Study of association models for determining the growth of the fleet of motor vehicles in the Metropolitan Region of Cariri, Ceará

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Abstract

The quality of life underlying the modern society can be attributed to several factors, among them, the technological and economic development experienced in recent years. Durable consumer goods are part of this modern society, such as automobiles. However, because most automobiles are powered by the combustion of fossil fuels, the emission of greenhouse gases is a worrisome environmental problem. The objective of this article is to analyze Gross Domestic Product (GDP) data, population and SELIC rate (SELIC stands for Special System of Settlement and Custody) in the period from 2001 to 2020 to evaluate the impact on the number of vehicles in the Cariri Metropolitan Region (RMC), using multivariate models. It was verified that the fleet of the RMC experienced an increase of 561.45% in the last 20 years. Three prediction models were tested and the conclusion was reached that for the next 20 years it is not sustainable to maintain the same growth already experienced, in a linear manner. Instead, the ideal is to adopt a model with growth forecast with a logarithmic function, i. e. with a stationary tendency in the long time. In a society where over 50% of vehicles are more than 10 years old, it is essential that public managers, the private initiative, the academic-scientific environment and society adopt sustainable practices and consider future scenarios to make decisions in order to preserve the environment and to ensure everyone's quality of life.

Keywords: Multiple Linear Regression; Vehicle Fleet; Cariri Metropolitan Region; Gross Domestic Product.

1. Introduction

The economic development can be visualized via several characteristics such as urbanization, economic indexes, industrialization and increased purchasing power of the population. One of the main items purchased are motor vehicles, being a durable consumer good that is used by several researchers as a parameter for economic development, a factor that generates the greenhouse effect and pollution in urban centers.

Authors such as Lopes et al. (2018) studied the environmental impacts of the increase in the amount of combustion vehicles in metropolitan regions, as well as the identification of the emission of polluting gases produced by these means of transportation.

According to (Huo et al., 2011) an increase in the vehicle fleet can cancel any benefit from the measures adopted to reduce emissions. The estimated number of the vehicle fleet can be determined by different approaches (Trofimenko, Donchenko, & Komkov, 2020).

To make the present research feasible, it was necessary to initially seek data sources, in order to identify the scenario that had already occurred. Therefore, the data concerning the number of vehicles per municipality in Ceará are available for consultation and subsequent analysis, as of the year 2001 in the portal of the National Traffic Department (DENATRAN, 2021). The information related to the GDP and population were obtained from the database of the Brazilian Institute of Geography and Statistics (IBGE, 2020). And finally, the annual SELIC rate was obtained from the database of the Central Bank of Brazil (BC, 2020).

The present work considers the vehicle fleet as a variable dependent on the GDP, on the SELIC rate and on the population size. Therefore, one can create representative models of the behavior of this variable from multivariate regression techniques.

Thus, this work aims to analyze GDP data, population and the annual SELIC rate to evaluate the impact of these variables on the number of vehicles in the Cariri Metropolitan Region (RMC), using the multivariate regression model. Having the following specific objectives: gather necessary data in reliable databases; generate statistical models according to the collected data; evaluate the proposed models.

The rest of the article is divided into 4 sections, Section 2 presents the theoretical framework, Section 3 presents the methodology, Section 4 presents the results and discussion, and Section 5 the conclusion.

1.1 Fleet growth and the environment

Much is discussed in the current scenario about the environmental impacts caused by various types of polluting sources. One of the main causes of air pollution by gases focuses on the vehicular fleet powered by fossil fuels. A study conducted in the Metropolitan Region of Fortaleza, Ceará-Brazil with data from Lopes et al. (2018), shows that the vehicle fleet of this region emits pollutants such as CO, NMHC, NOx, MP and RCHO and total, 89,646, 10,150, 17,907, 11,604 and 161 tons, respectively. Also according to the aforementioned author, of these inventoried pollutants, Otto cycle vehicles were responsible for the highest emissions of CO, NMHC and RCHO, while Diesel cycle vehicles were those that most emitted NOx and MP. Therefore, although the emission of greenhouse gases is a natural phenomenon, human activity is enhancing this fact in an unprecedented way (Shin, Choi, & Kim, 2018)

Therefore, although the increase in the vehicle fleet may seem a sign of growth and economic development, the environmental impacts arising from this practice can be very harmful, especially those from harmful gas emissions (Guimarães & Lee, 2010).

This is not only an environmental problem, but also a public health problem, since a 1% increase in nitrogen dioxide or ozone concentrations increases hospital admissions by 0.1% (Janke, 2014). Barbosa (2020) argues in his study that urban planning of cities should contemplate among other actions the reduction of motor vehicles.

Meanwhile, works such as that of Brasil et al. (2014) discuss the influence of parameters such as GDP, SELIC rate and population on the increase of the vehicle fleet in the State of Ceará. This study applies statistical methodologies such as multiple regression to forecast the vehicle fleet in the State of Ceará as function of GDP, SELIC rate and population. Such statistical method makes use of the least squares method to minimize model errors, thus enhancing the quality of the forecasts.

There are many definitions for multiple regression. According to Olive (2017) regression is the study of the conditional distribution [Y | x] of the response variable Y given the vector of predictors $x = (x_1,\dots, x_p)^T$, where the response variable is the one you want to predict, while the predictor variables are used to predict the response variable. Multiple linear regression, according to Vieira and Silva (2013), "allows treating efforts resulting from several analyses to obtain a flow surface with combined efforts", thus being an ideal option for application in projects similar to that of Brasil et al. (2014). To accept or reject hypotheses, when using the multiple regression method, the p-value must be less than 0.05 to reject the null hypothesis and accept the alternative hypothesis (AlAdham, Qasem, Al-Nimer, & Yousef, 2015).

It is noteworthy that vehicles, regardless of the amount of the fleet, represent an asset of added value, offering in addition to comfort, practicality, and has become indispensable to modern society (Gegner, 2011). The study of Amaral and Piubeli (2003) revealed that over the years the private vehicle has become a natural option to supply the need of the population.

Thus, it is essential to evaluate the growth of the vehicle fleet in the RMC, considering the past period and also trying to identify an association model for determining future fleet growth, considering that developed societies tend to use less polluting combustion means of transport and electric vehicles (Flesch, 2020) and considering that the increase in the vehicle fleet brings negative impacts (Keiko Yamaguchi, Silva, & Stefenon, 2018).

2. Methodology

According to Montgomery and Runger (2009) multiple regression is a regression model that contains more than one regressor. Regression analysis is widely applied in areas such as biology, physics or engineering (Hoffmann & Vieira, 2016), and that, according to Corrar and Theóphilo (2004) "consists of determining a mathematical function that seeks to describe the behavior of a given dependent variable based on the values of one or more independent variables".

In the present article there is a dependent variable, in this case Y, which represents the vehicle fleet in the RMC and three independent variables, namely X_1, X_2 and X_3, representing the RMC's GDP in Billion reais per year, the RMC's population and the annual SELIC rate, respectively. The intention is to obtain a mathematical equation

$$Y = a + b_1X_1 + b_2X_2 + b_3X_3 \qquad (1)$$

to analyze whether there is a linear association between the dependent variable Y and the independent variables X_1, $X_2$and X_3, through multiple linear regression analysis.

In the research conducted, secondary data were obtained regarding the RMC for a period of 20 years, comprising the years 2001 to 2020. For this, the secondary data were obtained as follows: the motor vehicle fleet per municipality were extracted from the website of the National Traffic Department (DENATRAN); the GDP per municipality, from the website of the Brazilian Institute of Geography and Statistics (IBGE); the SELIC rate from the website of the Central Bank of Brazil (BC); and the population of each municipality also from the IBGE.

It is necessary to consider the variable GDP, because at the time of the production of this work, in the official database, there is information available only up to the year 2018. Therefore, in this research, only for the GDP values for the year 2019 and 2020, a linear regression was used, made from the values collected from the years 2001 to 2018, being obtained the following predictive model, being the variable X the GDP value in the immediately preceding year:

$$\hat{Y}_{EstimatedGDP} = 1.027X + 0.313 \qquad (2)$$

This procedure was necessary due to the fact that having the values until the year 2020 was a crucial factor to verify the build of the statistical model.

The RMC was created in 2009, which includes the municipalities of Juazeiro do Norte, Crato, Barbalha, Caririaçu, Santana do Cariri, Farias Brito, Nova Olinda, Missão Velha and Jardim (Ceará, 2009, art. 1). However, the constitutive municipalities have the individual data prior to this period, being possible, therefore, to collect the data of vehicle fleet, GDP, population and SELIC rate, adding them later to represent the union of these municipalities.

The statistical analyses presented in this article were obtained through the computational tool RStudio (R Core Team, 2020) version 1.4.1106 © 2009-2021 RStudio, PBC, using the package rsm (Lenth, 2009), and through spreadsheet editor software Microsoft Excel version 2007 (Microsoft Corporation, 2007).

To verify normality it was used the Shapiro-Wilk test, so a p value < 0.05 indicates that you rejected the null hypothesis, i.e., the data do not follow the normal distribution. To verify independence, or the presence of autocorrelation, the Durbin-Watson test was used (Passuello, Ribeiro, & Cristina, 2021). To verify the homoscedasticity of the residues of the proposed models it was used the Breusch-Pagan test, which according to Tavares (2017) if this test is significant at the level of significance adopted (5%), the null hypothesis of homoscedasticity is rejected.

3. Results and discussion

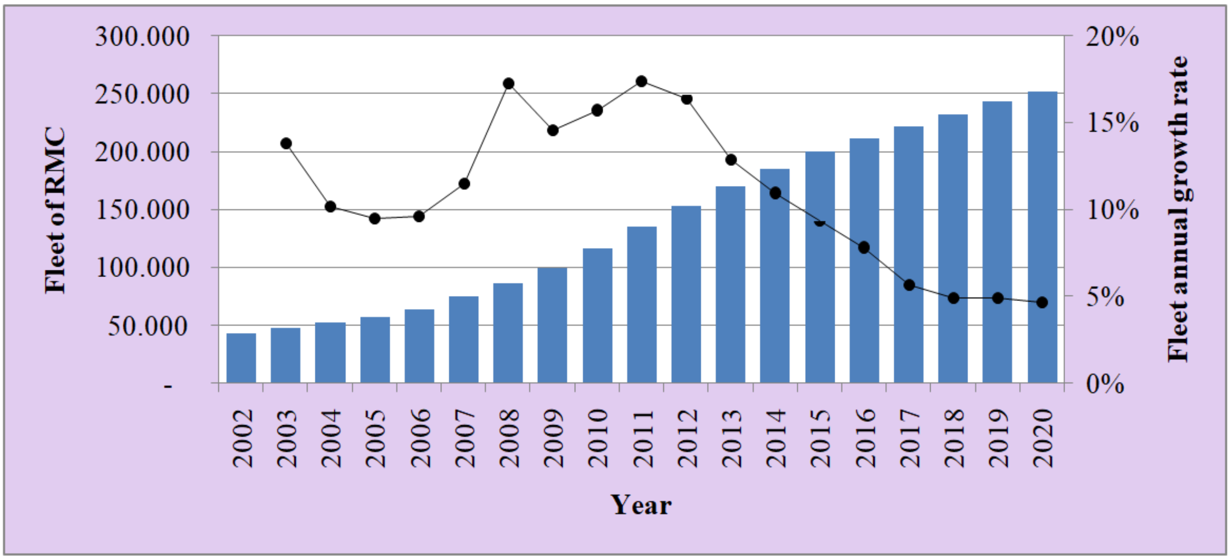
According to resolution 03 of 1990 of the National Council of Environment (CONAMA), air pollution is that resulting from changes in the physical, chemical or biological characteristics of the atmosphere, impacting the welfare of human beings, as well as the fauna and flora (CONAMA, 2005). One of the factors contributing to this pollution is the combustion generated by fossil fuels used in vehicles (Barbaresco, 2020). For this reason, it is essential, for the preservation of the environment and to provide sustainable development, that the growth of the vehicular fleet be analyzed so as to mitigate environmental problems that might arise from such growth.

Amarantes (2020) in his research goes beyond the concept of sustainability, studying the environmentally adequate disposal of end of life vehicles, a practice not yet effectively implemented in Brazil.

The secondary data used in the present research are presented in Table 1, in the appendix of the present work, containing the 20-years history, from 2001 to 2020, for the fleet, GDP, population and SELIC rate.

Through the data collected, the analysis of the growth of the motor vehicle fleet reveals that in 2020 the RMC accounted for a total of 251,588 vehicles, with an increase of 8,680 vehicles compared to the previous year (3.57% increase). At the beginning of the series under study, in 2001, the vehicular fleet was 38,036 cars, representing an increase of 56.45% in 20 years. Evaluating the evolution of the increase in the vehicle fleet, in the 20-year historical series, it can be seen that there was a more accelerated growth in the period from 2002 to 2011, both in absolute and relative numbers. Analyzing the absolute numbers, the graph reveals continuous growth, year after year, however, when analyzing the relative growth, which means the quantity of vehicles that increased in relation to the total quantity of vehicles in the previous year, one notices that from 2012 to 2020, the growth in the vehicle fleet presented a drop. Data is shown in Graph 1. Therefore, there is a deceleration in growth, tending towards a stabilization in fleet growth.

Graph 1: evolution of the vehicle fleet growth in the Metropolitan Region of Cariri - RMC.



Source: elaborated from DENATRAN data (2021).

Regarding the age of the vehicle fleet, the vehicles with 10 years or more of use correspond to 52.31%, as shown in Table 2. On the other hand, vehicles with up to 5 years of use represent 15.28%. The age of the vehicle fleet is directly related to the harmful effects to the environment, because in addition to increasing pollution, it can generate more accidents and breakage of parts (Coimbra, 2017).

Table 2: Vehicle fleet by age in the RMC

AGE OF THE FLEET	QUANTITY	RELATIVE FREQUENCY	CUMULATIVE FREQUENCY
With up to 5 years of use	38,435	15.28%	15.28%
Between 5 and 10 years of use	81,552	32.41%	47.69%
Between 10 and 15 years of use	63,542	25.26%	72.95%
With more than 15 years of use	68,059	27.05%	100.00%
TOTAL	**251,588**	**100.00%**	**-**

Source: elaborated from DENATRAN data (2021).

To perform the modeling and meet the second specific objective, it was used the multiple regression model, considering initially all the variables under study, called Model 1:

$$\hat{Y}_{\text{Fleet Estimated}} = -41{,}290 + 25{,}060X_1 + 0.126X_2 - 262.7X_3 \quad (3)$$

According to the result presented in Model 1, it is observed that for each 1 unit increase in the GDP there is an increase of approximately 25 thousand vehicles in the state fleet. In relation to the population, the addition of one more person corresponds to an increase of 0.126 vehicles. But the variation of the fleet estimate due to the increase of each percent point of the SELIC rate corresponds to a decrease of 262 vehicles. To verify whether Model 1 meets the purpose of the research and is statistically significant, hypothesis tests were conducted and data are shown in Chart 3. One notices that only variable X_1 is significant, therefore Model 1 was revised in an attempt to explain the variation in the vehicle fleet in the RMC.

For Model 1 the coefficient of determination value is approximately 0.9967 and it demonstrates that the GDP variation is responsible for 99.67% of the variation in the fleet increase of the RMC. The adjusted determination coefficient value was 99.61%. The standard error of the estimate was 4,689 vehicles. The Breusch-Pagan test presented a result for the p-value of 0.2142, not rejecting the null hypothesis at a significance level of 5%, therefore, the variance of the errors is constant (homoscedasticity). The Shapiro-Wilk test showed value of 0.8423, not rejecting the null hypothesis indicating normality in data distribution. The results are presented in Table 4.

The Model 2 is a variation of the Model 1, however considering only the independent variable X_1, that is, the variables X_2 and X_3 were disregarded, since they did not reach a significance level less than 5% of the F test, thus it was verified that such variables were not significant for the model in question. The predictive model of Model 2 is defined by:

$$\hat{Y}_{FleetEstimated} = 8{,}188.7 + 26{,}331.3X_1 \qquad (4)$$

Model 2 is representative as shown in Table 3, and therefore explains the variation of the vehicular fleet. However, Model 2 uses a simple linear model, which consequently represents a continuous linear increase of the vehicle fleet over time, a practice that is not consistent with the concept of sustainable development, nor even with the development of large urban centers. As pointed out by the results of the study conducted by Brasil et al. (2014), the constant growth of the vehicle fleet in Ceará causes an increase in pollution; the increase of individual vehicles in the Metropolitan Region of São Paulo/SP increased pollutant gases impacting society and the environment (Testa, 2015); Prata et al. (2019) evaluated the impact on the well-being of the population of the municipality of Itaperuna/RJ, reaching the conclusion that the increase in traffic congestion interferes in a harmful manner in the quality of life in medium and large cities; Bunn, Oliveira Filho and Zannin (2016) studied about the environmental noise pollution in Curitiba/PR, reaching the conclusion that the problem's solution demands actions from governmental agencies of planning, urban development, transportation, environment, education and scientific community; Pereira, Muniz and Junior (2020) reached the conclusion that the increase in heavy vehicles, such as trucks, are primarily responsible for the increase in CO_2 emissions in the state of Mato Grosso. Thus, given that there are limits on the use of environmental resources as well as physical limits imposed on the disorderly increase of the vehicle fleet, Model 2 explains the growth of the vehicle fleet in the last 20 years in the RMC.

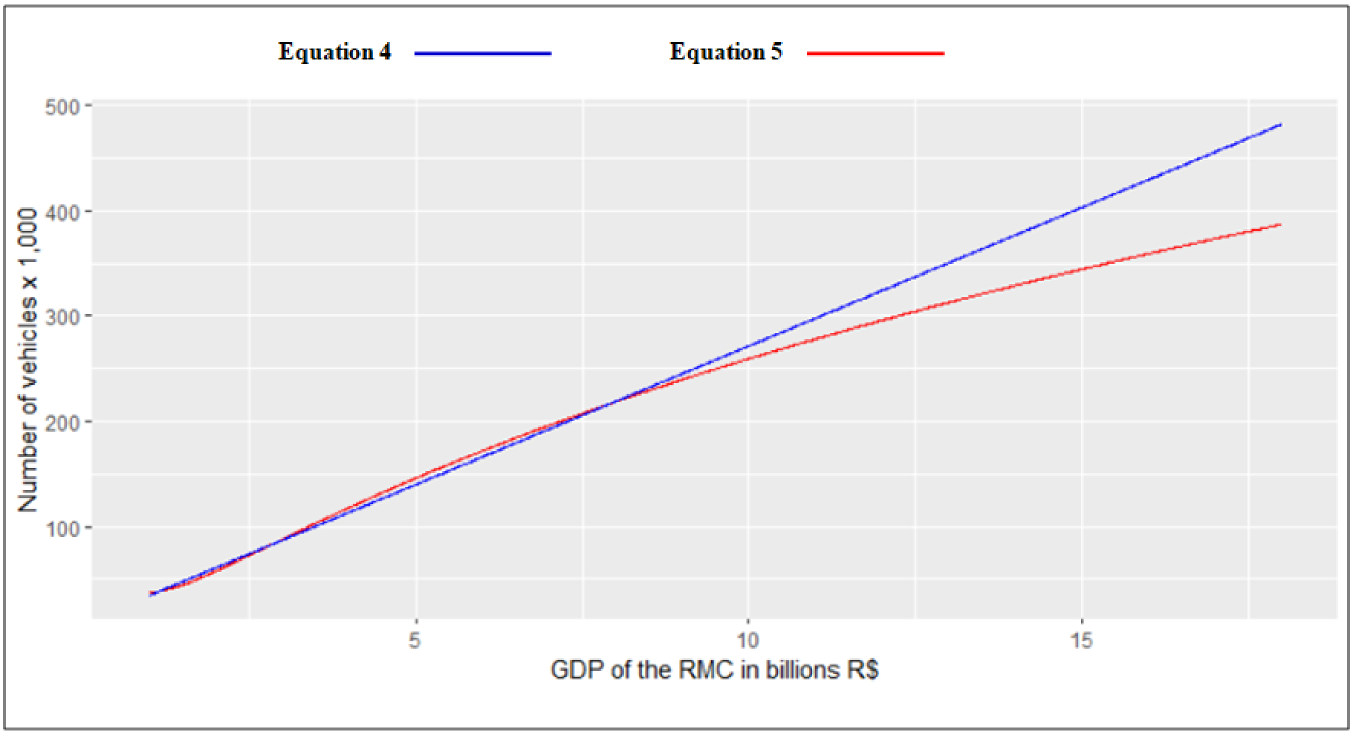
The coefficient of determination value is approximately 0.9965 demonstrates that the GDP variation is responsible for 99.65% of the variation in the fleet increase of the RMC. The value of the adjusted determination coefficient was 99.63%. The standard error of the estimate was 4,540 vehicles. The Breusch-Pagan test presented a result for the p-value of 0.07293, not rejecting the null hypothesis at a significance level of 5%, therefore, the variance of the errors is constant (homoscedasticity). The Shapiro-Wilk test showed value of 0.858 not rejecting the null hypothesis indicating normality in data distribution. The results are presented in Table 4.

However, considering that sustainable development demands a holistic vision that meets the current generations without compromising future generations (WCED, 1987), for the present study it was necessary to consider a future vision whereby vehicle fleet growth occurs in a sustainable manner, demonstrating a fleet growth stabilization after a given level of GDP in the RMC, as per Chart 2, which estimates the RMC vehicle fleet when GDP is of R$ 18 billion, approximately twice the value of 2020. Therefore, Model 3 was generated, which is also a variation of Model 1, considering only the independent variable X_1, that is, variables X_2 and X_3 were disregarded. The predictive model of Model 3 is defined by:

$$\hat{Y}_{FleetEstimated} = 37{,}589.3 + 41{,}833.0\,[\log(X_1)]^2 \quad (5)$$

Considering the behavior of the variable in the real world, of a trend towards fleet stabilization after a certain level, the logarithmic function was added to mathematically represent the behavior of the variable. Thus, Model 3 was considered to explain the growth of the vehicle fleet of the RMC for the next years.

Graphic 2: Projection of the vehicle fleet, generated from Equation (4) (blue line) and Equation (5) (red line). Simulated values for GDP between 0 and 18 billion (R$).



Source: prepared by the authors (2021).

The coefficient of determination value of approximately 0.9966 demonstrates that the GDP variation is responsible for 99.66% of the variation in the RMC fleet increase. The adjusted determination coefficient value was 99.64%. The standard error of the estimate was 4,483. The Breusch-Pagan test presented a result for the p-value of 0.06639, not rejecting the null hypothesis at a significance level of 5%, therefore, the variance of the errors is constant (homoscedasticity). The Shapiro-Wilk test showed value of 0.1597 not rejecting the null hypothesis indicating normality in data distribution. The results are presented in Table 4.

Table 3: Models tested to infer the variation of the vehicle fleet by the independent variables. Values of *p-value* for each model and variable. Significant values are marked in bold.

Variable	Model 1	Model 2	Model 3
Intercept	0.527	**0.00075**	**1.11e-14**
X_1	**1.2e-11**	**2e-16**	-
X_2	0.422	-	-
X_3	0.620	-	-
$[\log(X_1)]^2$	-	-	**2e-16**

Source: Prepared by the authors (2021)

The Shapiro-Wilk test reveals that the data have normal distribution, while the dependence between variables is verified by the Durbin-Watson test and the Homoscedasticity of the residuals is shown by the Breusch-Pagan test, according to Table 4.

Table 4: Results (p-values) of the tests for normality and autocorrelation of the residuals of the models. The significant values at 5% significance level are marked in bold.

Test	Model 1	Model 2	Model 3
Shapiro-Wilk	**0.8423**	**0.858**	**0.1597**
Breusch-Pagan	**0.2142**	**0.07293**	**0.06639**
Durbin-Watson	**0.3824**	**0.5575**	**0.2527**

Source: Prepared by the authors (2021)

The values of the coefficient of determination (R^2), which are used as a measure of quality of adjustment are presented, representing the percentage of the total variation that is explained by the models, are presented in Table 5:

Table 5: coefficients of determination (R^2) of the models.

	Model 1	Model 2	Model 3
R^2	0.9967	0.9965	0.9966
R^2Adjusted	0.9961	0.9963	0.9964

Source: Prepared by the authors (2021)

From tests with Equation (5) produced by model 3, it was observed that when surpassing the value of R$ 88 billion of GDP, the vehicle fleet presented growth inferior to 0.05% per Billion of increase in GDP in the RMC. Therefore, it is estimated a stabilization of the vehicle fleet growth starting at approximately 871 thousand units. This information is important for studies of pollutant absorption capacity and traffic, among others.

4. Conclusion

The study showed that in the last 20 years the Cariri Metropolitan Region experienced a vehicle fleet growth resulting from the increase in GDP. It is possible that this growth will continue in the coming decades, however, sustainable regional development demands from public managers, private initiative, the scientific-academic environment and society as a whole, actions so that the environment is not damaged, which would negatively impact the quality of life of the resident population.

Vehicle fleet growth tends to stabilize along the years, as projected by the linear logarithmic model (Model 3), therefore this model is more coherent when referring to future prospections. Over 50% of the current fleet is more than 10 years old, a characteristic that is associated with the increase of pollution and therefore becomes a worrisome factor.

The present study is technically limited by the data available for analysis, since there are no data available on the vehicle fleet by municipality of the RMC for the period prior to 2001, thus limiting the analysis of the historical series.

The need for changes in vehicle uses habits is reinforced, be they passenger cars, collective transportation vehicles, or vehicles for cargo transportation, for healthier and cleaner alternatives. For people, for instance, the opportunity to use bicycles is evidenced, serving mainly for commuting to work, since it would impact the daily use during most part of the week. Regarding public transportation, in some cities such as Juazeiro do Norte and Crato, there is the railway modal, provided by the subway of the Light Rail Vehicle (LRV) type, which has greater capacity to carry passengers than the other modalities. And for the transport of cargo, one suggests the analysis of the railway modal as well, this already established in the country, but which has lost relevance since the end of the 1970s.

For future studies, we highlight the possibility of comparing Models 1, 2 and 3 presented herein, in order to verify whether the projected scenario has been confirmed and whether Model 1 data has become representative. Thus, there is the possibility of updating the study in the near future, verifying the quantity of the vehicle fleet of the RMC when the GDP is of R$ 18 bn, approximately twice the GDP value in 2020. It is also possible to correlate the variation in environmental pollution with the variation in the vehicle fleet, as well as the impact on the lives of inhabitants and mitigating actions of environmental impacts.

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Appendix

Appendix 1. Vehicle Fleet, GDP, Population of the Cariri Metropolitan Region, and SELIC. Period from 2001 to 2020. The GDP values for 2019 and 2020 were imputed through linear regression made from the values collected from the years 2001 to 2018, according to Equation (2).

YEAR	FLEET OF RMC (Y)	GDP OF THE RMC IN BILLIONS (X_1)	POPULATION OF THE RMC (X_2)	SELIC RATE PER YEAR (X_3)
2001	38,036	1.130	506,137	11.21
2002	43,291	1.390	513,852	11.21
2003	47,702	1.565	521,311	11.22
2004	52,223	1.717	536,967	11.24
2005	57,234	1.891	545,633	11.25
2006	63,806	2.292	554,230	11.35
2007	74,825	2.494	539,383	11.25
2008	85,730	2.943	554,945	11.82
2009	99,151	3.390	560,325	9.50
2010	116,399	4.192	564,478	9.36
2011	135,430	4.699	569,616	11.04
2012	152,821	5.203	574,581	8.18
2013	169,466	5.770	586,010	7.93
2014	185,278	7.039	590,209	10.39
2015	199,640	7.254	594,237	12.52
2016	210,913	7.594	598,107	13.19
2017	221,227	8.373	601,817	9.52
2018	232,092	8.329	605,518	6.25
2019	242,908	**8.867**	609,358	5.80
2020	251,588	**9.419**	612,956	2.72

Source: based on IBGE (2020), DENATRAN (2020) and Central Bank (2021).