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CO2 EMISSIONS: A DYNAMIC STRUCTURAL ANALYSIS

EMISSÕES DE CO2: UMA ANÁLISE ESTRUTURAL DINÂMICA

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ABSTRACT

Purpose - The purpose of this article is to analyze the impact of energy consumption and economic growth on CO2 emissions worldwide and to present the temporary evolution of CO2 emissions during the pandemic.
Design/methodology/approach - The final sample was composed of 72 countries observed for a period of 15 years; the data were collected in the World Bank database. The analysis was performed using a structural dynamic data panel with fixed effects estimated by *Maximum Likelihood.*
Findings - The results indicate that energy consumption affects CO2 emissions directly and positively. GDP per capita has a double effect, 1) it affects CO2 emissions directly and negatively and 2) indirectly, through the path of energy consumption, it has a positive effect contributing to the increase of CO2 emissions. Double effect on carbon emissions is also identified for fixed capital, 1) direct and indirect positive effect on CO2 emissions and 2) negative indirect effect via GDP per capita. Still, the population affects CO2 emissions directly and positively and, from another perspective, the population's indirect influence is confirmed, reducing CO2 emissions via energy consumption.
Originality/value - It is concluded that the reduction of human activities due to forced confinement affected the global use of energy and contributed to the reduction of CO2 emissions in this period. It is suggested to government officials and the population in general to adopt post-pandemic measures related to the development of energy technology by alternative sources of energy.

Keywords: COVID-19; Carbon Dioxide Emission; Economic Growth; Population; Energy Consumption.

RESUMO

Objetivo - O objetivo deste artigo é analisar o impacto do consumo de energia e do crescimento econômico sobre a emissão de CO2 em escala mundial e apresentar a evolução temporária da emissão de CO2 durante a pandemia.
Design/metodologia/abordagem - A amostra final foi composta por 72 países, observados por um período de 15 anos, os dados foram coletados na base de dados do Banco Mundial. A análise é realizada através de um modelo estrutural de painel de dados dinâmicos com efeitos fixos estimados por *Maximum Likelihood*.
Resultados - Os resultados indicam que o consumo de energia afeta direta e positivamente a emissão de CO2. O PIB *per capita* apresenta um efeito duplo, i) afeta direta e negativamente a emissão de CO2 e ii) de forma indireta pelo caminho do consumo de energia apresenta um efeito positivo contribuindo para o aumento da emissão de CO2. Efeito duplo sobre a emissão de carbono também é identificado para o capital fixo, i) efeito direto e indireto positivo sobre a emissão de CO2 e ii) efeito indireto negativo via PIB per capita. Ainda, a população afeta direta e positivamente as emissões de CO2 e, sob outra perspectiva, se confirma influência indireta da população, reduzindo as emissões de CO2 via consumo de energia.
Originalidade - Conclui-se que a redução das atividades humanas devido ao confinamento forçado, afetou o uso global de energia e contribuiu para redução das emissões de CO2, neste período. Sugere-se aos governantes e a população em geral a adoção de medidas pós-pandemia relacionadas ao desenvolvimento de tecnologia energética por fontes alternativas de energia.

Palavras-chave: COVID-19; Emissão de Dióxido de Carbono; Crescimento Econômico; População; Consumo de Energia.

1 INTRODUCTION

The increase in energy consumption on a global scale has become a key focus in the 21st century given its direct effect on countries' economic growth. The gigantic economic development over the past few decades has resulted in increased demand for energy (especially fossil fuel), emphasizing its leading role in driving global climate change. However, this increase in energy consumption has become a global concern and has posed a serious risk to sustainability due to its negative effects on the environment. As a result, keeping this economic growth in balance in order to reduce the impact of global warming is one of the main challenges for all countries. (AKRAM et al., 2020).

Currently, the tiny particle that causes Coronavirus disease, called COVID-19, has become the biggest threat on planet Earth. This disease produces mild symptoms in most people, but it can also lead to severe respiratory diseases (WHO, 2020). This situation started on December 31st, 2019; when China alerted the World Health Organization (WHO) of several cases of unusual pneumonia in Wuhan, a city located in the central province of Hubei with approximately 11 million inhabitants. On January 7th, 2020, the identification of the severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) was announced (WHO, 2020a).

On March 12th, 2020, there were more than 118,000 cases in 114 countries and the WHO announced that COVID-19 could be characterized as a pandemic (WHO, 2020). On April 2nd, 1 million cases and more than 52,000 deaths were reported, affecting 204 countries and territories worldwide. Fifteen days later, the number of cases rose to more than 2 million. The world plunged into crisis because of the pandemic; in August 2020, the data reported 36,194,507 confirmed cases and 1,056,408 deaths in the world (HOPKINS, 2020).

According to Le Quéré et al (2020), as the number of coronavirus cases increases, government policies are adopted worldwide. Under WHO guidance, people should be confined to their homes (quarantine) and international borders should be closed, changing consumption patterns, reducing the need for transportation and movement of people. As a result, social isolation is leading

globally to drastic changes in sectors of the economy, mainly regarding the use of energy, with expected impacts on carbon dioxide emissions.

According to the International Monetary Fund (IMF), the necessary protective measures to combat the pandemic, anchored in population confinement, cause severe changes in economic activities around the world. As a result of the economic crisis for 2020, associated with COVID-19, there is a projection by the IMF which estimates a reduction of -3% in the global Gross Domestic Product (GDP) (IMF, 2020).

According to the International Energy Agency, global demand for energy fell by 3.8% in the first quarter of this year, including liquid fuels, natural gas, electricity, coal, and renewables. Due to the special circumstances brought about by the new coronavirus pandemic, there are changes in energy consumption, industrial production, and transport use, mainly due to the reduction in the demand for fossil fuels in the world (EIA, 2020).

For Khan, Ahmad, and Khan (2020), the serious problems the global economy is facing due to the pandemic restrict CO2 emissions, with benefits for humanity and for the recovery of the atmosphere, so, in addition to the pandemic problem, global warming and environmental pollution are central issues currently being discussed. The world economy essentially uses fossil fuels as its main energy matrix; however, the consumption of this energy causes an increase in greenhouse gases, thus intensifying the average temperature of the planet's atmosphere, changing sea level conditions, and causing severe weather conditions and recurrent precipitation (PALA, 2020).

The purpose of this article is analyzing the impact of energy consumption and economic growth on CO2 emissions worldwide (AKRAM et al., 2020; MUSAH et al., 2020; KHAN, AHMAD, and KHAN, 2020; GESSESSE and HE, 2020) and presenting the temporary evolution of CO2 emissions during the pandemic (ANJUM, 2020; MITRA et al., 2020; WANG et al., 2020).

This article is organized as follows: section two refers to the review of studies; the third section presents the data and the variables, it also describes the method. An econometric analysis of the estimated data and the empirical results thus obtained are discussed in the fourth section; the conclusions are in section five.

2 CO2 EMISSION, ENERGY CONSUMPTION, AND ECONOMIC GROWTH

In this section, the main discussions that investigated the relation between the effect of energy consumption and economic growth on CO2 emissions recently investigated in different parts of the world and the methodological approaches used in the studies will be presented.

Khan, Ahmad, and Khan (2020) analyzed the relation among CO2 emissions, energy consumption, income, foreign direct investment (FDI), and the flow of personal remittances received as an instrument of economic growth for the economies of Brazil, Russia, India, China, and South Africa (BRICS) from 1986 to 2016, using annual data. Through panel cointegration analysis, the results showed that personal remittance flows are increasing CO2 emissions in Brazil, Russia, and China, while in India, personal remittances have been shown to help reduce the CO2 emission. In addition, FDI has a significant positive effect, that is, it increases CO2 emissions in the BRICS region. Finally, the authors confirm energy consumption as the most polluting factor, as environmental degradation is enormous in all countries that make up the BRICS because of energy consumption.

Using the panel data model, Musah et al (2020) analyzed the relation among carbon emissions, renewable energy consumption, economic growth, urbanization, and total population in 16

West African countries. The study covered the period from 1990 to 2018 with annual data collection. The results show that CO2 emissions and renewable energy consumption did not have vital influence on economic growth. Also from the sample set, the variables of urbanization control and total population had no material effect on GDP.

Akram et al (2020) carried out an empirical analysis involving a panel of 66 developing countries between 1990 and 2014. The applied data were from the World Bank database and the Environmental Kuznets Curve (EKC) hypothesis was used for data analysis. The aim of the study was to examine the heterogeneous effects of energy efficiency, energy consumption, nuclear energy consumption, economic growth, renewable energy, and urbanization on carbon emissions within the context of the environment. Based on the results, the study found that: energy efficiency reduces CO2 emissions; renewable energy reduces CO2 emissions; the consumption of nuclear energy reduces CO2 emissions; economic growth increases CO2 emissions, but the square of economic growth reduces CO2 emissions and shows the existence of the EKC hypothesis in developing countries.

To analyze the causal link among carbon dioxide emissions, energy consumption, and gross national product in China, Gessesse and He (2020) used an Autoregressive Distributed Lag (ARDL) limit cointegration test approach in the period from 1971 to 2015. The results indicated that the ARDL model confirms a long and short term cointegration relation among the variables. In the long-term relation, the growth in CO2 emissions has been less than the growth rate of per capita income and confirms the existence of the EKC hypothesis in China in both short and long terms. According to the authors, fossil energy consumption is the main driver of both environmental deterioration and Chinese economic growth; therefore, they suggest decarbonized economic structures with efficient energy consumption.

Salazar-Núñez et al (2020) investigated the existence of causal relations among energy consumption, carbon dioxide, and GDP using the cointegrated panel data model. For this, they used data from 79 countries in the period from 1980 to 2014 with different levels of development divided according to average per capita income in high, medium high, medium low, and low. For groups of countries with high and medium high per capita income, there is a positive relation between energy consumption and gross domestic product and a negative relation between gross domestic product and carbon dioxide emission, since when new technologies are developed, one can achieve the reduction of CO2 emissions. The results are mixed for the medium low and low groups.

Pala (2020) investigated the relation among economic growth, energy use, labor force, and gross capital formation in the G20 countries from 1995 to 2016. The variables were collected from World Bank indicators. Based on the various tests carried out, a bidirectional relation between energy consumption and economic growth is presented, and the feedback hypothesis is valid for the G20 countries, that is, both are interrelated. The conclusion, in general, considers the causal relation between economic growth and energy consumption as an important political implication for the G20 countries and suggests that energy conservation should be carefully designed to avoid an undesirable impact on the economy. Still, one of the main tasks of energy policy is energy conservation, which means efficient use of energy and reduction of greenhouse gas emissions through alternative energies.

In order to verify the impact of economic growth, industrial production, and electricity consumption on CO2 emissions, Yorucu and Varoglu (2020) applied dynamic panel techniques to data from 23 small island countries globally chosen from: the Caribbean, the Pacific Ocean, the Atlantic Ocean, the Indian Ocean, and the Mediterranean Sea from 1977 to 2017. The results indicate that there is no causal relation between the economic growth variable on CO2 emissions; however, there is a long-term causal relation on the part of both industry and electricity consumption on CO2 emissions. The authors concluded that the increase in industrial production and the increase in electricity

consumption lead to a rise in the level of carbon dioxide emissions in small island emerging countries in different parts of the world.

Verifying the nexus among renewable energy consumption, economic growth, trade, urbanization, and CO2 emissions in Australia and Canada, between 1960 and 2015, was the objective of the study conducted by Rahman and Vu (2020). Using annual data, the study showed that, in Canada, in the long run, economic growth and urban population increased CO2 emissions, while trade increased CO2 emissions in both short and long terms. For Australia, the results show that economic growth increases CO2 emissions in both periods, while trade and renewable energy consumption decrease CO2 emissions in the short term. The findings demonstrate the long-term bidirectional causality among CO2 emissions, economic growth, and renewable energy consumption.

Shaari, Abdul Karim, and Zainol Abidin (2020) conducted an empirical autoregressive distributed lag model test to verify the effects of oil, natural gas consumption, and global national production on CO2 emissions in 20 member states of the Organization of Islamic Cooperation with annual data from 1990 to 2017. The results show that, in the long term, global national production can contribute to further environmental degradation. The study also showed that the effect of oil consumption is greater than the effect of gas consumption on the environment. Therefore, the authors suggested that it is important to consume more renewable energy, such as the solar one, and biodiesel to replace non-renewable energy, particularly oil, in an attempt to conserve the environment.

3 GLOBAL CLIMATE IMPACTS RESULTING FROM COVID-19

As the transmission of COVID-19 increases, the whole world quickly adopted social confinement with restriction of human mobility, and studies on these effects on the environment were boosted. According to Arora, Bhaukhandi, and Mishra (2020), the imposition of quarantine interrupted, on a large scale, the main sources of pollution, such as: transport, industries, and fossil fuel power plants. Such sources, considered responsible for the increase in the production of all pollutants, are the cause of greenhouse gases and greatly affect the various environmental parameters.

Boretti (2020) investigates the recent outbreak of coronavirus and the hypothesis about the emission of CO2 to be anthropogenic. The analysis of the measures applied to limit the spread of the virus, in which airlines reduced their flights, factories and businesses were closed, and citizens were confined to their homes, caused a drastic reduction in the emission of carbon dioxide. Therefore, current activity, reduced in recent months at the height of the COVID-19 pandemic, provides new data to demonstrate exactly that carbon emissions are anthropogenic. The author concluded that the emission of CO2 into the atmosphere has anthropogenic causes, that is, human activity contributes overwhelmingly to the increase of CO2 atmospheric concentration.

Forster et al (2020), using national mobility data in 125 tracked nations, found global reductions in GHG emissions from February to June 2020. The authors claim that this situation is due to the global response to the COVID-19 pandemic, since it led to a sudden reduction in GHG emissions and air pollutants in the period under study. On the other hand, according to the authors, an economic recovery towards green stimuli and reduction in investments in fossil fuels is necessary; in this case, it is possible to avoid a warming of 0.3 °C until 2050.

Gillingham et al (2020) explored the short-term effects of COVID-19 in reducing CO2 emissions and air pollutants in the United States. The study took place in the categories of fuels, natural gas, and electricity. The results indicate that the biggest percentage drops in energy consumption

are aviation fuel and gasoline, with reductions of 50% and 30%, persistent with estimates of personal vehicle travels. In contrast, the use of natural gas in residential and commercial buildings decreased by almost 20%, while the global demand for electricity, including demand for coal-fired electricity, decreased by less than 10%. While commercial and industrial use of electricity may have been affected by the outages, part of the decline was offset by increased demand for residential electricity from people who stay at home. The reductions imply a total reduction of around 15% in daily CO2 emissions; these declines correspond to reductions in energy use.

Liu et al (2020) surveyed daily stocks of CO2 emissions in real time from January to April 2020 based on energy generation activity for 29 countries, industry for 73 countries, road transport for 406 cities; aviation, maritime transport, and emissions from commercial and residential sectors for 206 countries. The results indicate that the reduction in human activities during the COVID-19 pandemic affected global energy use and also CO2 emissions. The reductions related to COVID-19 in CO2 emissions compared to 2019 were: in road transport, -15.5%; energy, -6.4%; industry, -4.4%; aviation, -28.9%; residential, -2.7%; and international transport, -15%. Regionally, CO2 reductions in China were -6.9%; followed by Europe, -12.0%; and the USA, -9.5%. According to the authors, the unprecedented reduction in global CO2 emissions in this period was 7.8% compared to the same period last year.

Diffenbaugh et al (2020) investigated the impacts of coronavirus-related social confinement on two multidisciplinary pathways. First: energy, emissions, climate, and air quality; second: poverty, globalization, food, and biodiversity. In the words of the authors, in the short term, reductions in mobility and economic activity reduced the use of energy in the commercial, industrial, and transportation sectors, and the use of energy may have increased in the residential sector. In this sense, there is a decrease in energy consumption; consequently, this affects the levels of greenhouse gas emissions and air pollutants during the pandemic period. Although there is uncertainty about the duration of the pandemic, its economic effects seem very likely to last for years. Individual, social, and governmental responses to these economic effects influence the long-term trajectory of the human footprint on the Earth System.

4 METHODOLOGICAL ASPECTS AND DATA

To carry out the study proposed in this article, a set of data extracted from the World Bank database (WORLD BANK, 2020) on a global scale from 2004 to 2018 was used, covering a period of 15 years. The final sample was composed of 72 countries, according to Table 1.

Table 1: Distribution of countries in continental regions

Region	Name of the countries
America	Argentina, Brazil, Canada, Chile, Colombia, Ecuador, Mexico, Peru, US, Venezuela
Asia	Azerbaijan, Bangladesh, China, Hong Kong SAR, India, Indonesia, Iran, Iraq, Israel, Japan, Kazakhstan, Kuwait, Malaysia, Oman, Pakistan, Philippines, Russian Federation, Saudi Arabia, Singapore, Sri Lanka, Thailand, Turkey, United Arab Emirates, Vietnam
Africa	Algeria, Egypt, Morocco, South Africa
Europe	Austria, Azerbaijan, Belarus, Belgium, Bulgaria, Croatia, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Latvia, Lithuania, Luxembourg, Netherlands, North Macedonia, Norway, Poland, Portugal, Romania, Russian Federation, Slovakia, Slovenia, Spain, Sweden, Switzerland, Turkey, United Kingdom
Oceania	Australia, New Zealand

Source: made by authors

Countries with data that did not exist for the entire period were excluded, so we worked with balanced data, which represented a total of 1,080 observations.

The description of the variables are presented in Table 2, according to studies by Khan, Ahmad, and Khan (2020); Musah et al (2020); and Salazar-Núñez et al (2020), that analyzed the causal relation among CO2 emissions, energy consumption, and economic growth in several countries; the dependent variable, in this research, was represented with the emission of carbon dioxide "emi_c". The variables of interest that make up this study: emission of carbon dioxide (t-1) "emi_c_1", energy consumption "ene_c", GDP per capita "gdp_c", in addition to the control variables: internal credit to the private sector "cre_c", gross fixed capital formation "cap_c", and total population "pop_c".

Table 2: Description of the variables

Name of the variables	Measuring units	Source
Carbon dioxide emission	metric ton per capita	WDI
Energy consumption	one kilogram of oil equivalent	WDI
GDP *per capita*	Real GDP per capita	WDI
Domestic credit to the private sector	annual growth rate in US $	WDI
Gross fixed capital formation	annual growth rate in US $	WDI
Total population	number of inhabitants	WDI

Source: made by authors

The dependent variable of carbon dioxide emission comprises the gas that comprises one carbon particle and two oxygen particles. It arises naturally or as a by-product of burning fossil fuels from fossil carbon deposits, such as: oil, gas and coal, burning of biomass, or changes in land use and industrial processes (for example, cement production). It is understood that the emissions of carbon dioxide (CO2) are calculated as a record of CO2 discharge per capita in metric tons. It is considered the main anthropogenic greenhouse gas (GHG) that affects the Earth's ecosystem. As a result, it is the reference gas against which other greenhouse gases are measured and, therefore, it has great potential for global warming (IPCC, 2020).

The energy consumption variable of interest is defined as primary energy referring to commercialized fuels, including both renewable and modern ones that are used in electricity generation. Its origin is from natural resources: winds, water resources, and solar energy; as from fossil resources: wood and coal; oil, natural gas, and uranium (IPCC, 2020). This indicator was used by the work of (ABBAS, 2020) and when the impact was examined, a positive correlation was observed between these two variables: carbon dioxide emissions and energy consumption.

Another variable of interest, the GDP per capita, is the Gross Domestic Product divided by the population, which is considered the sum of the gross added value of all producers that are resident in the economy, plus taxes on the product, and less the subsidies that are not included in the value of the products. The calculation is carried out without deductions for depreciation of manufactured assets or for depletion and degradation of natural resources. This indicator is measured through the work of Akram et al. (2020), according to the author, there is a positive correlation between GDP and CO2 emissions. Data are in current US dollars (WORLD BANK, 2020).

Regarding the domestic credit variable of control to the private sector, it refers to financial resources provided to the private sector by financial companies, such as loans, purchases of unlisted securities, commercial credits, and other accounts to be received that establish a refund request. For some countries, these transactions include credit to public companies. Private sector development and investment have the potential to contribute to growth, since private markets are influencers for productivity, job creation, income increase, and poverty reduction. Private investments can help provide the basic services and conditions that empower poor people, improving health, education, and infrastructure (WORLD BANK, 2020).

The gross fixed capital formation variable of control includes land improvements, such as: fences, ditches and sewers, etc.; it still refers to purchases of facilities, machinery and equipment, also in the construction of roads, railways, and the like, including schools, offices, hospitals, private homes, and commercial and industrial buildings. In addition, net acquisitions of valuables are also considered capital formation. Data are in current US dollars (WORLD BANK, 2020).

Total population is the variable of control that counts all residents, regardless of legal status or citizenship. The increase in the human population, whether as a result of immigration or more births than deaths, can affect natural resources and social infrastructure. Significant population growth negatively impacts the availability of land for agricultural production and worsens the demand for food, energy, water, and social services. This can put pressure on a country's sustainability and affect the government's commitment to maintaining infrastructure and public services (WORLD BANK, 2020).

In this analysis, multivariate statistical procedures of structural modeling were used. Path analyzes were plotted in all situations using the system of equations to estimate the direct and indirect effects of the explanatory variables on the dependent variable. The equations relating the dependent and independent variables are according to [1], [2], and [3].

$$LNemi_{c,t} = LNemi_{c,t-1} + LNene_{c,t} + LNgdp_{c,t} + LNcap_{c,t} + LNpop_{c,t} + \varepsilon_1. \quad [1]$$

$$LNgdp_{c,t} = LNcre_{c,t} + LNcap_{c,t} + LNpop_{c,t} + \varepsilon_2. \quad [2]$$

$$LNene_{c,t} = LNgdp_{c,t} + LNpop_{c,t} + LNemi_{c,t-1} + \varepsilon_3. \quad [3]$$

In regression estimation, a characteristic aspect of structural modeling is observed, because in the model, the variables named as pop_c, cre_c, and cap_c are presented as independent variables, while gdp_c and ene_c are presented as both dependent and independent variables. In contrast, emi_c forms the model-dependent variable. All analyzes were performed using the values in natural logarithm (NL) using the software R (ROSSEEL, 2012).

5 RESULTS

The results of the estimates of the applied structural model in a dynamic data panel with fixed effects are shown in Table 1 to investigate the effects of energy consumption, population, economic growth, and gross fixed capital formation on CO2 emissions for 72 countries at global scale. All variables were transformed into natural logarithm forms and the estimated results are significant at 1%.

As shown in Table 3, energy consumption had a strong positive impact on carbon dioxide emissions, which means that an increase in energy consumption increases the carbon dioxide emission rate by 0.458. This result confirms the statements of Vaca and Cartuche (2018) that observed a 0.69 impact of energy consumption on carbon dioxide emissions presented in a global panel. They are also in agreement with the studies by Gessesse and He (2020) and Khan, Ahmad, and Khan (2020), which showed the causality between energy consumption and carbon dioxide emission. This result is justified since the use of more energy can produce more CO2 emissions due to the strong dependence on traditional fossil fuel energy in most countries.

Table 3. Estimated standardized coefficients of the dynamic data panel structural model with fixed effects. CO2 emission dependent variable (emi_c). Annual values logarithmized in the period from 2004 to 2018.

Variables	Coefficient	Standard error	Ratio *t*	p-value	IC.inf.	IC.sup.
emi_c						
ene_c	0.458	0.016	29.156	0.000	0.427	0.489
cap_c	0.137	0.022	6.291	0.000	0.094	0.179
emi_c_1	0.450	0.018	24.846	0.000	0.415	0.486
pop_c	0.174	0.013	13.541	0.000	0.149	0.199
gdp_c	-0.123	0.019	-6.324	0.000	-0.161	-0.085
ene_c						
gdp_c	0.163	0.022	7.522	0.000	0.120	0.205
pop_c	-0.328	0.022	-15.061	0.000	-0.370	-0.285
emi_c_1	0.846	0.018	47.965	0.000	0.812	0.881
gdp_c						
cre_c	-0.047	0.017	-2.702	0.007	-0.081	-0.013
cap_c	0.949	0.010	91.373	0.000	0.929	0.969
pop_c	-0.122	0.018	-6.774	0.000	-0.158	-0.087

IC. inf. = Confidence interval, limit below to 95%; IC.sup. = Confidence interval, limit upper to 95%. Variables (emi_c = CO2

emissions, ene_c = energy consumption, cap_c = gross fixed capital formation, gdp_c = gross domestic product per capita, pop_c = population, cre_c = domestic credit, and emi_c_1 = CO2 emissions in (t-1)).

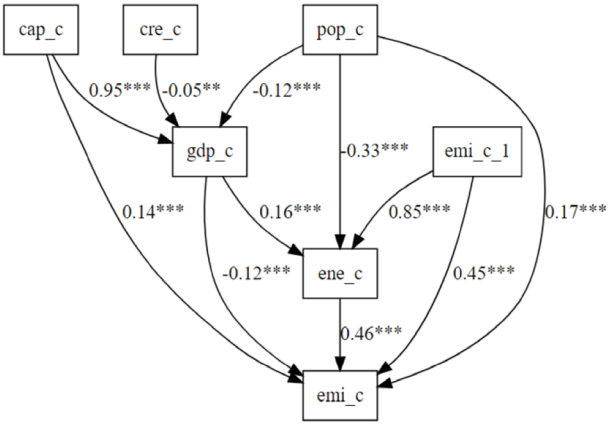
The results of fixed capital indicate a positive direct relation in the model where an increase in fixed capital tends to raise the carbon dioxide emission rate by 0.137. Consistent with the results of Zubair, Samad, and Dankumo (2020) when affirming the existence of unidirectional causality of fixed capital over CO2 emissions. In addition to this direct effect, there is an indirect influence on the CO2 emission of 0.071 through the path cap => gdp => ene => emi, causing a positive impact on CO2 emissions. On the other hand, the negative indirect effect of -0.114 through the path cap => gdp => emi reaffirms the words of Abbas et al (2020) about the influence of fixed capital on economic growth and reflects on the indirect decrease in CO2 emissions.

The coefficient value 0.174 in Table 1 shows a positive and significant impact about population growth on CO2 emissions. Previous research such as Mohmmed et al (2019) and Rahman and Vu (2020) corroborate this position by indicating that population has a positive and statistically significant effect on the emission of carbon dioxide. According to Musah et al (2020), CO2 is expected to increase due to human activities that normally need a greater demand for transport, energy, and industrialized inputs. Thus, if a large number of the population in the countries is involved in related economic activities, then CO2 is likely to increase as well. It is also noteworthy that population growth exerts a negative pressure on CO2 emissions; this negative effect is identified by the coefficient -0.150 through the path pop => ene => emi. In this case, the negative indirect effect is justified by the possible growing awareness of ecological actions and the rational use of energy by the population, that is, the increasingly rational use of energy.

The results demonstrate that Gross Domestic Product per capita has a negative effect on the emission of carbon dioxide. It can be inferred that an increase in GDP would reduce the CO2 emission rate by about -0.123. Consistent with previous research such as the results estimated by Muhammad (2019), which indicated that economic growth causes a decrease in CO2 emissions in emerging countries by -0.089. According to Salazar-Núñez et al (2020), a negative relation between gross domestic product and carbon dioxide emission would be justified since reduction of CO2 emissions can be achieved due to the development of new technologies. In addition, this relation is also justified by the use of alternative sources of energy generation (FARABI et al., 2019; VACA, 2019; and GESSESSE and HE, 2020). However, the results of Akram et al (2020) and Rahman and Vu (2020) indicate that the increase in economic growth positively impacts the increase in carbon emissions. This positive effect of GDP on CO2 emissions is evident from the indirect path (Figure 1) of energy consumption (gdp => ene => emi = 0.075).

The diagram shown in Figure 1 illustrates the proposed relations, as well as the magnitude of the direct and indirect effects among the dimensions presented for this stage of data analysis. The diagram was structured based on the theoretical scheme of the causal relation among CO2 emissions, energy consumption, and economic growth in several countries (YORUCU and VAROGLU, 2020; PALA, 2020; AKRAM et al., 2020; and KHAN, AHMAD, and KHAN, 2020).

Figure 1. Structural graph of the dynamic panel with fixed effects estimated by Maximum Likelihood



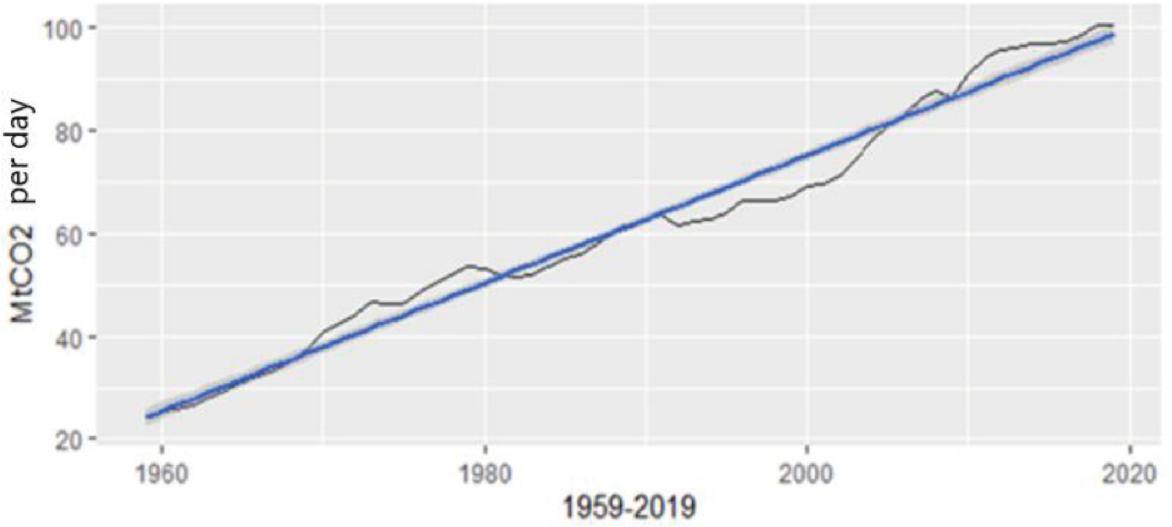
Note: Confidence interval with p <0.001; emi_c = carbon dioxide emissions; ene_c = energy consumption; pop_c = population; gdp_c = gross domestic product per capita; cap_c = gross fixed capital formation cre_c = domestic credit, and emi_c_1 = carbon dioxide emission in (t-1).

Based on the path analysis, the direct effect with the greatest impact on the emission of carbon dioxide was the variable energy consumption, as it presents a standardized regression coefficient equal to 0.46. It should be noted the great influence of the autoregressive characteristic (t-1) on CO2 emissions. Secondly, the effect of the variable population with a standardized beta corresponding to 0.17 stands out. The dimensions of gross fixed capital formation and gross domestic product had their coefficients corresponding to 0.14 and -0.12 respectively.

Next, in Figure 2, the average annual daily emissions in the period 1959-2019 are presented, taking into account the indexes of metric tons of carbon dioxide equivalent (MtCO2) coming mainly from the use of fossil fuel, one of the main drivers of the CO2 emissions into the atmosphere (WORLD BANK, 2020). In 1959, the measure of 24.3 metric tons of carbon dioxide equivalent is presented and, over time, carbon dioxide emissions increased by about 1% per year in relation to the previous decade and, in 2019, 100.3 MtCO2 were registered globally.

Le Quéré et al (2020) provide quantitative results (Figure 3) regarding the temporary daily reduction in CO2 emissions during the period of forced confinement in the pandemic of COVID-19. For analysis, the author considered sectors of industry, surface transport, public buildings and commerce, residential, and aviation. The measures comprise the equivalent of approximately 85% of the world population and about 97% of global CO2 emissions.

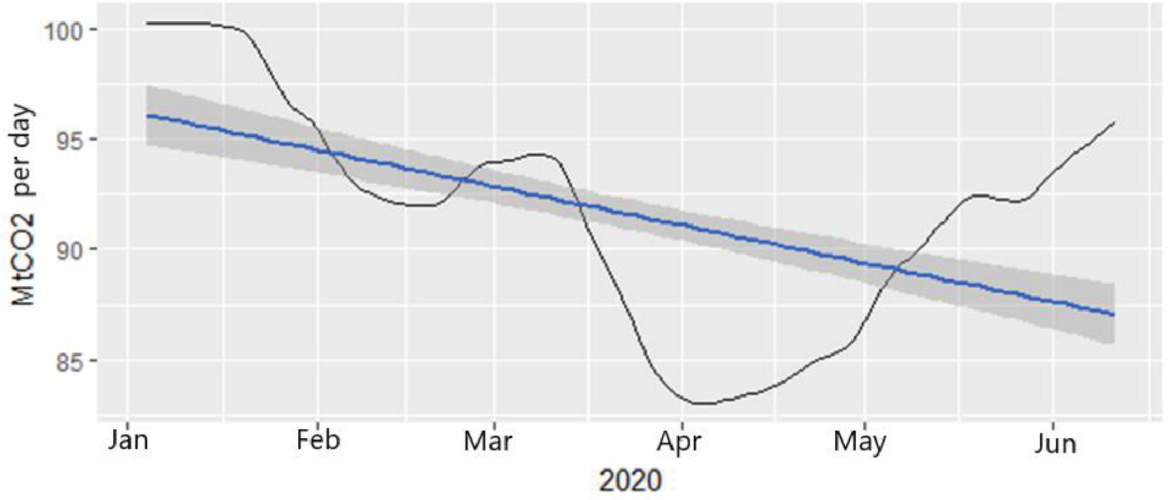
Figure 2: CO2 emissions over time



Note: MtCO2 = metric tons of carbon dioxide equivalent (Global Carbon Project, 2020).

According to Tracker (2020), greenhouse gas emissions are expected to decrease as a result of restrictions set to flatten the COVID-19 curve and control the pandemic. The areas that may be most affected as a result of the pandemic are: supply of energy and electricity, land transport and mobility, aviation, industry, buildings, and land use.

Figure 3: CO2 emissions during pandemic



Note: MtCO2 = metric tons of carbon dioxide equivalent (Global Carbon Project, 2020).

Before the COVID-19 pandemic, CO2 emissions had a gradual growth, however, the measures imposed on citizens worldwide changed this scenario, in particular due to changes in daily activities in sectors such as: electricity, aviation, transportation, industry, etc. (LE QUÉRÉ et al., 2020). The estimated changes, recorded from January to July 2020 (Figure 3) only quantify the effect of the containment, which reduced the daily global CO2 emission by about 17% until April 2020 compared to the same period in 2019. For each country, the maximum daily reduction was 26%; however, the maximum daily reduction did not occur on the same day among countries and, therefore, the reduc-

tions for each country individually are more pronounced when they are compared to the maximum global daily reduction.

6 CONCLUSION

From the empirical analysis of this work, fundamental economic and social implications are derived. Firstly, the advance of economic activity with the increase in energy consumption, mainly through the use of fossil fuels, propagates the emission of carbon dioxide in the environment. Secondly, the compulsory decrease in the displacement of people and automatically a sudden reduction in global economic activity have resulted in a decrease in CO2 emissions.

In this sense, population confinement due to the COVID-19 pandemic is leading to drastic changes in society with expected impacts on economy and also on the emission of greenhouse gases. For this reason, the main focus of this work was to analyze the impact of energy consumption and economic growth on CO2 emissions worldwide and to present the temporary evolution of CO2 emissions during the pandemic.

This work provides subsidies for discussion and improvement of the theme due to the great growth in global GHG emissions observed in recent years and the challenge of limiting climate change in line with the Paris Climate Agreement. Bearing in mind that, in contemporary society, the relation among energy consumption, rapid economic expansion, and the main sources of carbon dioxide emissions are emerging and relevant issues.

In highlight, it is observed the expressive factor of the relation between energy consumption and carbon emission; it is concluded that energy consumption directly and positively affects the CO2 emission, the main factor refers to the excessive dependence on fossil fuel traditional energy by most countries since the use of more energy can produce more CO2 emissions (GESSESSE and HE, 2020; YORUCU and VAROGLU, 2020; SHAARI, ABDUL KARIM, and ZAINOL ABIDIN, 2020; KHAN, AHMAD, and KHAN, 2020).

For the economic growth and carbon emission nexus, GDP per capita directly and negatively affects CO2 emissions. Economic growth affects countries' carbon emissions, confirming that greater economic growth leads to a decrease in carbon emissions. This magnitude is justified by technological development and the use of alternative sources of energy generation (FARABI et al., 2019; VACA, 2019; GESSESSE and HE, 2020). On the other hand, in disagreement with the indirect influence of GDP in this research, previous studies report the presence of an inverse relation, suggesting that the increase in economic growth positively impacts the increase in carbon emissions (RAHMAN and VU, 2020; KHAN, AHMAD, and KHAN, 2020). This reverse relation is evident as an indirect influence.

A reasonable relation between population and CO2 emissions is confirmed; it is concluded that population directly and positively affects carbon dioxide emissions. Most studies have reported that population increasing generates more CO2 emissions by increasing the demand for transport, energy, and industrialized inputs. Thus, if a large number of the population in the countries is engaged in activities related to the economy, then CO2 is likely to increase (RAHMAN and VU, 2020; MUSAH et al., 2020). From another perspective, the indirect influence of the population in the reduction of CO2 emissions through the rational use of energy and ecological awareness is confirmed. It should also be noted that the population has an indirect influence by reducing carbon emissions.

A double effect on carbon emissions is also identified for fixed capital: first, fixed capital positively affects, both directly and indirectly, CO2 emissions, since the increase in fixed capital contributes to energy consumption (ZUBAIR, SAMAD, and DANKUMO, 2020). Second, by driving

economic growth via GDP, fixed capital indirectly and negatively impacts carbon emissions (ABBAS, 2020).

When confronting the conclusions presented so far, with the temporary evolution of CO2 emission during the pandemic, it is confirmed that the reason for the increase in CO2 emission in the last decades has, as main factor, the anthropic actions, driven by the consumption of energy derived from fossil fuels. Thus, the restrictions of human mobility, in this year of social confinement, contribute to the discussion on the theme of how human activity contributes to the increase in the atmospheric concentration of GHG.

This year, after verifying the temporary evolution of CO2 emissions during the pandemic, it is concluded that, because of the global pandemic, there is a sudden reduction in greenhouse gas emissions (FORSTER et al, 2020; BORETTI, 2020). Therefore, the reduction in human activities during the coronavirus pandemic, due to forced confinement, affected the global use of energy and contributed to the reduction of CO2 emissions in this period (LIU et al., 2020; LE QUÉRÉ et al., 2020).

The pandemic has changed the habits of the world population with direct consequences in economic, environmental, and health areas. With the results, the momentary reduction in CO2 emissions is confirmed mainly due to the decrease in the consumption of energy from petroleum and fossil fuels. For this reason, it is suggested that governments and the population in general adopt post-pandemic measures related to the development of energy technology by alternative sources of energy, such as hydroelectric, geothermal, wind, solar, and biofuel to reduce the excessive dependence on traditional polluting energy.

Political decision makers who are responsible for the development of countries are faced with the need to design and implement policies and programs aimed at economic growth with actions aimed at the consistent reduction of CO2 emissions, such as: promoting environmental awareness and applying strict environmental regulations. In contrast, although industrialization consumes a large amount of energy resources, countries can and must implement energy efficient policies and projects as well as using clean technology products.

The social trauma of confinement and associated changes can alter the future trajectory in unpredictable ways, however, the COVID-19 pandemic and the climate crisis are closely intertwined as the pandemic seriously affects economies. In addition, most of the changes observed in 2020 are likely to be temporary as they do not reflect structural changes in the economic, transportation, or energy systems. There is also a need to continue reducing greenhouse gases even in the post-COVID scenario within a sustainable growth for the preservation of the planet on which we live.

Two limitations of this study are highlighted; the first one refers to the exclusion of some countries due to restrictions of complete data regarding some variables. The second one, for the same reason, the period was limited between 2004 and 2018. For future studies, it is recommended to add the nations that were excluded in the present research in addition to considering longer durations in the research analyzes once such data are fully available.

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1. Definition of research problem		√
2. Development of hypotheses or research questions (empirical studies)	√	
3. Development of theoretical propositions (theoretical work)	√	
4. Theoretical foundation / Literature review	√	√
5. Definition of methodological procedures	√	
6. Data collection		√
7. Statistical analysis	√	
8. Analysis and interpretation of data		√
9. Critical revision of the manuscript	√	
10. Manuscript writing		√