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Environmental Sustainability Index for Colombia: Implications and Considerations for Its Calculation

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ABSTRACT

In recent years, there has been a growing need to consider environmental sustainability as a main component in the development of countries. This is how, within the framework of the Sustainable Development Goals, environmental sustainability is an important component of directing investment projects and is on the agenda of a good part of the developed and emerging countries. In this paper, components are considered for the calculation of an environmental sustainability index, using at a methodological level the behavior of the energy sector, waste management, air quality, pollution levels, optimization in the use of the earth and biodiversity. The final diagnosis for Colombia shows a good behavior of the indicators where 14 of 18 have improved substantially over time, showing a real commitment in environmental terms, while for the rest of the metrics, there are government initiatives that seek to reduce the problem.

1. INTRODUCTION

In strictly economic terms, development was initially determined by the dynamics of the per capita income of the inhabitants of a country, this perspective left aside elements that are currently of great relevance such as poverty, discrimination, unemployment, as well as the distribution of resources [1]. Although there is currently no consensus on the term development, there is no doubt about the evolution that it has presented in recent years [2], the first contributions has been made by determining that the proposal of development is to reduce poverty, inequality, as well as unemployment. Even conceiving a development scenario is technically impossible, when none of these three variables shows improvement, despite showing increases in GDP per capita. Within the process of adding more elements and depth to the concept, Sen [3] states that development could be considered as a mechanism for access to the real freedoms that people can experience. Although from the initial definitions, development implied a growth in GDP per capita. According to Sen [3], this indicator is clearly important for society, to the extent that it enhances the freedoms achieved by people. At this point it should be noted that freedom also depend on other elements such as the inclusion of education and health. It should be noted that Sen's contributions are the basis for calculating the Human Development Index (HDI) that since 1990 has been calculated by the United Nations Development Program.

Without a doubt, economic development is a multidimensional concept that includes an important set of variables. It should be noted that within the most relevant elements that take place when understanding it, the following stand out: Structural transformations, human development, democratic participation and good governance, well-being and freedoms, and environmental sustainability [4]. Although most of the pillars under which development is circumscribed have been examined in depth, economic development from the perspective of environmental sustainability has been one of the least analyzed elements. For this reason, it will be studied in more detail in this investigation.

Sustainable development is defined as a prevailing need in today's world, where excessive production levels are exhausting the planet's ability to renew itself. Faced with this dynamic, the Global Footprint Network [5] makes annual estimates on resource management, determining that the consumption patterns presented in 2019 require 1.75 planets to be guaranteed naturally.

In other hand, "during the last 30 years of the century, the global average temperature increased by about 1.8˚C, representing the same increase as that which occurred in the previous 70 years" [6]. These new geoclimatic "conditions will define the production and consumption decisions of the economy, generating among others: i. decrease in the sources that generate water, ii. modification in the pattern of precipitations, iii. extreme climatic events, iv. rise in sea level, which ultimately have repercussions on the well-being and v. quality of life of human beings, and therefore on their level of development" [6].

In this sense, the objective of the research is to build an environmental sustainability index for Colombia, which allows understanding the state of the multiple variables that intervene in its dynamics using the methodology of Cook et al. [7] that defines as central variables the behavior of the energy sector, garbage and waste management, air quality and pollution, water quality, land use for agricultural and fish farming activities, and biodiversity of forests and soils.

This article is composed of a first section where it is contextualized about the challenges of today's society in terms of sustainability, secondly, it presents the methodological components of the index calculation. In the third section, the results are presented in terms of percentage measurement for the period 2012 to 2017 to finally address the results, discussion and conclusions.

2. CONTEXTUALIZATION

The current conditions of extreme degradation have defined some challenges for modern societies [8]. Although ecosystems have certain levels of resilience, having historical information, as well as indicators that determine the state of nature, can help mitigate impacts in the medium term. Properly constructed theories are characterized by the absence of policies related to environmental measurements, for this reason it is relevant to identify which indicators can provide signs of change, to incorporate them into current theories [9].

Environmental decisions have historically been determined in an ad hoc manner, where solutions to each problem have been proposed in isolation. In this sense, it is necessary, deeper reflections that include within their reasoning the paths of consumption and production. Likewise, the emergence of legislation on the subject, as well as institutions that seek to achieve better results, are supported by the creation of efficient sustainability indicators [9].

Like the definition of development, the conception of the sustainability index has been changing over time. In this way, the first index used was the gross domestic product, which was introduced after the end of the Second World War, although this is one of the most used indices in general terms, from the field of sustainable development, it presents a natural inability to measure the social costs of interventions, as well as the environmental impacts [10]. Clearly after the incorporation of the GDP as an indicator to determine the dynamics of sustainable development, a series of additional measurements were constructed that added more value to the research question and gave other elements to the subject.

The inertia that the subject acquired naturally gave way to the construction of instruments that made it possible to measure sustainable development in a comprehensive manner, although the first indicators such as the GDP, the Green GDP or the Human Development Index (HDI) did not include multidimensional variables in their calculations, other indices such as the Environmental Vulnerability Index (EVI), Environmental Performance Index (EPI), Ecological Footprint (EF) and the Happy Planet Index (HPI) measure the problem in a transversal way, allowing to characterize the level of sustainability within a country, allowing the definition of policies and action frameworks, however, when taking measures between a group of countries, their scope are quite limited [11].

The environmental sustainability index of Cook et al. [7], unlike those previously mentioned, has the advantage that it is a multidimensional tool that has the possibility of being applied to any set of countries, facilitating the implementation of aggregate policies, and allowing to identify its effectiveness over time [12]. Additionally, the methodology adopts a multi-step process to build the indicator, a method quite similar to the one adopted by the United States Environmental Protection Agency (EPA).

Cook et al. [7] used as a methodology the construction of a team of experts on environmental sustainability issues, who, through focus groups and interviews, initially defined the most relevant variables that gravitate around the issue. Once the pillars have been determined, all the indicators that can adequately explain their dynamics are defined, regardless of whether these are available or not in the countries to be analyzed.

Subsequently, a criterion is defined that allows selecting the most relevant indicators according to five criteria: 1) political relevance, 2) satisfaction of the needs of policy makers, 3) ability to capture multiple components without presenting the risk of duplication of information 4) significance, that is, ability to represent relevant and truthful information and 5) availability and quality of information. Finally, thresholds are defined from which the different variables show an adequate behavior or not.

3. METHODOLOGY

Based on an exploratory-type quantitative methodology, the index is presented, by using a set of categories that allow the determination of sustainability over time.

For the development of the index, the variables described in the following Table 1 were considered; each one of these variables registers its veracity from the different sources of information from which the data was obtained so that any replication exercise allows similar results; additionally, to the brief description of each indicator, facilitating the reader's recognition and importance of the values presented.

Due to the difficulty in obtaining data in similar periods, but with the aim of presenting results under a representative historical record, a period between 2012 and 2017 was adopted, facilitating the operation but also the veracity of the information.

Allowing the evaluation of progress towards sustainable development based on an environmental sustainability index, makes it easier for developing countries such as Colombia to recognize where the gaps are or what the most latent needs are and, based on this, guide government initiatives. and other interested entities for a collective, conscious and more effective management process.

Table 1. Variables for index development

TOPIC	*INDICATOR*	*UNIT OF MEASUREMENT*	*SOURCE*
Energetic behavior	Intensity of coal use and electricity generation	CO_2 emissions (kt)	World Bank Indicators
	Intensive use of electricity in economic activities	Energy intensity level of primary energy (MJ/$2011 PPP GDP)	World Bank Indicators
	Renewable energy generation	Kilowatt per hour (kWh)	World Bank Indicators
Waste management	Total volume of waste generation	Total volume of municipal waste generation, expressed in thousands of tons	OECD
	Recycling level	Percentage of recycled waste over the total waste generated	OECD

	Waste sent to landfill	Percentage of garbage generation that is thrown into the landfill	OECD
Air quality and pollution	Total emissions of sulfur oxide (Sox)	Annual Average Concentration (μg/m³)	IDEAM (Colombia)
	Total emissions of nitrogen oxide (Nox)	Annual Average Concentration (μg/m³)	IDEAM (Colombia)
	Total PM 2.5 emissions	Annual Average Concentration (μg/m³)	World Bank Indicators
	Total PM 10 emissions	Total amounts, measured in thousands of tons of PM 1.0	IDEAM (Colombia)
	Total emissions of carbon monoxide (CO)	Total quantities, measured in thousands of tons of CO	IDEAM (Colombia)
	Total emissions of volatile organic compounds (other than methane)	Total quantities, measured in thousands of tons	IDEAM (Colombia)
	Total greenhouse gas emission (kt of CO_2)	Total measurement in thousands of tons of Co_2 equivalent (Mtco2e)	OECD
	Carbon intensity for economic activities	Kilograms per 1,000 USD, Thousands	OECD
Water quality and contamination	Extraction of fresh and underground water	Percentage of freshwater and groundwater extraction, as a long-term ratio of available water	N/A (the data is not available for Colombia)
	Water treatment	Percentage of the population connected to water that received at least one secondary treatment	OECD
Land use agriculture and fishing	Pesticide use	Total pesticide used per crop and expressed in kg per hectare of land	Ministry of Environment, Housing and Territorial Development
	Fertilizer consumption	Total use in crops expressed in kilograms per hectare (Includes Nitrogen, phosphate and potassium)	FAO
	Fish stock sustainability	Average Aggregate Ratio	N/A (the data is not available for Colombia)
Forest biodiversity and soil degradation	Endangered species	Total number of threatened species on the red list	World Bank Indicators
	Logging	Number of hectares deforested per year	IDEAM & OECD
	Protected areas	Terrestrial and marine protected areas (% of the total territorial surface)	World Bank Indicators
	Soil erosion	Soil erosion by water and air	N/A (the data is not available for Colombia)

4. RESULTS

Most of the information was cut to the year 2017, being possible to analyze the growth rates for a period of six years (2012-2017). As stated in the study of [7], the evaluation criteria of each variable are defined under the following parameters:

Green: Growth rates greater than 1%
Yellow: Growth rates between 0% and 1% (including extremes)
Red: Growth rates less than 0%
Grey: Information not available

It should be noted that, for decrease indicators, the colors apply in the following way:

Green: Growth rates less than -1%
Yellow: Growth rates between -1% and 0% (including extremes)
Red: Growth rates greater than 0%
Grey: Information not available

Table 2 shows the results of the measurements for the different indicators, taking the previous conventions as a reference.

The results of the calculations show that 5 of the 23 variables do not have information for the period of analysis, these variables are: Total emissions of volatile organic components (other than methane), extraction of fresh and groundwater, sustainability of the fish stock, endangered species and soil erosion.

Table 2. Measurements for different indicators of the index

		Growing Rate					
Indicator	**Indicator Type**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**
Intensity of coal use and electricity generation	Increase	3.2%	5.8%	3.1%	1.8%	-1.4%	0.3%
Intensive use of electricity in economic activities	Increase	-2.5%	-1.5%	-1.7%	-1.1%	-0.4%	0.7%
Renewable energy generation	Increase	27.7%	-5.4%	2.5%	4.0%	3.4%	3.0%
Total volume of waste generation	Increase	1.3%	-0.6%	4.9%	6.4%	4.1%	2.0%
Recycling level	Increase	0.0%	0.0%	0.0%	0.0%	0.0%	153.3%
Waste sent to landfill	Increase	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%

Total emissions of sulfur oxide (Sox)	Decrease	-7.1%	-35.9%	-55.0%	-87.9%	23.0%	75.5%
Total emissions of nitrogen oxide (Nox)	Decrease	-20.5%	-32.9%	-19.9%	-0.8%	-8.2%	4.6%
Total PM 2.5 emissions	Decrease	-1.3%	-3.6%	-4.9%	-5.6%	-4.8%	-3.5%
Total PM 10 emissions	Decrease	-4.8%	-17.4%	10.1%	6.0%	3.5%	-3.2%
Total emissions of carbon monoxide (CO)	Decrease	-29.1%	-19.7%	-18.7%	-2.6%	-2.7%	11.0%
Total emissions of volatile organic compounds (other than methane)	Decrease	ND	ND	ND	ND	ND	ND
Total greenhouse gas emission (kt of CO2)	Decrease	0.7%	2.3%	4.0%	3.1%	1.9%	1.9%
Carbon intensity for economic activities	Decrease	-4.5%	-3.0%	-0.4%	-0.5%	-0.9%	0.0%
Extraction of fresh and underground water	Increase	ND	ND	ND	ND	ND	ND
Water treatment	Increase	1.5%	2.2%	1.8%	1.2%	0.3%	0.3%
Pesticide use	Decrease	-2.3%	-2.3%	-2.3%	-2.3%	-2.3%	-2.3%
Fertilizer consumption	Decrease	11.5%	-3.4%	-4.7%	-6.0%	3.0%	4.9%
Fish stock sustainability	Increase	ND	ND	ND	ND	ND	ND
Endangered species	Decrease	ND	ND	ND	ND	ND	ND
Logging	Decrease	-52.0%	-21.2%	-24.4%	-35.1%	15.0%	18.0%
Protected áreas	Increase	3.8%	7.5%	7.5%	7.5%	7.5%	28.5%
Soil erosión	Decrease	ND	ND	ND	ND	ND	ND

5. ANALYSIS AND DISCUSSION

The set of complementary variables, show the following individual result, for the defined period of analysis. It is important to mention that during the period 2012 to 2017, the budget invested in Colombia for the development of social policies and with a focus on sustainability has doubled. During that period there was additionally a governmental stability that allowed for a more in-depth analysis than could be done in any other government. Additionally, in that period of time the transition in the peace process was generated giving more possibilities to think in better ways to achieve sustainability.

Energetic behavior

Intensity of coal use, this parameter is increasing in most of the analysis period, reaching a maximum value of 86,091 CO_2 emissions (kt). After 2015, the variables decreased, reaching 85,187 in 2017. For many experts, this indicator is an important proxy of the proper dynamics of the productive sector. The intensive use of electricity in economic activities can be understood in various ways. On the one hand, its growing behavior is a witness to the industrialization process that the country is facing, while on the other hand, when its behavior is relatively constant, it can give clues about the incorporation of other energies into the productive system. In the case of Colombia, this indicator shows a relative downward trend.

Colombia is a country rich in energy, both in fossil and in renewable resources. Energy exploitation and production depends on 93% of fossil fuels, while the rest comes from renewable energies such as hydropower and biomass [13]. The high dependence on hydroelectric resources puts the country at periodic risk of scarcity and high energy prices, as evidenced in 1992 and 1993 with the phenomenon of El Niño [13] and these situations seem to be more significant because of the process of climate change that we face [14]. Of the dynamics of renewable energy generation in Colombia, the peak achieved in 2009 stands out, which had an average growth between 2012 and 2017 of 5.9%.

Waste management

The increase of waste presents a growing behavior and it is natural that the variable grows as a consequence of the population migration to the large cities of the country, in addition to the increase in consumption patterns as a consequence of the growth of the middle class. Although the growth of waste is normal, developing policies that improve recycling standards and make more use of resources are necessary. In this sense, the Ministry of the Environment in Colombia highlights paper and cardboard (53%) as the most recycled material, followed by metals (25%), glass (13%), plastic (7%) and timber (2%). The 8.1% registered in 2017 (graph 5) represented 500,000 tons. Finally, finishing the resource management block, for the analysis period (2012-2017), the percentage of waste sent to the landfill was constant and always located at a value of 92%.

Air quality and pollution

Greenhouse gas emissions derived from human activities, which accumulate in the planet's atmosphere, are the main cause of climate change. For this reason, the international scientific community grouped in the intergovernmental panel on climate change has developed standardized methodologies that allow the state of the release of particles into the air to be determined in each of the countries [15], centered on four pillars: Energy, waste, industrial processes and product use, and agriculture, forestry, and other land uses. Once you have access to information, appropriate intervention is allowed through policies and timely mitigation measures. There is a decreasing trend in the level of emissions for the analysis period, where the average decrease rates for the 6 years are -14.6%, -13.0% and -4.0%, respectively. On the other hand, PM 10 emissions show a decrease of 1.0% on average for the analysis period, carbon monoxide emissions show growth from 2007 to 2010, where they subsequently decrease continuously until reaching 10234 tons in 2017. The emission of greenhouse gas is perhaps the most mediatic variable when monitoring the phenomenon of global warming, it is for this reason that there is a commitment on the part of all countries seeking to control their behavior in order to achieve the goal of not increase the temperature more than 2 degrees Celsius until the year 2050 [15]. From 1990 to 2017, greenhouse gas emissions have grown by an average of 2.01%. Carbon intensity represents the relative imbalance of greenhouse gas emissions in GDP. When variations occur, these reflect changes in the mix between energy and fuel used in an economy. In the case of Colombia, the downward trend in the indicator is clear, which gives evidence of the lower relative use of this factor in productive tasks.

Water quality and contamination

In Colombia, decree 1575 of 2007 defines as drinking water or water suitable for human consumption, that which, due to its physical, chemical and microbiological characteristics, does not represent risks to human health in direct consumption (direct drinking, food preparation or personal hygiene) [16]. In that order of ideas, from 2009 to 2017 the percentage of the population connected to treated water grew from 84.7% to 92.4%.

Land use, agriculture and fishing

For developing countries, building a strong agricultural sector is key to achieving more sustainable growth paths, participating more actively in international trade, achieving soil sustainability, and managing watersheds. However, the use of pesticides, although it represents a greater intensity of productive activities, also affects water quality and terrestrial and agricultural biodiversity. In the case of Colombia, the use of pesticides increased between 1997 and 2008, reaching a maximum value of 152 kg per hectare in 2000, this indicator is located at 36.6 kg in 2017.

Fertilizers, on the other hand, show a growing trend for the period 2012-2017, however, it is important to note that nitrogen and phosphates contribute to soil acidification, water pollution and biodiversity losses, for this reason, its use should be regulated to avoid harmful effects on the environment. Graph 15 shows the behavior of the variable.

Environmental biodiversity and soil degradation

The environmental categories are undoubtedly one of the most relevant parts in the construction of a sustainability index. For this reason, its adequate behavior reflects a better dynamic on the part of this variable. Thus, in the case of the total number of species found on the red list, although it was not possible for Colombia to determine a trend in said variable, for the year 2018, 452 were found among mammals, plants and birds. The felling of forests, measured as the number of hectares deforested annually, went from 2.6 million in 1990 to 197, 159 in 2018.

Finally, terrestrial areas are fully or partially protected areas of at least 1000 hectares taking in account as scientific reserves with limited public access, different natural parks and protected landscapes. Areas managed for sustainable use. Over time, both land and sea areas have grown substantially, representing 15.7% of the national territory in 2018.

Result analysis

Based on the results obtained, coal is increasing due to the increase in the level of production; waste shows growth due to consumerism; the country's freshwater reserves are increasingly diminishing; in the use of the land, the level of fertilizers and pesticides are greatly affecting; addition to the felling of trees and change in biodiversity due to new construction and exploration.

After the individual analysis of the different indicators of environmental sustainability, it is important to make an aggregate diagnosis based on the results of Table 2, in this way, of the 23 indicators analyzed, 5 do not have trend information as required by the analysis, of the remaining 18, 38.9% showed growth in absolute value greater than 1% (Green), 27.8% are on the yellow scale and 33.3% are under the red indicator. It should be noted that these percentages are obtained based on the behavior of the indicator in the last year. However, when performing the same analysis taking the average annual growth as a reference, the results are different: green 77.8%, yellow 5.6% and red 16.7%.

These results indicate a favorable behavior on the part of the sustainability index in the country, which evidences the efforts of the government in the different work blocks, as well as the alignment of the institutions to face all the variables. However, special care must be taken with the variables of: Intensive use of electricity in economic activities, Total greenhouse gas emissions (kt of CO_2) and fertilizer consumption.

Regarding the intensive use of electricity for economic activities, the country has been developing an aggressive proposal that seeks to create wind farms on the Caribbean coast of the country, if an operation is achieved in 50% of the usable area of La Guajira, it could generate 90% of the installed electricity generation capacity in the country and leave behind the dependence on traditional energy sources.

In the case of greenhouse gas emissions, Colombia contributes 0.46% of the global value [15], a value that could double by 2030. For this reason, designing a method that allows acting in the matter becomes an immediate target. In this order of ideas, the Colombian Low Carbon Development Strategy (ECDBC), which is a short, medium, and long-term development planning program led by the Government and which has the support of the National Planning Department and the Sectorial Ministries, proposes more than 100 sectoral mitigation options within the framework of the Paris Agreement, thus managing to define specific controls on this problem and improving environmental quality.

Finally, regarding the last variable, which is the consumption of fertilizers, although the trend was growing until 2017, it is difficult to reverse this variable, given how little technology is agriculture in the country.

As an additional element of discussion, it is relevant to comment that the methodology proposed in this study has components that could be adapted to those proposed by Cortés-León and Gutiérrez-Fernández [16]. This identifies, similar to the current study, the review of international, national and specific indicators. As an additional consideration to the methodology, the selection of indicators is proposed through the method of weights by average [17] panel of experts [18] and the use of the Delphi method. As future research, the consolidation of the model is proposed through its implementation in a longer period of time for its subsequent validation in order to support decision-making in sustainable development policies [19].

6. CONCLUSIONS

It is important to note that the overwhelming growth of recent years, where variables such as GDP have become a determining and central factor, must be accompanied by indicators of environmental sustainability. In this sense, the indices have evolved naturally, including an ever greater number of variables. In the specific case of Cook et al. [7] that builds the index that was replicated in this article, it is worth noting that this methodology was endorsed by experts on the subject, it has theoretical and reliability bases when performing the calculations, it includes a series of multidimensional variables, facilitates the implementation of policies and allows the different countries to be ranked, even compared to the [11] index, which has been widely accepted, adds the possibility of being applied to a group of countries, facilitating the implementation of aggregate policies. Due to these arguments, this methodology differs from the others analyzed in this paper.

In the case of information, given its multiple multidimensionality, it was not possible to find some variables (Total emissions of volatile organic components (other than methane), Extraction of fresh and groundwater, Sustainability of the fish stock, Species in danger of extinction and soil erosion), however, 78% of the variables could be determined. In the original work by Cook et al. [7], a very similar situation occurs when the countries of Norway and Finland are analyzed, finding 79% and 63%, respectively.

In terms of environmental sustainability, it can be concluded that Colombia presents a good performance, where of the 18 indicators analyzed, 77.8% have grown on average more than 1% for the last 5 years, 5.6% grew less than 1%, while 16.7% of the information analyzed presented a deterioration in their behavior. For these last indicators, although the results are not as expected, there are specific efforts from the central government that seek to improve their performance in the short term.

Finally, the design of the policy has been important, that is, from the control and monitoring of the variables, efforts are observed by the different organizations to be in international standards, and even more so is this moment when the country has been formally accepted by the OECD. It should be noted that these efforts should not be short term if you really want to combine economic growth with a permanent environmental vision.

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