer, IDB, 2017, p.1). The following chapters discuss the importance of investment in sustainable cities, the role of cities, itself and potential financial sources in Colombia.

10.1 Investment in infrastructure

Infrastructure planning has long been disconnected from climate change agendas and investors still tend to ignore the potential of sustainable infrastructure. Investments are often not aligned with the Paris Agreement and the country's NDCs. (Mercer, IDB, 2017, pp. ii, 7)

Currently, due to inadequate infrastructure natural disasters generate 2 billion USD every year in Latin America, without considering the loss of human life (Bonilla, 2017). The current economic situation and the low real interest rates in most of the countries, indicate potential not only to foster growth, but also to implement the Paris Agreements (OECD, p.4). Therefore, it is of great importance to build a green infrastructure that is in line with the SDGs and the Paris Agreement. Cities play a major role in achieving this goal.

Although sustainable infrastructure demands high costs, in the short-term sustainable infrastructure can create demand for labor and supplies, and in the long-run sustainable infrastructure reduces risks and negative externalities, including pollution. The C40 cities, a network of the world's megacities, tackled this in 2017 by releasing an analysis on how to reduce emissions in cities to reach the goal of the Paris Agreement. (McKinsey Center for Business and Environment, 2017, p.5)

The cities mention amongst their ambitions to decarbonize the grid by expanding renewables, to optimize energy efficiency within buildings, to provide affordable and low-carbon mobility options, and to improve waste management (McKinsey Center for Business and Environment, 2017, pp.6-8).

What stands out in the C40 sustainable ambitions, is that they do not mention energy savings in the construction material. They do not involve embodied energy in their analysis to reach the goal of the Paris Agreement. Private financing is also characterized by this trend. Between 2010 and 2016 private financing accounted for 2 trillion USD and the major part went to the energy sector. Finance for renewables accounted for 50% (OECD, 2017, p.264). As already discussed, Medellin's sustainable construction focus does also lies in operational energy and not in embodied energy.

Therefore, it is highly important to expand the concept of sustainable infrastructure to embodied energy. LC3 must be included in sustainable infrastructure discussions and should be fully embraced by the mayors of the megacities. It must be shown that LC3 can considerably contribute to the goal of the Paris Agreement. Financial institutions could support cities to raise awareness about the potential of LC3 and to support the construction of houses and other infrastructure projects built with LC3.

10.2 Financial institutions

In Colombia, governmental institutions that work with environmental topics received only a small part of their funding from the national budget. Therefore, direct investments in climate change mitigation come mainly from international sources (Jaramillo, 2014, p.5).

Banks remain an important infrastructure financing player, accounting for roughly 80% of green infrastructure financing globally (OECD, 2017, p. 276). Development banks and development finance institutions especially are essential in supporting countries to reach their NDCs. They already play a considerable role in infrastructure financing in developing countries. Between 2010 and 2015, development and state-owned banks accounted for 21% of privately-financed infrastructure projects in developing countries.

Pension funds and life insurance companies have been increasingly active in infrastructure investments (OECD, 2017, p.268).

» The Inter-American Development Bank

The Inter-American Development Bank (IDB) has an important role in financing economic, social and institutional projects in the Latin American and Caribbean region (LAC). Since 1959, the IDB provides loans, grants, guarantees and innovative and sustainable solutions in the region (IDB, 2017a). The IDB has been the second-largest international lender to Colombia after the World Bank (Jaramillo Gil, 2014, p.16) The IDB has supported 926 projects as of May 2018. The current focus area of the IDB comprises, amongst others issues, climate change and environmental sustainability (IDB, 2017a).

Recently, NDC Invest has been created by the IDB to transform the national commitments of the LAC countries into achievable investment plans.

The goal is to provide clients with a comprehensive and simple package of support that will be adapted to different needs (Tennant, 2016).

» The Sustainable Infrastructure Program

IDB Invest and the Department for Business, Energy and Industrial Strategy of the UK (BEIS) created the Sustainable Infrastructure Program (SIP), which supports the IDB Group's efforts to promote sustainable infrastructure development in Latin American and Caribbean countries by accelerating private sector investment to implement the NDCs (IDB, 2017b). SIP will support the development of sustainable, low carbon, and climate resilient infrastructure through grants for technical cooperation and blended finance for loans, equity and guarantees. (Shumkov, 2017).

» The Global Environment Facility

The Global Environment Facility (GEF) is one of the major financing sources of environmental projects. The GEF is already active in Colombia and is also mentioned in the Sectorial Action Plan of the industry.

A request of support from the GEF can be initiated by the government, NGOs and the private sector or other entities of the society. (MinAmbiente). The GEF supported the creation of a technological and institutional platform basis for a verified emission reductions market mechanism. It also facilitated efforts of voluntary mitigation of greenhouse gas emissions in Colombia (GEF, 2016).

» Paris Agreement funds

The Paris Agreement stipulates that developed countries should take the lead in providing financial resources. The Parties agreed in negotiations that the promised annual amount of USD 100 billion in Copenhagen, cannot be the ceiling of finance commitment, but rather represents the floor of financial commitment. However, the Agreement contains only vague language when it comes to financial contributions. The Parties only decided to set up a new financial goal beyond USD 100 billion per year prior to 2025. (WBCSDb).

10.3 Interim summary

The following pull factors summarize the demand creation for LC3.

- Smart Cities aim at increasing the quality of life with a minimal use of resources. The government of Medellin should recognize LC3 as a huge potential for the Smart City to continue as Colombia's innovation capital. The government should financially incentivize construction firms to construct future infrastructure and building projects with LC3.
- Although the government subsidized social houses in the last years, Colombia still faces a considerable lack of social houses. The voluntary Carbon Market could be linked to social houses. The acquired carbon bonds by firms could be invested in future social houses that are constructed with LC3.
- Eco-Labeling for sustainable buildings has become increasingly popular in Colombia. LC3 should be included in these certificates and be considered as a standard for sustainable infrastructure projects.
- The UN SDGs 9, 11, and 12 foster sustainable infrastructure and production as well as low carbon cities. Cement firms could demonstrate their corporate responsibility by contributing to these SDGs with the use of LC3.
- As cities play a major role in contributing to the Paris Agreements, investment in a climate resilient and low-emission infrastructure is crucial. Currently investment in infrastructure is mainly concentrated on the energy sector. The concept of sustainable infrastructure should be perceived more holistically. The focus should be extended to embodied energy. Financial institutions such as the Inter-American Development Bank with its NDC Invest branch and the GEF, which are already active in Colombia should support Colombia's government and the cement industry with the LC3 implementation.

11. Barriers

This chapter aims at showing potential barriers to the implementation of LC3.

» The current focus of the environmental policies lies on operational energy in building use and not on embodied energy.

As shown above, Colombia has various policies and initiatives that favor sustainable construction measures. There exist not only at the national level, but also at the local level, different policies that aim at optimizing a green development path. However, as

already mentioned, the focus of all the environmental policies lies on operational energy and not on embodied energy. The discussion on clean energy and on energy efficiency concerns only buildings once they are constructed. Policies, such as the Resolution 549 of 2015 seek to boost energy efficiency by setting a maximal level of water and energy use. However, it should be noted that contrariwise to Europe, in Colombia energy has always consisted in a large part of green energy. Furthermore, the goal to reduce energy in houses by 50% does not represent an ambitious reduction goal, as energy consumption is already low. Whereas in Europe, cooling, lighting and refrigerators consume a lot of energy, the operational energy in social houses in Colombia is less significant. Therefore, the pure focus on energy efficiency of buildings in their use stages seems rather inappropriate. A shift to the material used for the construction of buildings is needed. This would also facilitate the acceptance of LC3 as a viable less-emitting cement production method.
According to Zambrano from the CCCS, a reason for the restricted focus on embodied energy is the lack of information about materials. Clear information about energy and water use are required to react to the inefficiency and to adopt policies that have a clear goal on how much to reduce. However, it is expected that the construction sector will be regulated more strictly in the near future, as information about materials will increase (Zambrano, personal communication, January 2018).

» There is a general lack of public information on environmental issues and a lack of clear lines on how to reach the NDCs.

Moreover, in personal conversations with Argos, the CCCS and civil society, it is evident that there is a general lack of public information on environmental issues (Personal communications, November 2017 – January 2018). Whereas there is a clear goal to reduce the greenhouse gases by 20% until 2030, there is no clear vision on how to reach this goal. The PAS of the industry only mentions vaguely on how to reach the reduction goal and states measures that could be contemplated, such as a clinker reduction, but the action plan does not set clear lines. There is neither a maximum level of CO_2 emissions admissible for the cement sector nor a carbon tax, for example.

» There seems to be a lack of coordination between the different ministries and between the government and the private sector.

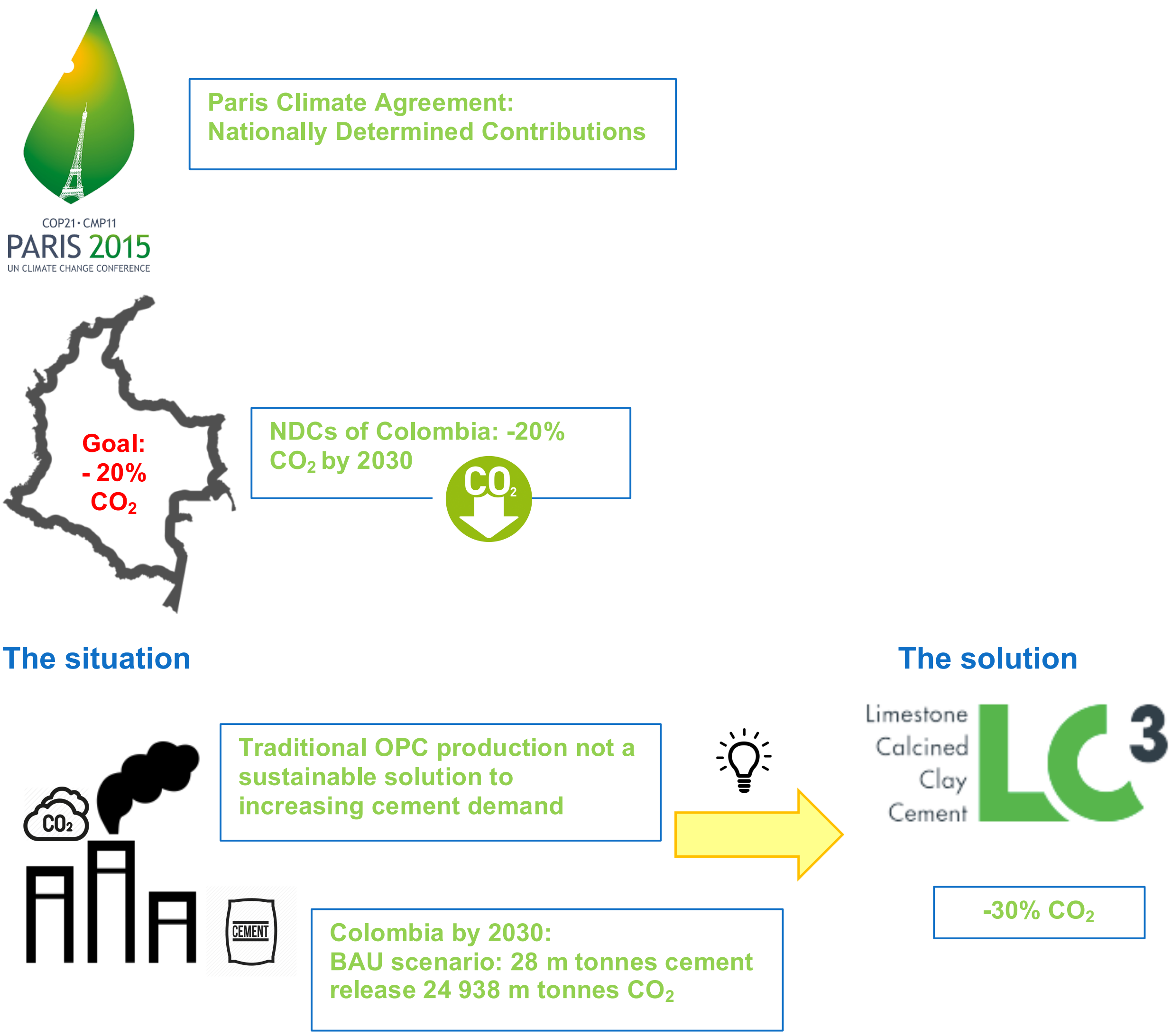
The PAS of the industry and housing should work more closely, as the cement sector and the housing sector are intrinsically linked. The increase in housing does also boosts the increase in cement production. As the ministry of housing seeks to foster sustainable building it should cooperate with the ministry of the industry and focus on the energy used for the construction materials.

According to Argos, the private sector is often left alone when it comes to climate change adaption. Argos, for example, bases its sustainable contributions more on initiatives at the international level, such as the CSI (Personal communication, November 2017) Furthermore, in a conversation with Zambrano from the CCCS, it resulted that the existing financial incentives are often not known by the private sector and therefore not embraced (Personal communication, January 2018).

VI Conclusion and Recommendations

The current OPC cement production is not a sustainable solution to increasing cement demand in emerging and developing countries. It is estimated that the business as usual scenario with OPC would release 2.34 Giga tonnes of CO_2 by 2050. In order to halt climate change and to reach the goals made at the Paris Climate Agreement, it is necessary that the cement sector considers LC3 as a viable alternative cement production.

The goals



What it takes

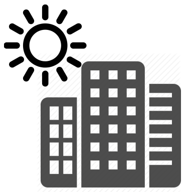
Given environmental policies promote sustainability measures but LC3 not yet known

Raise awareness about LC3,
Inclusion of LC3 in environmental debate

Embrace given financial incentives that promote sustainable production methods

Smart City Medellin

Eco Labeling



Link Voluntary Carbon Market with social housing

Embrace non-financial incentives

Financial institutions: Extend focus to embodied energy

Foster cooperation between ministries, NGOs, private sector

The outcome

By 2030 50% LC3 & 50% OPC production:
→ Reduction of 4.55 m tonnes CO2
→ 6.7% of 20% reduction goal could be achieved with alternative cement production

The purpose of this thesis was to answer three main questions: 1.) How the LC3 cement production contributes to the NDCs of Colombia, 2.) Which environmental policy framework in Colombia favors or restricts the wide-spread dissemination of LC3 and 3.) Which pull factors are necessary to convince the construction sector in Colombia to adopt LC3.

1.) Research question

LC3 contributes considerably to the reduction goal of 20%, which means a reduction of 68 m tonnes of CO_2 by 2030 in Colombia. At the national level, if half of the cement production were produced with LC3, this would account for 6.7% of the national reduction goal of 68 m tonnes. This thesis has shown that LC3 is not only interesting at national level, but also at the sectorial, local, and entrepreneurial levels is the impact of LC3 is substantial.

Recommendations:

» As the cement sector plays an important role in Colombia's economy and as cement consumption tends to increase in the future, it is highly important to implement LC3 in Colombia.

» As Colombia committed itself to the NDCs, the considerable contribution of LC3 to the NDCs should be promoted amongst governmental institutions.

» The ministry of the industry and the housing sector should be aware of the huge opportunity that LC3 represents to achieve part of the CO_2 reduction goals.

2.) Research question

This thesis has shown that the given environmental policy framework clearly seeks to foster a green development path. The PAS of the industry mentions the cement sector explicitly and the need to find clinker substitutions. The PAS of the housing sector promotes the use of sustainable materials. Not only national and sectorial policies but also local policies in Medellin promote sustainable construction measures. However, the focus lies on operational energy and not on embodied energy which might restrict the wide-spread dissemination of LC3.

Recommendations:

» A strong marketing of LC3 is needed to raise awareness about the opportunity of saving CO_2 emissions considerably. Policymakers should include LC3 in the environmental debate and focus on a holistic approach, including embodied energy.

The ministry of housing and the ministry of the industry should cooperate more closely regarding the achievement of the sectorial reduction goals as the construction and housing sector are interlinked.

» Further, a more cooperative approach is also needed between the private and public sector. Commonly, the different entities should elaborate a concrete action plan for the cement sector and set clear lines on how to reach the CO_2 reduction goals.

3.) Research question

The thesis has shown different financial and non-financial incentives. Colombia has already established various financial incentives that promote green technologies and sustainable production methods. When implementing LC3, these incentives should be embraced with the purpose to reduce entrepreneurial costs. Moreover, it might be possible that in the future the carbon tax will be extended to cement firms. Another interesting incentive are mine royalties, which might not be applicable to the overburden that is required in LC3 production. LC3 demand can be further created through the continuing lack of social houses. Future social houses that are built with LC3 can be linked to the voluntary carbon market. Firms can invest their acquired carbon bonds in the construction of social housing. Further, the government of the Smart City Medellin could demonstrate with the promotion of LC3 its willingness to pursue a green development path and contribute to the SDGs 9, 11 and 12. Additionally, investment in low-carbon infrastructure is becoming more popular.

Recommendations:

» Firms should be better informed about the existing financial incentives when it comes to clean technologies and environmental sound production methods.

» Cement firms should be aware that the existing carbon tax might be extended to other industries. By implementing LC3 they can reduce costs that might arise in the future due to a carbon tax and demonstrate their corporate responsibility.

» As urbanization increases in Colombia, private enterprises that offer carbon bonds should include infrastructure projects built with LC3 in their project offerings.

» The growing urbanization in Colombia should be realized as a big potential by financial institutions to extend the focus from operational energy to embodied energy. Sustainable solutions, such as LC3, are needed to guarantee a low-carbon and climate-resilient infrastructure.

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13. Declaration of Independence

“I hereby declare that I have written this thesis without any help from others and without the use of documents and aids other than those stated above, that I have mentioned all used sources and that I have cited them correctly according to established academic citation rules”

Zürich, 20 May 2018

Luzia Gysin

14. Annex

This table below shows the projected cement production in Colombia until 2050. 2020, 2030, and 2050 contain low- and high cement demand scenarios.

	2014	2015	2016	2017	2020: low demand	2020	2030:low demand	2030	2050:low demand	2050
Projection Cement production	11'970'000.00	12'800'000.00	12'100'000.00	12'500'000.00	16'000'000.00	20'000'000.00	21'000'000.00	28'000'000.00	32'000'000.00	40'000'000.00
CO2 OPC (90% clinker)	10'660'841.00	11'400'064.00	10'776'623.00	11'132'875.00	14'250'080.00	17'812'600.00	18'703'230.00	24'937'640.00	28'500'160.00	35'625'000.00
Cement production LC3: 50%	5'985'000.00	6'400'000.00	6'050'000.00	6'250'000.00	8'000'000.00	10'000'000.00	10'500'000.00	14'000'000.00	16'000'000.00	20'000'000.00
Cement production OPC: 50%	5'985'000.00	6'400'000.00	6'050'000.00	6'250'000.00	8'000'000.00	10'000'000.00	10'500'000.00	14'000'000.00	16'000'000.00	20'000'000.00
CO2 LC3 (50% clinker)	3'377'874.00	3'612'096.00	3'414'556.00	3'527'438.00	4'515'120.00	5'643'900.00	5'926'095.00	7'901'460.00	9'030'240.00	11'287'800.00
CO2 OPC (90% cllinker)	5'330'421.00	5'700'032.00	5'388'312.00	5'566'438.00	7'125'040.00	8'906'300.00	9'351'615.00	12'486'820.00	14'250'080.00	17'812'600.00
CO2 OPC+LC3	8'708'295.00	9'312'128.00	8'802'868.00	9'093'876.00	11'640'160.00	14'550'200.00	15'277'710.00	20'388'280.00	23'280'320.00	29'100'400.00
Diff BAU-LC3 scenario CO2	1'952'546	2'087'936	1'973'755	2'038'999	2'609'920	3'262'400	3'425'520	4'549'360	5'219'840	6'524'600
Cement	CO2/t OPC	MJ/T OPC								
P35	890.63	5292.38								
LC3-50	564.39	4367.53								