

APPLICATION OF THE SYSTEM DYNAMICS METHODOLOGY FOR MODELING AND SIMULATION OF THE GREENHOUSE GAS EMISSIONS (GGE) IN CARTAGENA DE INDIAS (COLOMBIA)

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Abstract

This communication shows the first results of the application of the System Dynamics methodology for the modeling and simulation of greenhouse gas emissions (GGE), especially carbon dioxide (CO₂) in the district of Cartagena de Indias (Colombia). In the developed model, the key variables responsible for emissions of greenhouse gases have been identified, as well as the representative variables of the identity KAYA (energy intensity, Gross Domestic Product-GDP, energy consumption and population) are considered. The tool used for simulation has been VENSIM, software widely used in System Dynamics.

Based on historical data, the results of the simulations in different scenarios, from a baseline scenario, show that CO₂ emissions present a trend of gradual increase over time, a very serious situation which would require special attention by both the environmental and urban planning authorities, establishing proactive environmental policies and strategies that will stabilize this growth. The Systems Dynamic modeling can become a very powerful and cheap tool that allows the improvement of their decision making.

Keywords: *System Dynamics, carbon dioxide, greenhouse gases, models, simulation, KAYA identity, Cartagena de Indias.*

1. Introduction

There is an eminent concern about the gradual warming that is presenting in the atmosphere and on the surface of the earth as a result of the emissions of greenhouse gases from anthropogenic activities, affecting the natural balance of the climate system.

In response to this need, our approach was to analyze the evolution of the behaviour of CO₂ emissions in the city of Cartagena applying the identity of Kaya and using the tool of the System Dynamics, to understand and explain the evolution of CO₂ emissions. At the same time, it was trying to find the main reasons for such developments, with the aim of awareness to the society of the need to implement and support national and regional policies, in order to reduce emissions of greenhouse gases.

2. The District of Cartagena de Indias

In 1985 the Cultural and Tourist District of Cartagena de Indias was declared humanity cultural heritage by UNESCO [1]. It has an extension of 609.1 km², of which 551.1 km² (91.14% of the territory), relate to the rural area and the remaining 54 km² (equivalent to

8.86%), comprise the urban area. By contrast, 8% of its population is in the rural area, whereas 92% remaining is located in the urban area.

2.1 Location and geographical conditions

The District of Cartagena de Indias is located in north of Colombia, on the Caribbean Sea within the coordinates 10° 26' North Latitude and 75° 33' West Longitude, as shown in Figures 1 and 2 respectively. With an annual average temperature of 28°C, a relative humidity of 90% and an annual average rainfall of 1100 mm, is the capital of the Department of Bolivar and it is located at a distance of 1204 Km from Bogota [1].

The territory District is composed of a series of islands, peninsulas, and inland water bodies, which make up the insular area and a continental area. These conditions and the presence of the bodies of water make of Cartagena a city with special morphological characteristics and a beautiful natural landscape but, at the same time, they constitute it in a system of great environmental fragility [1, 3].



Figure 1. Map of Colombia.

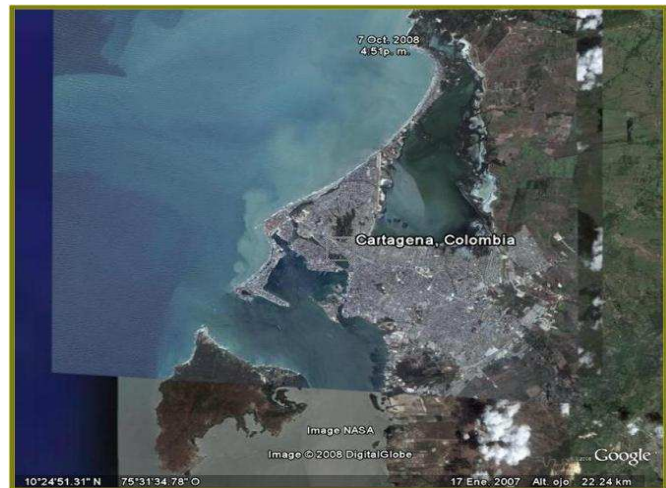


Figure 2. Map of Cartagena de Indias.

2.2 Population and economic dimension

In the year 2004, its population reached 1,004,074 inhabitants, 927,656 in the municipal head-board (92.4%) and 76,417 inhabitants (7.6%) in their municipalities. [1, 4].

In recent years, the economy of the city has experienced a wide tertiary process, reflected in increases in the participation of trade and services sectors in employment. The dynamism of the port and the growth of tourism activity propitiated the boom of the economic activities of support, which led to outsourcing. Despite the boom and the dynamism experienced in the city by the activities mentioned, the level of reached development is significantly lower than the indicators of socio-economic welfare indicators achieved by the other five major cities in Colombia [2, 3].

Within this economic activity, include the trade, the tourism (Trade, Hotels and Restaurant), the logistics for the international trade, the public administration (Government), and education. The construction sector also makes an important contribution to the economy of the city.

2.3 Environment, technology and industrial processes

The main environmental problem in the city is its water bodies, these have been modified substantially, and at the moment, some of them as the “Ciénaga de la Virgen” and the “Caños interiores” are environmentally fragile. Fillers affect water bodies constituting one of the major ills of these. The city's air does not present acute problems, although the long or medium term if it can become a problem. However, the lack of systematic measurements makes it difficult to analyze in depth the problem [3]. On the issue of greenhouse gases, to date very few studies about them have been done.

In Cartagena, administrative entities generally do not typically share information formally. It seems that every entity refers to specific sources sometimes self-generated and rarely exchanged. This generates competition and hinders coordination. Despite the existence of two environmental authorities in the city Cardique and EPA which is the county environmental agency, the information collected does not allow a comprehensive assessment of the environment in Cartagena. This should become a real concern that will hardly make preventive and corrective measures, leading too much uncertainty does not specify the impact of actions undertaken [6, 7].

The EPA (Environmental Public Establishment Cartagena) is a public agency law enforcement district, endowed with administrative and financial autonomy, its own assets and legal personality responsible to manage, within the area of its jurisdiction, the environment and natural resources and promote sustainable development in accordance with the laws and environmental policies and national, regional and local.

To know the real state of the environment in Cartagena, from October 2006 is preparing a report on the Urban Environment Outlook, GEO-called Cartagena project, promoted by an agreement between the United Nations Program on Environment (UNEP) and the District of Cartagena City Hall through the Public Establishment Environmental (EPA), and advance by the Observatorio del Caribe Colombiano. Its purpose is to identify actions and strategies to tackle environmental problems of the city and aims to be instrumental basis for decision making by managers of public policy and private sector [3]. The GEO report analyzes the social, economic, physical, biological, climatic and geographical of the city and an analysis of the factors of pressure, state, and impact on the environment and society's response, in public and private, to cope with environmental problems.

The industry of Cartagena is located in the Industrial sector called “Mamonal”, it has a strategic location to have a huge stretch in front of the bay of Cartagena. It stretches along some 14 kilometres and covers an approximate area of 3,100 hectares. Here are located some 100 companies engaged in food processing or manufacturing, plastics, chemicals, pesticides, fertilizers curtimbres, cement, petroleum, metallurgy, among others [1,6].

Industrial activities are responsible for much of the pollution in the coastal marine area of Cartagena. Since the 1990s, there have been spills, industry makes to the Cartagena Bay: nutrients, waste fuel and fertilizer, and most industrial effluent, such as sodium carbonate, ammonia, phenols, hot springs, among other, which produce a change in water quality and use of either accumulate in organisms or sediments [1]. However, we must highlight the effort Mamonal industry in reducing discharges, with the signing and implementation of Cleaner Production agreement signed in 1996 where important achievements have been reducing their waste discharges.

2.4 Electric energy consumption.

In Cartagena, the energy sector is very important, both from the point of view of the expectations of economic growth, as the supply of the demand that are required to maintain and consolidate this growth and improve the levels of well-being of the population [1]. The electrical system of the Bolivar department serves its domestic demand of approximately 270 megawatts (MW), through the national interconnection system and “Termocartagena” generation (180 MW). In the “Ternera” electric substation which is operated by “Transelca”, the Bolivar system connects to “Termocartagena” and “Sabanalarga” with a voltage level of 220 kV, shaping what is known as 220 kV ring. In the city of Cartagena, the residential sector has the highest use of electricity (especially in the middle and lower strata, where is concentrated most of the population of the city), followed by the official, commercial and industrial sector [6].

2.5 Vehicle pool

The fleet of Cartagena is composed of some 30,000 vehicles shaped for buses, minibuses, motorcycles, taxis and cars. Many of these used for functioning petrol, natural gas vehicle (NGV) and oil for diesel engines (ACPM) [3], representing a significant contribution to the emissions of greenhouse gases in the city.

3. The Greenhouse Gases (GHG)

The so-called greenhouse gases (GHGs) are those gaseous constituents of the atmosphere, both natural and anthropogenic, that absorbs and re-emits infrared radiation. The atmosphere is composed largely of nitrogen and oxygen, these gases account for 99% of its composition. Greenhouse gases are in the remaining 1% and are the cause of the increase in average temperature on earth [16, 17]. The main gases are carbon dioxide (CO₂), nitrous oxide (N₂O), methane (CH₄), tropospheric ozone (O₃) and aerosols (CFC's), the ability to contribute to greenhouse gases each depends its persistence in the atmosphere and the efficiency with which retain the infrared radiation emitted by the earth [16,17].

The greenhouse effect causes an increase in average temperature of the earth, due to an imbalance between the flow of incoming and outgoing energy in the climate system. This imbalance, in which the incoming energy from the sun into the atmosphere is greater than that coming out of it, resulting in the accumulation of heat, with a delay, reflected in an increase in surface temperature of the earth, [18, 19].

We have seen that global CO₂ emissions, far from stabilizing, have experienced significant growth in recent years. Clearly, one factor behind the increase in global CO₂ emissions is the growth of economic activity. However, this growth may be due to greater prosperity of the inhabitants, or simply to an increase in the population [25]. Numerous factors influence the level of CO₂ emissions, such as economic development, population growth, technological change, resource endowments, institutional structures, patterns of transportation, lifestyles and international trade [24, 25].

The identification of the magnitude and sources of greenhouse gas emissions of a country is a fundamental tool for planning their economic and environmental [21]. In contrast, when a particular country or region has a strong economic growth, this is based on intensive use of energy, and this, mostly from the burning of fossil fuels. This phenomenology is due mainly to the energy model prevailing in our days, which is based on intensive consumption of nonrenewable energy, whose characteristics are its availability in time and space, and relatively easy distribution [24, 25, 27].

Year	Trade	Industry	Rural	Urban	Transport	Electricity	Transformation	Total (Million of tonnes of CO ₂)
1996	0,33	22,41	2,15	1,85	21,42	5,41	12,81	66,37
1997	0,39	22,84	2,16	1,98	22,18	6,52	12,86	68,93
1998	0,43	23,41	2,17	2,13	23,07	8,14	13,05	72,40
1999	0,46	23,84	2,18	2,32	24,05	8,09	13,18	74,13
2000	0,49	24,22	2,20	2,57	25,13	9,64	13,43	77,70
2001	0,52	24,65	2,23	2,84	26,21	10,03	13,77	82,26
2002	0,54	25,09	2,26	3,12	27,34	11,34	14,14	83,84
2003	0,57	25,56	2,29	3,40	28,54	12,86	14,51	87,72
2004	0,59	25,96	2,31	3,65	29,8	14,32	14,87	91,50
2005	0,62	26,39	2,34	3,90	31,11	18,70	15,26	98,30
2006	0,64	26,83	2,37	4,14	32,44	20,26	15,64	102,34
2007	0,67	27,30	2,39	4,39	33,84	24,51	16,04	109,13
2008	0,70	27,79	2,41	4,65	35,29	24,97	16,46	112,27
2009	0,73	28,30	2,43	4,92	36,81	30,42	16,90	120,50
2010	0,76	28,33	2,46	5,19	36,39	33,43	17,36	126,41

Figure 3. CO₂ emissions by economic sector in Colombia

There is a growing trend in emissions is expected that by 2010 these exceeded 120 million tons, so by the end of the next decade will have the greatest growth in emissions is expected for the power sector [28, 29]. In 1996 this sector was responsible for 8% of total CO₂ emissions, by 2002 that percentage increased to 14% and for 2008 was 22%. To describe the emissions of greenhouse gases into the atmosphere especially CO₂, have proposed the model of the Kaya identity, which will be described below.

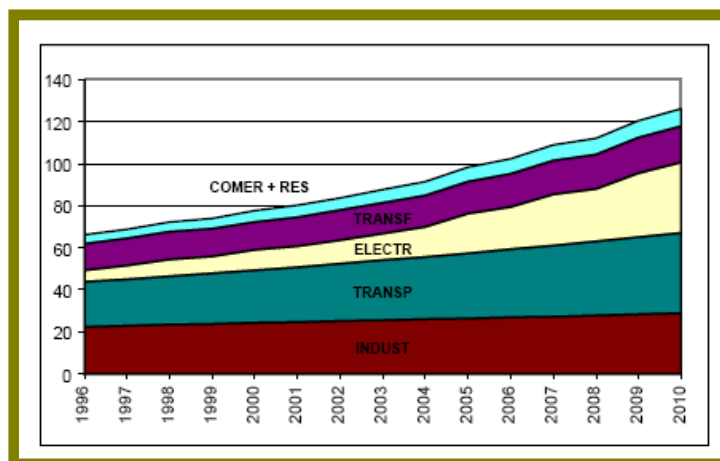


Figure 4. CO₂ emissions by economic sector (Million tonnes)

4. Identity of KAYA

It is a commonly used analytical tool to explore what the main driving forces of this behaviour pollutant carbon dioxide (CO₂) [24, 25, 30]. According to this identity, a country's emissions are decomposed into the product of four basic factors (influenced by other factors): index of carbonization or carbon intensity of energy (defined as the CO₂ emitted per unit of energy consumed, CO_{2i} / Ei), energy intensity (defined as the energy consumed per unit of GDP, Ei / GDPi), economic rent (defined as GDP per capita, GDPi / Pi) and Pi population [24, 25, 27, 30]. The calculation of CO₂ emissions in Cartagena, in this work is represented by Equation 1:

$$CO_2 \text{ (ton)} = \text{Production Vector (CO}_2\text{/Kwh)} \times \text{Energy Intensity (Kwh/USD\$)} \times \text{GDP (USD\$)} \quad (1)$$

The first component reflects the mix of fuels or energy sources of a country, the second is associated with energy efficiency in the provision of different goods and services but also to other factors, having special relevance the transport model and the sectoral structure of the economy, while the third is a measure of economic rent. In turn, the product of the first two factors shows the emission intensity of GDP [24, 25].

This is a generic model to use and adaptable to a given period and geographical environment. It also allows to introduce different scenarios of GDP, efficiency improvements in energy intensity as in CO₂ emissions per kWh from different energy sources [30].

In contrast to mitigate CO₂ emissions, the global cycle of C is recognized as one of the major biogeochemical cycles due to its role in regulating the atmospheric concentration of CO₂ [31, 32]. The increasing concentrations of CO₂ in the atmosphere are an important contribution to climate change. Forests play a key role in the global C cycle because they store large amounts of C in vegetation and soil, exchange C with the atmosphere through photosynthesis and respiration, are sources of atmospheric C when disturbed by human causes or natural (forest fires, use ill-use systems, cut and burned for conversion into non-forest uses) and become atmospheric C sinks (so, net transfer of CO₂ from the atmosphere to land) during the abandonment of land and its regeneration after the disturbance. Human beings have the potential, through forest management, to alter the C stocks and fluxes of forest thereby altering its role in the C cycle and potential for climate change [31, 32].

The absorption of CO₂ is produced by the natural process of photosynthesis. In this process, plants absorb, in addition to CO₂, other chemicals to produce nutrients for their survival, while regulating the concentration of carbon dioxide in the atmosphere. This places the vegetation in an important place in the carbon cycle [16, 32].

5. Methodology

The methodology used in this paper to simulate and model emissions of greenhouse gases (GHGs) in particular CO₂, in the city of Cartagena, began with activities such as collection of primary information about population projections, gross domestic product GDP, consumption energy, fuel consumption by motor vehicles., etc.) analyze the relationship between different variables problems affecting GHG emissions, implementation of the causal diagram, operating assumptions and model scenarios, the simulation model using Vensim ® software. Finally, the interpretation of the results of the simulation.

System Dynamics is a methodology for modelling, simulation and analysis of complex systems, originally made by Jay Forrester, to understand how systems change over time [8, 9]. A system is defined as the collection of elements that interact continuously in time, to form

a whole [9]. The basic objective of the System Dynamics is to understand the structural causes of system behaviour. [10]

This methodology uses concepts from the field of feedback control to organize information in a computer simulation model, which represent real-world variables. The resulting simulation shows implications of the system behaviour represented by the model. Thus the system dynamics model building permits after a careful analysis of the elements of the system. [9, 11, 12].

The simulation can be understood as the process of providing data to a model that represents some system under study, activate the procedures for processing such data model and then obtained the responses generated, analyzing the behaviour likely to have the system when carrying out the actions that correspond to the data provided initially [9].

Data from variables to model and simulate the emissions of greenhouse gases in the city of Cartagena, are from official and private entities located in the city. The group of institutions that provided such information to make: Mayor of Cartagena, Cartagena Chamber of Commerce, National Bureau of Statistics (DANE), Public Establishment Environmental (EPA) and Electrocosta SA.

The main variables that explain the evolution of CO₂ emissions in Cartagena are: GDP, population, energy consumption, vehicle fleet and the relationship between energy consumption and GDP (energy intensity). These variables are introduced into the model to simulate its dynamics.

5.1 Population

In the case of Cartagena, the increase of the population is a worrying factor, because it generates an increase in demand, which increases the pressure on the resources of housing, energy, water, food and environment. This demand does not find an offer sufficiently abundant to allow the sustainability of urban ecosystem. Figure 5 shows the historical behaviour of the projected population of the District, based on estimates of NADS (National Administrative Department of Statistics).

Years	Population
1995	713.570
1998	782.205
2000	829.476
2001	853.566
2002	877.980
2003	902.688
2004	927.657
2005	952.855
2006	978.309
2007	1.004.015
2008	1.029.994
2009	1.056.231
2010	1.082.712
2011	1.112.712

Figure 5. Projected population of Cartagena.

Source: DANE–Secretaria de Planeación Distrital

5.2 Gross domestic product (GDP)

The GDP represents the final result of the productive activity of resident units of production. It is measured from the standpoint of the added value, of the final demand or of the end uses of goods and services, and primary incomes distributed by resident units of production [4]. CO2 emissions are highly correlated with variables such as GDP or population. Regarding the evolution of Gross Domestic Product, Cartagena had a share in the National GDP of 3.91% in the year 2003. Similarly presented increases and, in some cases, decrease in the same, as shown in the Figure 6.

YEAR	CARTAGENA GDP CONSTANT OF 2003 MILLION PESOS	CARTAGENA GDP CONSTANT OF 2003 MILLION DOLLARS
1998	2623	1,146
1999	2499	1,091
2000	2675	1,168
2001	2744	1,198
2002	2969	1,297
2003	3122	1,364
2004	3271	1,429
2005	3434	1,500
2006	3588	1,567

Figure 6. GDP growth in Cartagena.

Source: DANE - Cuentas Regionales, Cálculos Unidad de Investigaciones
"Cartagena de Indias Puertas de las Américas".

5.3 Power Consumption

Given that the CO2 emissions are closely related to energy consumption for each region in particular. Below are shown in the Figure 7, the records of energy consumption in Cartagena.

The energetic intensity is calculated as the ratio of the gross domestic consumption of energy and the GDP and measures the energy consumed to produce the same amount of GDP. The differences in energetic intensity can be explained mainly by two situations: for the differences in the efficiency in the use of energy (using different amounts of energy to get the same production), or because economic activity is nodding on sectors more or less intensive in the use of energy [35].

For this case in particular the energetic intensity for the city of Cartagena, was calculated between the ratios of the historical averages of energy consumption (kWh) and GDP (USD\$),

obtaining a value of $85,71 \frac{Kwh}{USD\$}$.

Year	Power Consumption Kwh
2000	92.837.612
2001	95.747.933
2002	100.393.811
2003	105.945.752
2004	111.497.967
2005	117.049.634
2006	122.796.697
2007	127.975.523
2008*	131.812.791

Figure 7. Energy consumption of Cartagena.

Source: Electrocosta S.A., E.S.P.

* Consumption until November of 2008

5.4 Fleet structure

Since the last two decades, the vehicle fleet or mobile Cartagena has increased as shown in the Figure 8. This has contributed to increase of the air pollution as a result of the gases that are emitted through exhaust pipes. However, most of the cars do not emit the same quantities of gaseous pollutants, because their degrees of contamination are several reasons, some of them are: the kind of engine they use, the type and quality of fuel used and geographical characteristics of location [20].

Año	Total
1990	3.172
1991	4.367
1992	5.757
1993	8.330
1994	12.074
1995	15.501
1996	18.198
1997	20.774
1998	23.034
1999	24.152
2000	25.057
2001	25.830
2002	26.548
2003	27.354
2004	29.326
2005	25.817
2006	29.763

Figure 8. Cartagena fleet. Source: Departamento Administrativo de Transito y Transporte - DATT

6. Causal diagram of CO₂ emissions

To represent the causative agents of CO₂ emissions in a hierarchical manner, it is necessary to understand each element independently, its incidence and causes that determine its behaviour. Once identified the main causes of CO₂ emissions in Cartagena, examines the natural relations of causation between each of the variables, obtaining the causal model diagrammed. The variables that are part of this causal diagram, is listed here: population, energy consumption, CO₂ emissions, natural absorption of CO₂, forest mass, food consumption.

6.1 Hypothesis of functioning of the Model

Through this work is to study the CO₂ emissions in the city of Cartagena, gas is the main cause of the average increase of the Earth's temperature and consequently of the climate change.

The model describes the general dynamics of CO₂ emissions in Cartagena, considering a simulation period of 20 years, from 2000 to 2020.

The hypotheses with which the model is made are:

- The human population depends on birth and death.
- The human population with its activity generates wealth to reach its level of welfare, which will be measured by GDP.
- To perform these activities will consume energy.
- The amount of energy consumption depends on the technology that is being used. This factor is measured through an indicator called: Energetic intensity. (Energy consumption / GDP).
- The technology is represented through an energetic vector. The energetic vector is the set of primary energy that are used to cover the demand of energy. In this model we have been considered two: natural gas and fuel oil.
- Emissions by energy consumption depend on the proportion of fossil fuels that are used to cover the demand of energy and the emission factor of these.
- The consumption of fossil fuels used by the fleet of the city generates large quantities of CO₂ emissions.
- Vegetable coverage (hectares) in the city absorbs CO₂ in the atmosphere.

6.2 Definition of variables

From these hypotheses have been selected the level of variables of the model, as well as the variables of flow of each one of the level of variables, parameters., etc. Later, there are detailed each of them.

Level of Variables: CO₂ emissions and population.

Auxiliary: emissions, births, deaths, gross domestic product (GDP), energy consumption, gas natural emission, fuel oil emission, fuel oil emission, ACPM emission, petrol emission and GNV emission.

Parameters: natural absorption of CO₂, birth rate, death rate, GDP per capita, energetic intensity, natural gas emission factor, fuel oil emission factor, ACPM consumption, petrol consumption, NGV consumption, petrol emission factor, ACPM emission factor and NGV emission factor.

6.3 Simulation Model

The programming model is made in the software Vensim ®, the integration method used is Runge Kutta and the passage of time is of a year. The period simulation ranges from 2000 to 2020. In Figure 9, shows the model built in dynamics of system.

7. Results and discussion

In this section are presented the results of the functional relations of the variables problems (population-GDP, energy consumption-GDP, births / population), the analysis of the causal diagram and the behaviour of CO₂ emissions in Cartagena obtained through the modelling and simulation with the program Vensim.

7.1. Analysis of Functional Relationships

The functional relations between the different variables of flow and level variables have been analyzed and compared with the sources of information public and private consulted. These functional relations directly affect CO₂ emissions in Cartagena.

7.1.1. Relationship GDP-Population.

For the city of Cartagena shows a direct relationship between the data of GDP and the population, as illustrated in the Figure 6. This behaviour is explained by an improvement of the growth of the economy in Colombia through the years. Which increases the use of energy, and thus to a gradual increase of CO₂ emissions in the city.

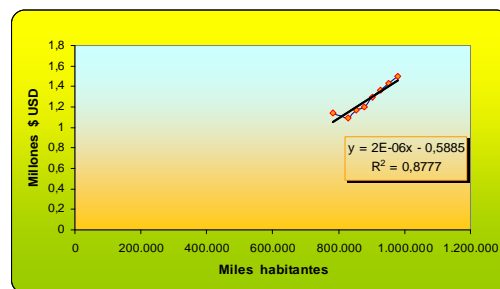


Figure 10. Relationship GDP-Population

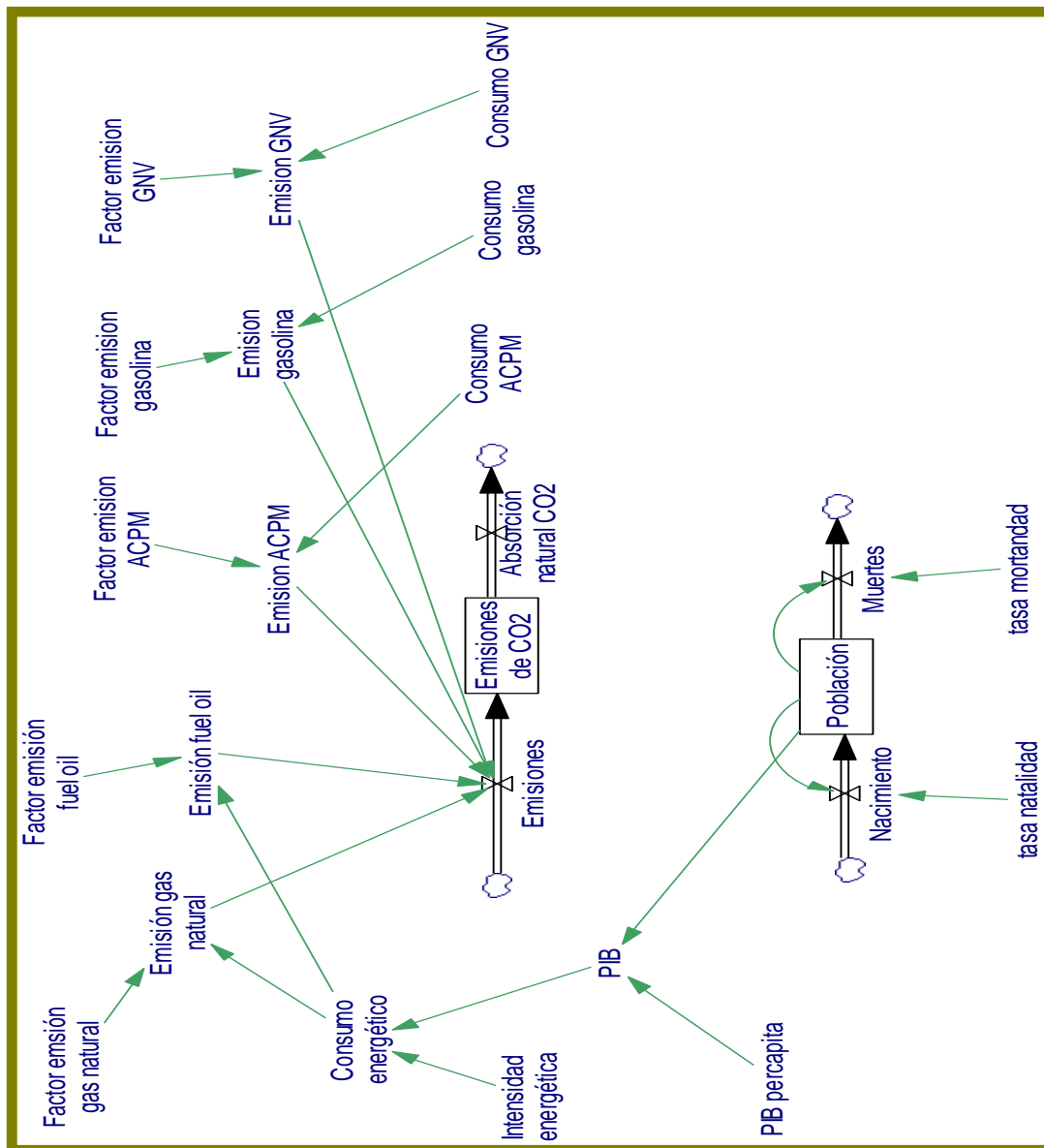


Figure 9. Model emission and absorption of CO₂ in Cartagena de Indias

7.1.2. Relationship GDP- Energy Consumption.

Between 2000 and 2008 there has been a growth in energy consumption. In explaining the evolution of energy consumption in relation to the evolution of GDP, it is observed that the population of Cartagena with its economic activity generates wealth to achieve its level of welfare, demanding energy consumption. In this case in particular, the value of energy

intensity is $85,71 \frac{Kwh}{USD\$}$. Figure 11 shows the phenomenon described above.

7.1.3. Relationship Population – Births

The population growth is the main factor of pressure in the city of Cartagena, in addition to the limited availability of land in existing urban areas. This has resulted in changes in the use of land that have reduced vegetable coverage in the city. It foresees a progressive growth in the coming years to keep the current sociocultural conditions in the city.

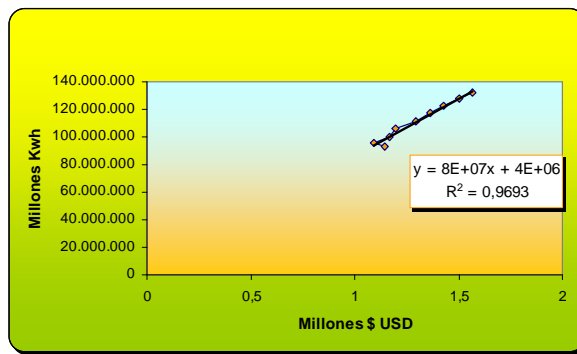


Figure 11. Relationship GDP- Energy Consumption

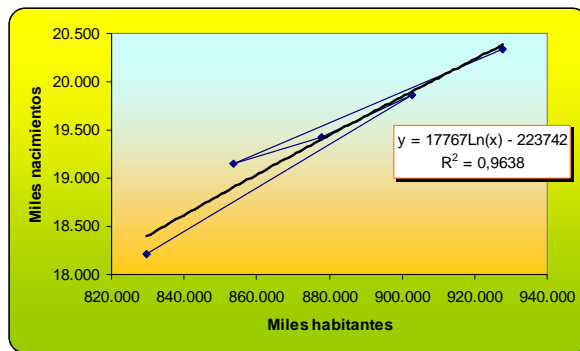


Figure 12. Relationship Population – Births

7.2. Analysis of Causal Diagram of CO₂ emissions in Cartagena

Based on the causal diagram shown in Figure 13, is observed that emissions of CO₂ emitted into the atmosphere framed several relations that will be described below. The population growth demands an energy consumption to perform different activities, these activities require fuel consumption. The fuel combustion produces CO₂ emissions, as mechanisms for reducing these emissions, the forest of the city through photosynthesis absorbs the CO₂ emitted into the atmosphere. The use of soil by population growth, reduces the forest, therefore, is reduced the capacity of absorption of CO₂ in the atmosphere.

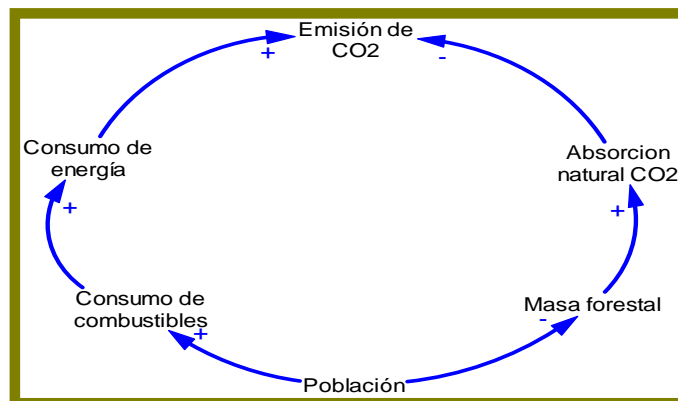


Figure 13. Causal Diagram of CO₂ emissions

7.3 Simulation results of CO₂ emissions

The results obtained considered the analysis of the scenario base. This represents the evolution of the current behaviour of CO₂ emissions in Cartagena de Indias. Below there were detailed the most representative results of this study.

The current overview of the emissions of carbon dioxide (CO₂) in Cartagena, as shown in Figure 16, is linked directly to population growth, with gross domestic product (GDP) energy consumption and fossil fuel consumption (natural gas, fuel oil, gasoline, natural gas vehicles, oil for diesel engines). This shows that the Kaya's identity is a tool of urban environmental planning.

Based on these results is displayed what in Cartagena is projected to increase their CO₂ emissions in the next 20 years, demonstrating their desire to boost its economy. In contrast with this scenario base, the obligatory implementation of Clean Development Mechanism (CDM) and the Rational Use of Energy, in all production processes in the city will reduce consumption, energy costs and the production of greenhouse gases.

All this leads to the improvement in efficiency in the management of their energetic resources that dampens the generation of carbon dioxide. Moreover, the amount of CO₂ emitted in Cartagena might be regulated by the vegetable coverage of the city through the process of photosynthesis.

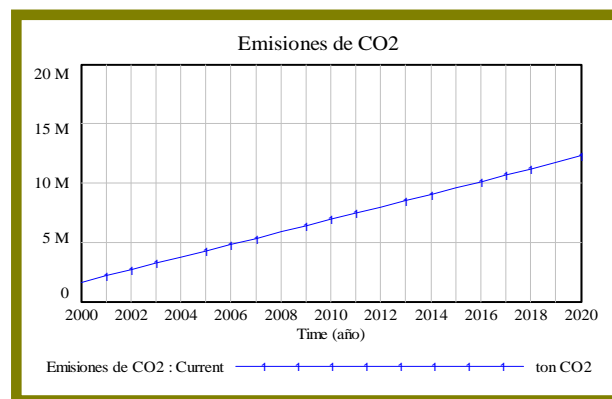


Figure 14. Simulation CO₂ emissions in Cartagena

In terms of population of Cartagena (Figure 15), shows the rapid urbanization process that has lived in general in the country, and in addition, confirms a significant demographic phenomenon to consider for future planning.

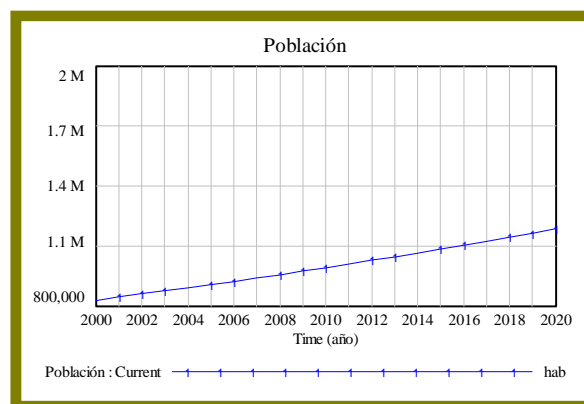


Figure 15. Simulation population of Cartagena

In the case of GDP and energy consumption represented in Figures 16 and 17 respectively. It is observed that these increase progressively, for the dependence with the dynamics of population growth.

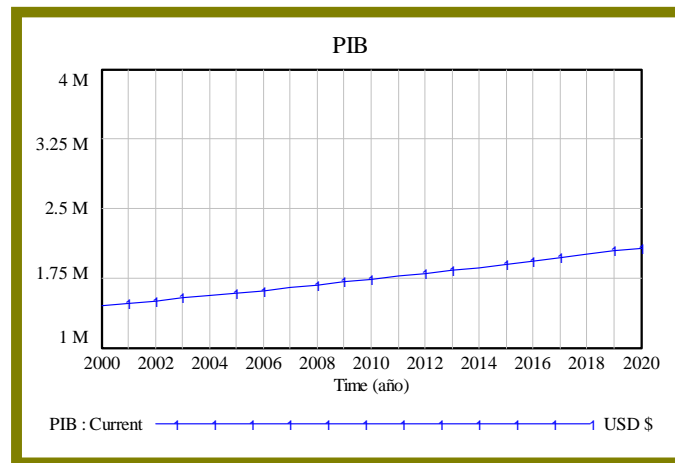


Figure 16. Simulation GDP in Cartagena

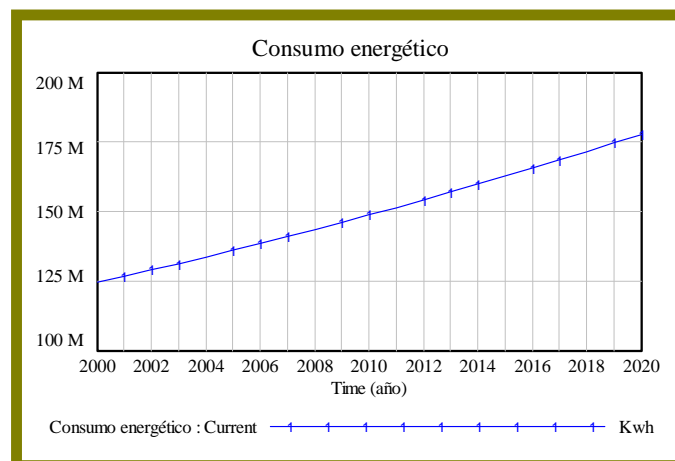


Figure 17. Simulation energy consumption of Cartagena

8 Conclusions

The results generated in this work through the use of the System Dynamics to study the evolution of CO₂ emissions in the city of Cartagena allowed to study the way of interacting in the main variables of the system, with a good approximation to the real environmental system of the city.

The estimates of CO₂ emissions from the base scenario show a progressive increase of this gas, a situation that must be taken into account in urban and environmental planning of the city, to adopt policies that lead to the decrease of these emissions.

Indisputably the emissions of greenhouse gases can be reduced considerably in the city, if used the potential of renewable energies, such as solar photovoltaic and solar thermal. Considering the climatological advantage held by the city for the parameters of solar radiation and brightness solar, a situation that is wasted by the authorities of district government to mitigate the greenhouse effect.

The data of the parameters applied in the system studied, come from official and private entities of Cartagena, but this search of information was quite difficult in some cases.

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