Production and current expenditures: A study of CO2 emissions in Ecuador's manufacturing industry

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Abstract

The activities developed in industrialization processes contribute to the deterioration of the environment. In this context, global organizations generate mitigation alternatives through sustainable strategies. Thus, the main aim is to analyze the impact of manufacturing industry production in Ecuador on the environment caused by the total emissions present in the atmosphere. This research has a quantitative approach and empirical level, and the source of information was a structural survey of companies in 2020 issued by the National Institute of Statistics and Census. The methodological process was developed through the description, correlation of variables, and a multiple regression econometric model to explain the relationship between industrial production, current expenditure, and CO2 emissions. The results show that the manufacturing industry generates two million tons of polluting gases annually because of economic activity and the use of fossil fuels. The activities in which fuels are used are first boilers, then motive power, and finally transportation. This study shows a directly proportional relationship between production, current expenditure, and CO2 emissions, where an increase in production implies a greater generation of emissions and, therefore, more current expenditure. This behavior is driven by the dependence on fossil fuels and industrial use. However, it is important to note that air pollution does not depend solely on these factors.

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1. Introduction

Air pollution contributes to global warming and is the main risk factor affecting half of the global population, spreading diseases, and deteriorating the environment [1]. Construction, energy, industry, transportation, and agriculture are sectors that emit large amounts of polluting gases into the atmosphere, which cause extreme weather events to occur with greater frequency and intensity [2], affecting the population, productivity, and dynamic flow of the economy. Globally, the average annual emissions per inhabitant is four tons (t) of carbon dioxide; in 2020, it reached 31.5 GtCO2 which comprises 80% of global demand [3], [4]. Regions such as North America and Europe exceed this amount, yet they generate the greatest amount of renewable energy [5]. In



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other words, the regions that pollute the most are those that seek and use alternative energy. The United Nations Framework Convention on Climate Change seeks to reduce and stabilize carbon dioxide emissions through the assistance of economically independent countries that meet the needs of their populations without relying heavily on external resources [6]. For example, China is an independent country that invests in renewable energy generation, leading to a change in Latin America's energy matrix [7]. In Latin America and the Caribbean, the primary energy supply is fossil fuels, comprising 38% and 23% of the transportation and industry sectors, respectively [8]. The dependence on fossil fuels for different productive activities within industry and logistics are factors that contribute to air pollution [9] and the development of respiratory and cardiovascular diseases [10].

Manufacturing is a sector that is directly and proportionally linked to a country's economic growth [11]. This sector not only contributes to social and public welfare through the import of raw materials and the production and export of finished products [12] but also plays an important role in Ecuador's economy, with a 24% share of Gross Domestic Product (GDP) [11]. The manufacturing industry includes activities such as food processing, beverage and cement, lime, and gypsum manufacturing, which are not only significant in terms of employment generation but are also essential for food security and the country's economic development [13]. However, it is responsible for 52.9% of the environmental impact [14], which reflects the need for more effective environmental management in this industry, especially because of its dependence on nonrenewable resources such as fossil fuels in various production processes [15]. In this context, corporate responsibility is a key issue to be considered by all companies, regardless of their size or activity [16], because it seeks to improve the economic, social, and environmental conditions of the environment in which they operate to contribute and strengthen the objectives of sustainable development [17].

GVA is a macroeconomic expression that evaluates the activity of different sectors of the economy [18]; in other words, it is equivalent to the territory's GDP [19]. This is the result of the production of goods and services after deducting intermediate consumption and taxes [20] and can also be understood as the accounting balance based on the transactions of the economic agents, company, family, and government corporate GVA is an indicator of profitability and productivity at the micro-economic level [21]. Within this context, there is a GVA expressed in "green dollars," a symbolic way of expressing what the environment pays for each dollar generated in the productive processes of economic activities to reduce environmental impact [22].

Environmental regulations based on expenditure or investment show an inverted U-shaped relationship with pollutant gas emissions from the manufacturing industry [23]. The current expenditure in this sector is oriented towards the prevention, reduction, treatment, or elimination of waste, whether gaseous, liquid, or solid, from the company's operational activity, which is effective in a short time period [24]. In addition, investment serves the same purpose as protecting the environment but focuses on the acquisition of special equipment that controls pollution and uses cleaner technology with visible results over a longer period [25]. It is important to recognize that investing in and generating current expenses are viable actions to mitigate environmental pollution [26]. However, to maximize the effectiveness of environmental measures in the manufacturing sector, it is necessary to consider the balance between the two approaches.

In this order of ideas, the purpose of the study is to analyze the CO2 emissions generated as a function of current expenditure and manufacturing production in Ecuador, through the contribution of information in the existing literature, data from secondary sources, and quantitative analysis tools.

The remainder of this article is organized as follows: Section 2 presents the materials and methods, Section 3 presents the results, Section 4 discusses the results, and Section 5 concludes the paper.

2. Research method

The research is quantitative, with information obtained from secondary data sources such as the 2020 ENESEM survey conducted by INEC. This study employs 703 manufacturing companies. The categories of analysis were

the size of the company, the province where it was located, the main economic activity, the type of fuel used, and the production process in which it was used.

The methodological process was developed in three stages: (i) describing the behavior of CO2 emissions and production in the manufacturing sector, (ii) relating the variables using Spearman's correlation coefficient, and (iii) using a multiple regression econometric model to explain the incidence between the variables under study, as shown in Figure 1.

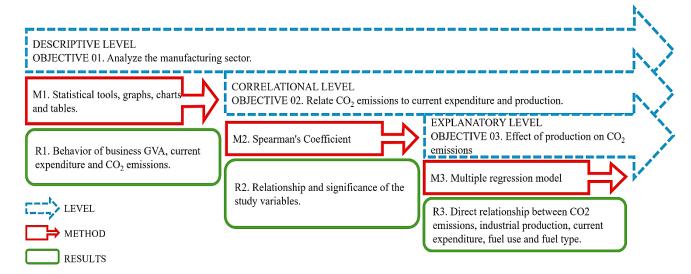


Figure 1. Levels and methods of research development

To obtain the amount of CO2 emitted, the units of fuel consumed by the industry were converted to kilograms of CO2 using the conversion factor proposed by the INEC (see Appendix 1). For the calculation and proper handling of the units, it was necessary to convert kilograms to tons. The behavior of carbon dioxide emissions by fuel and main fuel use, production through business GVA, and current expenditures were analyzed. For the descriptive study, statistical tools, graphs, diagrams, and tables were used to show the behavior of the variables under study prior to their analysis.

To establish the correlation between CO2 emissions and business GVA of the manufacturing sector, Spearman's rho coefficient (ρ) was applied after evaluating the normality distribution, which indicates that the data are non-parametric because the P value < 0.05. This correlation coefficient varies from -1 to +1, ranging from perfect negative correlation to perfect positive correlation, as shown in Appendix 2. Finally, a multiple regression model with control variables was used to evaluate the effects of manufacturing output and current spending on emission generation. Through equation 1.

$$y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \dots + \beta_k X_k + \mu$$
 (1)

This will allow us to test the following hypotheses:

H1: the production of the manufacturing sector has not significant effect on CO2 emissions.

H2: the current environmental expenditure of manufacturing companies has no significant effect on CO2 emissions.

3. Results

3.1. Descriptive statistics

The following variables were detailed in the research development: production, current expenditure, and CO2 emissions, according to the production process that emitted it and the type of fuel and/or liquid lubricant. Of the 703 manufacturing companies in Ecuador, according to the INEC ENESEM 2020 database, 590 are large companies (5 million or more and 200 employees or more) and correspond to 84% of the total, 13% were

medium-sized companies 'B' (2–5 million and 100–199 employees), and 3% were medium-sized companies 'A' (1–2 million and 50–99 employees). It is also noteworthy that 71% of industries are in the provinces of Guayas (273) and Pichincha (223), which are cities with the greatest diversification and economic development, with sectors that generate productive differentiation and dynamism in the country's economy. Regarding industrial production, it is noteworthy that the highest level is found in the province of Guayas, followed by Manabí, which together account for 83% of such production. 87% of CO2 emissions were generated in Guayas, Pichincha, and Imbabura, with the participation of 502 companies engaged in different economic activities. The data indicated above and for the rest of Ecuador's provinces are shown in Figure 2.

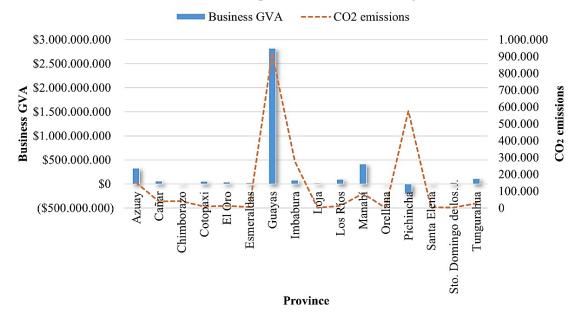


Figure 2. Business GVA and CO2 emissions

The provinces of Imbabura and Loja have the highest current expenditure to mitigate environmental impact (Figure 3), and large companies stand out for their greater concern for environmental care and meeting quality standards; therefore, they allocate part of their expenses to reducing emissions of polluting gases into the air.

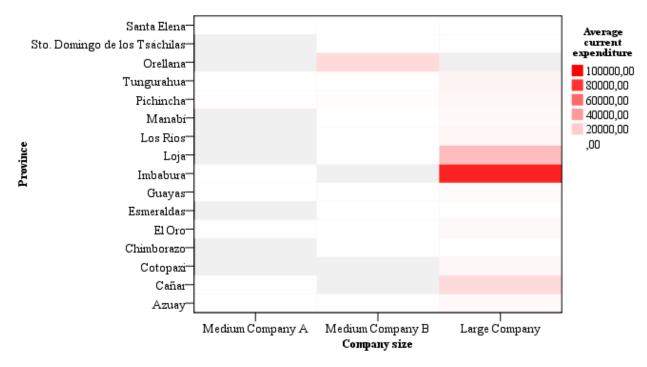


Figure 3. Current spending by company size and province

Regarding industrial production, the activity of "processing and preservation of fish, crustaceans, and mollusks" was the one with the highest production during the study period (\$818,630,958), comprising 73 companies distributed mainly in the coastal region. On the other hand, the activity of "manufacture cement, lime and plaster" is the sector that emits the largest number of polluting gases (479,763.03 t), this activity is mainly developed in two large companies located in Guayas and Imbabura. The descriptions of the emissions and production of the remaining activities are shown in Figure 4.

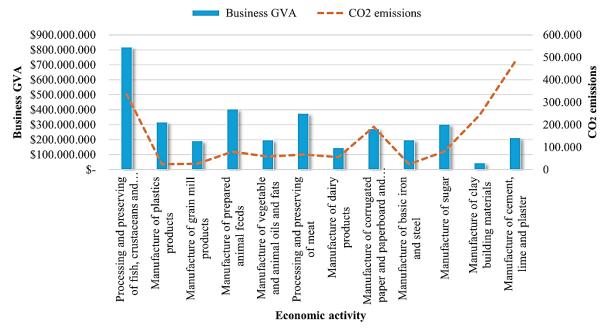


Figure 4. Production and CO2 emissions from economic activities

The most used fuel in the industrial sector is diesel (36.5%), followed by residual fuel oil (35.1%); therefore, as the most used fuel, they generated the most emissions during the study period (Figure 5), 69 of which used it as a source of energy for their activities. Regarding the use of fuel in the industry, its use in boilers represents 39% of the total emissions, as well as its use in motive power and refrigeration (24.9%). The use of boilers to generate steam emits 846,708.27 t, mostly using fuels, such as diesel and residual fuel oil. Motive power and refrigeration emit 539,193.46 t of CO2 and mainly use fuels, such as natural gas and residual fuel oil, for motors, electric pumps, and industrial refrigeration equipment.

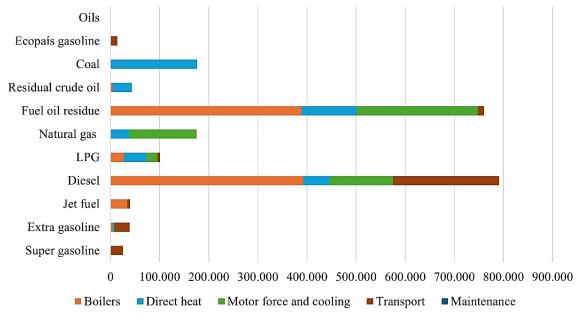


Figure 5. Fossil fuel and liquid lubricants

For the development of the research, the correlation between the dependent variable, CO2 emissions, and the independent variables, business GVA and current expenditure, was established to analyze the environmental impact generated by economic activities in the industry. The ρ Spearman results show that the correlation between CO2 emissions and business GVA is 0.445, which corresponds to a moderate positive correlation. That is, an increase in the production of manufacturing industries contributes to an increase in atmospheric carbon dioxide emissions. The correlation between CO2 emissions and current expenditure is 0.236, which is a low positive correlation; that is, an increase in the current expenditure of manufacturing industries contributes to an increase in atmospheric CO2 emissions. This relationship is statistically significant at a bilateral level of 0.01 and a confidence level of 99%.

Scatter plots were used to analyze the relationship, where the y-axis represents the dependent variable (CO2 emissions) and the x-axis represents the independent variables (business GVA and current expenditure), as shown in Figure 6. In (A), the points formed an ascending straight line, indicating a positive correlation between the variables. In (B), the dots do not show a clear pattern but are distributed in an ascending manner, indicating a low positive correlation between the variables.

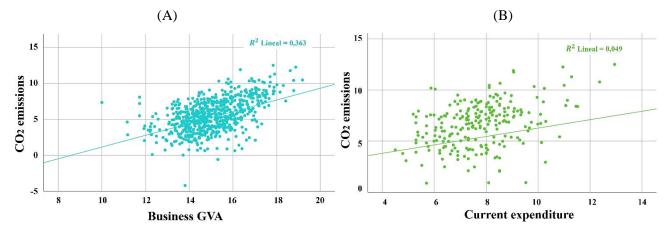


Figure 6. Scatter plots of the study variables

The relationship between the amount of CO2 emissions (dependent variable) and different types of fuels and liquid lubricants (control variables) makes it possible to determine the control variables that have a significant effect on the dependent variable and their level of incidence (see Table 1). From the results shown in Table 1, it is highlighted that diesel generates the highest CO2 emissions because of its higher consumption and therefore presents a high positive correlation, and the one that generates the least emissions is Ecopaís gasoline, which is not significant. The details of other fuels are presented in Table 1.

| Variables | | CO ₂ emissions | Correlation | |
|------------------|----------------|---------------------------|-------------------|--|
| C1' | Spearman's rho | .229** | T 141 | |
| Super gasoline | Sig. (bil.) | 0.000 | Low positive | |
| F1: | Spearman's rho | .287** | I | |
| Extra gasoline | Sig. (bil.) | 0.000 | Low positive | |
| Let five1 | Spearman's rho | .073** | V 1 | |
| Jet fuel | Sig. (bil.) | 0.002 | Very low positive | |
| Discal | Spearman's rho | .793** | III ale manistima | |
| Diesel | Sig. (bil.) | 0.000 | High positive | |
| LPG ¹ | Spearman's rho | .288** | I avv magitiva | |
| LPU | Sig. (bil.) | 0.000 | Low positive | |

Table 1. Correlation between CO2 emissions and fossil fuels and liquid lubricants

| Variables | | CO ₂ emissions | Correlation | |
|-------------------------------|----------------|---------------------------|----------------------|--|
| | Spearman's rho | .117** | | |
| Natural gas | Sig. (bil.) | 0.000 | Very low positive | |
| David - 11 1 davi | Spearman's rho | .307** | T | |
| Fuel oil residue | Sig. (bil.) | 0.000 | Low positive | |
| Desidual amade ail | Spearman's rho | .093** | Very low positive | |
| Residual crude oil | Sig. (bil.) | 0.000 | | |
| Cool | Spearman's rho | 0.042 | Very low positive | |
| Coal | Sig. (bil.) | 0.083 | | |
| Essesial sassins | Spearman's rho | 0.009 | Varratarra a sitirra | |
| Ecopaís ² gasoline | Sig. (bil.) | 0.695 | Very low positive | |
| Oils | Spearman's rho | .355** | Low positivo | |
| Olis | Sig. (bil.) | 0.000 | Low positive | |

¹ Liquefied petroleum gas

The relationship between the amount of CO2 emissions (dependent variable) and the main use of different fuels and liquid lubricants (control variables) allowed us to determine the control variables that had a significant effect on the dependent variable and its level of incidence (Table 2). From the results, it is important to mention that the use of boilers to generate heat causes higher CO2 emissions. Therefore, it presents a very high positive correlation, and those that generate less emissions are motor power and coal. The details of other fuels are presented in Table 2.

Table 2. Correlation between CO2 emissions and the use of fossil fuels and liquid lubricants

| Variables | | CO ₂ emissions | Correlation |
|-------------------------|----------------|---------------------------|--------------------|
| Boilers | Spearman's rho | .928** | Vory high positive |
| Doners | Sig. (bil.) | 0.000 | Very high positive |
| Direct heat | Spearman's rho | .746** | High positive |
| Direct neat | Sig. (bil.) | 0.000 | High positive |
| Motor force and applies | Spearman's rho | .627** | Modernate moditive |
| Motor force and cooling | Sig. (bil.) | 0.000 | Moderate positive |
| Tuonomout | Spearman's rho | .692** | Moderate moditive |
| Transport | Sig. (bil.) | 0.000 | Moderate positive |
| Maintananaa | Spearman's rho | .707** | High positive |
| Maintenance | Sig. (bil.) | 0.000 | High positive |

3.2. Econometric estimation

A multiple regression model with control variables was used to evaluate the effect of the manufacturing sector production on CO2 emissions in Ecuador. The dependent variable is CO2 emissions; the independent variables are business GVA and current expenditure; the control variables are the types of liquid fuels and lubricants and the main use in which they are employed. Scenarios were modeled to determine which variables were more significant and provided a better fit to the model.

Model 1 comprised CO2 emissions as the dependent variable, business GVA and current expenditure as independent variables, and types of fossil fuels and liquid lubricants as control variables.

² 87-octane fossil fuel

Table 3. Scenario comparison

| Variable | mod1 | mod2 | mod3 | mod4 |
|-----------------------|--------------|--------------|--------------|--------------|
| Business GVA | .00003866*** | .00003938*** | .00003882*** | .00003944*** |
| Current expenditure | .42099566*** | .42487421*** | .42374019*** | .42677876*** |
| CV ¹ super | -37.988.468 | | | |
| CV extra | 52.229.349 | 45.703.943 | 32.336.971 | |
| CV jet fuel | 8541.6113* | 8576.9491* | | 8647.1811** |
| CV diesel | 62.876.116 | | 33.769.254 | |
| CV LPG | 36.277.044 | | 2.975.865 | |
| CV natural gas | 24065.347*** | 24357.788*** | 23918.9*** | 24325.255*** |
| CV fuel oil residue | 4951.8622*** | 5237.6263*** | 4860.7938*** | 5309.0589*** |
| CV residual crude oil | 33890.116*** | 34160.139*** | 34437.614*** | 34284.923*** |
| CV coal | 86675.442*** | 85367.74*** | 85763.255*** | 84800.236*** |
| CV ecopais | 1319.2667** | 1070.4958* | | 994.62378* |
| _constant | -842.3876* | -42.520.495 | -44.027.384 | -27.135.712 |
| aic^2 | 34.349.248 | 34.347.937 | 34.358.801 | 34.347.631 |
| bic^3 | 34.419.793 | 34.402.203 | 34.413.066 | 34396.47 |
| | legend: | * p<0.05 | ** p<0.01 | *** p<0.001 |

¹ Control variable

To compare the models, the aic and bic criteria were used to evaluate the goodness of fit and complexity of each model. A model was better when its values for both criteria were lower (Table 3). Mod1 includes all control variables, while in mod2 super gasoline, diesel, and LPG. In mod3, super gasoline, jet fuel, and ecopaís gasoline are excluded. Finally, in mod4, non-significant variables were eliminated.

The results in the table above allow us to reject H1 and H2. Therefore in this work, CO2 emissions are significantly affected by manufacturing output and current expenditure of firms on environmental activities.

Mod4 was selected as the most appropriate model because of the values obtained for the aic (34347.63) and bic (34396.47) modes. Although mod1 is more complex, as indicated by its high bic value (34,419.793), it also shows a lower fitting ability, as evidenced by its high value (34,349.248). This shows that despite the higher complexity of mod1, its ability to explain the data is lower than that of mod4. Note that a model with more variables or complexity is not the best model.

Table 4. Model 1 summary

| Model | R | R squared | Standard error of the estimate | ANOVA test statistics |
|-------|-------|-----------|--------------------------------|-----------------------|
| 1 | 0.772 | 0.595 | 6638.58529 | 0.000 |

Table 4 shows that there is a relationship of 0.772; this value represents a high positive correlation; that is, CO2 emissions are directly proportional to production (business GVA), current expenditure, and the type of fossil fuel and liquid lubricant. In addition, R2 is 0.595, and the independent variables, business GVA, current expenditure, and types of fuels explain 59.5% of the dependent variable, CO2 emissions. However, when analyzing the variance (ANOVA), a significance of 0.000 was obtained; this value was less than 0.05. Therefore, a significant relationship exists between explained and explanatory variables.

Additionally, the coefficients of all independent variables are positive and have a positive relationship with the dependent variable. This means that if the explanatory variables (production, current expenditure, jet fuel,

² Akaike information criterion (aic)

³ Bayesian information criterion (bic)

natural gas, residual fuel oil, residual crude oil, coal, and Ecopaís gasoline) increase, then the explained variable (CO2 emissions) also increases. In the case of current expenditures, the coefficient is positive because the results are evident in the long term.

Table 5. Model 1 coefficients

| | Model | Non-standardiz | zed coefficients | Standardized coefficients | t | Sig. |
|---|---------------------|----------------|------------------|---------------------------|--------|------|
| | ivioder | В | Std. Dev. | Beta | | |
| | (Constant) | -271.357 | 187.084 | | -1.450 | .147 |
| | Business GVA | 3.944E-5 | .000 | .189 | 9.366 | .000 |
| | Current expenditure | .427 | .027 | .532 | 15.932 | .000 |
| | CV jet fuel | 8647.181 | 3329.900 | .040 | 2.597 | .009 |
| 1 | CV natural gas | 24325.255 | 2109.084 | .180 | 11.534 | .000 |
| | CV fuel oil residue | 5309.059 | 726.712 | .119 | 7.306 | .000 |
| | CVresidualcrudeoil | 34284.923 | 2762.434 | .196 | 12.411 | .000 |
| | CV coal | 84800.236 | 12973.491 | .199 | 6.536 | .000 |
| | CV ecopais | 994.624 | 435.494 | .036 | 2.284 | .023 |

Dependent variable: CO₂ emissions

Model equation 1:

 $CO_2 \ emissions = -271.357 + 0.0000394X_1 + 0.427X_2 + 8647.18X_3 + 24325.26X_4 + 5309.06X_5 + 34284.92X_6 \\ + 84800.24X_7 + 994.62X_8 + \mu$

 CO_2 emissions = -271.357 + 0.00004 business GVA + 0.427 current expenditure + 8647.18 jet fuel + 24325.26 natural gas + 5309.06 fuel oil residue + 34284.92 residual crude oil + 84800.24 coal + 994.62 ecopais + μ

The model predicts CO2 emissions as a function of independent variables. It was observed that business GVA and current expenditures had a positive effect on CO2 emissions. This suggests that as these values increase, so do the emissions. Although the current expenditure is intended to mitigate the environmental impact, in this single-year study, it appears to have the opposite effect, contributing to an increase in emissions. Furthermore, the positive coefficients for the different fuels indicate that an increase in fuel consumption is directly related to an increase in CO2 emissions.

Model 2 consists of CO2 emissions as the dependent variable, business GVA and current expenditure as independent variables, and the use of fossil fuels in the manufacturing sector's production processes as control variables.

Table 6. Model 2 summary

| Model | R | R squared | Standard error of the estimate | ANOVA test statistics |
|-------|------|-----------|--------------------------------|-----------------------|
| 2 | .715 | .512 | 7288.62850 | .000 |

Table 6 shows that there is a relationship of 0.715; this value represents a high positive correlation, and CO2 emissions are directly proportional to production (business GVA), current expenditure, and the main use of fossil fuels. In addition, R2 is 0.512, which means that independent variables such as business GVA, current expenditure, and types of fuel explain 51.2% of the dependent variable, which is CO2 emissions. However,

when analyzing the variance (ANOVA), a significance of 0.000 was obtained; this value was less than 0.05. Therefore, a significant relationship exists between explained and explanatory variables. Next, the coefficients were analyzed, and the equation of the second model was formulated.

The coefficients of all the independent variables are positive and have a positive relationship with the dependent variable. This means that if the explanatory variables (production, current expenditure, boilers, and motive power) increase, the explained variable (CO2 emissions) also increases.

Table 7. Model 2 coefficients

| | Model | Non-standardized coefficients | | Standardized coefficients | t | Sig. |
|---|---------------------|-------------------------------|-----------|---------------------------|--------|------|
| | | В | Std. Dev. | Beta | | C |
| | (Constant) | -336.095 | 220.345 | | -1.525 | .127 |
| | Business GVA | 5.733E-5 | .000 | .275 | 14.886 | .000 |
| 1 | Current expenditure | .606 | .015 | .755 | 41.015 | .000 |
| | CV boilers | 1381.775 | 436.127 | .055 | 3.168 | .002 |
| | CV motor force | 1536.985 | 474.600 | .056 | 3.238 | .001 |

Dependent variable: CO₂ emissions

Model equation 2:

$$CO_2$$
 emissions = $-336.095 + 0.000057X_1 + 0.606X_2 + 1381.76X_3 + 1536.99X_4 + \mu$

 CO_2 emissions = -336.095 + 0.00006 business GVA + 0.606 current expenditure + 1381.76 boilers+ 1536.99 motor force + μ

The model focuses on predicting the amount of CO2 emissions as a function of independent variables. It was observed that business GVA and current expenditures, as explained above, have a positive impact on emissions. Additionally, the presence of a higher number of boilers in use, as reflected by the positive coefficient, indicates a direct relationship with emissions. Finally, the power of the engines used in the industry is related to an increase in CO2 emissions.

4. Discussions

During the study period, large manufacturing sector companies achieved \$123,321,427.06 in production adapting to changes in the economy; when considering a hypothetical scenario without the pandemic, production was projected to reach \$125,970,672.00 [27], which implies a difference of US\$2 million. This fact highlights the impact of COVID-19 on the industry; however, it is important to note that companies have adopted innovation strategies, such as online sales and home delivery, to be competitive in the market.

The province of Guayas has 273 companies, representing 72% of national production and 42% of the total emissions. The relationship between industrial activity and air pollution is evident; the higher the production, the higher the emission of polluting gases [28]. In other words, the volume of emissions is closely linked to the number of industries involved and the amount they produce. This hypothesis was confirmed in the case of Guayas Province.

The leading economic activity in production is the processing and preservation of fish, crustaceans, and mollusks, with the participation of 73 medium-A, medium-B, and large companies, located mainly in the coastal region of Ecuador. This sector has positioned the country as the fourth largest exporter of products, such as shrimp, tuna, salmon, and fishmeal [29]. The manufacturing of cement, lime, and gypsum emits the greatest amount of CO2; it has a negative impact on the population, environment, and biodiversity of the area where it

is located. Two large companies involved in this activity in Mexico have generated disputes between environmentalists and businessmen because of their effects on the environment and public health [30].

The use of fossil fuels is directly related to CO2 emissions; likewise, an increase in energy consumption leads to an increase in industrial production and, consequently, waste generation [31]. The industrial sector contributes significantly to total atmospheric emissions. Diesel is responsible for 36.5% of these emissions and is used in numerous activities within production processes owing to its price and adaptability [32]. It is necessary to reduce the dependence on these non-renewable resources and opt for cleaner and more sustainable energy sources such as solar, wind, hydroelectric, and geothermal energy.

5. Conclusions

There is a direct relationship between CO2 emissions, industrial production, current expenditure, and type of fuel used. This implies that increases in business GVA translate into increases in atmospheric CO2 emission. Hypotheses H1 and H2 show the significant effect of manufacturing output and current environmental expenditures of firms on CO2 emissions in the Ecuadorian economy. In this sense, the findings of this work have implications for the construction of economic and environmental policy; it is necessary to rethink manufacturing production to change the energy matrix, raw materials, and other processes with the aim of reducing emissions. The state can play an important role through credits, subsidies, and technological projects that gradually reduce dependence on traditional production processes.

In the period analyzed Ecuador emitted 2,168,980.25 t of 22, industrial production was \$3,902,437,268.00; while the average current expenditure to mitigate the effects of emissions was \$100,000. Although companies allocate resources for environmental management, they do not have an immediate effect on reducing pollution; therefore, their results may appear in the medium or long term.

It is necessary to implement sustainable practices in the manufacturing sector on a massive scale to reduce greenhouse gas emissions and lead to significant improvements in air quality and health. However, the transition to these practices requires continuous investment in clean and efficient technologies that stimulate the creation of new products and processes to improve competitiveness and promote long-term economic growth. In this context, compliance with environmental measures enhances the reputation of industries in terms of social and environmental responsibilities.

The State must take an active role in generating the appropriate incentives for companies that contribute to the improvement of the environment, consider the energy transition, and implement nonlinear production models, which may be based on carbon credits, joint investments, or tax exemptions. Research can promote the revision and updating of economic models to effectively incorporate the environmental costs and benefits of sustainability to strengthen and support existing theories on the importance of environmental sustainability in economic development, business decision-making, and public policy.

The limitations of the study arise from the database used, which corresponds to the ENESEM 2020 conducted by the INEC. There was a notable presence of missing values that were adequately treated, which hindered the exploration of other variables of importance within the context of the research. In addition, the absence of records in some companies regarding the number of gallons of fossil fuels or liquid lubricants used in industrial processes was identified.

Future research should extend the study to various sectors, such as services, commerce, mining, and construction, with the objective of comparing results and determining which sector implements environmental sustainability strategies to reduce the emissions of polluting gases into the environment. Thus, a comparative approach would make it possible to identify which sectors show greater commitment to sustainable practices and social responsibility. It is essential that industries know how much they emit in order to take concrete measures to take care of the environment and consider the transition to alternative energy sources, in line with Sustainable Development Goal 12, which seeks to ensure sustainable production and consumption patterns.

Declaration of competing interest

The authors declare that they have no known financial or non-financial competing interests in any material discussed in this paper.

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Author contribution

DA, AA, and MR designed the study. NL and AA developed the methodology used in this study. DA, AA, and NL analyzed the data. DA, NL, and MR wrote the paper with input from all authors.

Ethical approval statement

Ethical approval is not applicable to this research.

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Appendix 1Conversion ratio of fossil fuel and liquid lubricant to kg of CO₂

| Fossil fuel and liquid lubricant | Conversion ratio |
|----------------------------------|------------------|
| Super gasoline | 9.026 |
| Extra gasoline | 8.866 |
| Jet fuel | 8.538 |
| Diesel | 10.337 |
| LPG | 3 |
| Natural gas | 50.064 |
| Fuel oil residue | 9.763 |
| Residual crude oil | 9.905 |
| Coal | 2.827 |
| Ecopaís gasoline | 7.318 |
| Oils | 0.6526 |

Appendix 2 *Range and degree of relationship*

| Range | Degree of relationship | |
|---------------|--|--|
| -1 | Large and perfect negative correlation | |
| -0.90 a -0.99 | Very high negative correlation | |
| -0.70 a -0.89 | High negative correlation | |
| -0.40 a -0.69 | Moderate negative correlation | |
| -0.20 a -0.39 | Low negative correlation | |
| -0.01 a -0.19 | Very low negative correlation | |
| 0.00 | Null correlation | |
| +0.01 a +0.19 | Very low positive correlation | |
| +0.20 a +0.39 | Low positive correlation | |
| +0.40 a +0.69 | Moderate positive correlation | |
| +0.70 a +0.89 | High positive correlation | |
| +0.90 a +0.99 | Very high positive correlation | |
| +1 | Large and perfect positive correlation | |