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# Environmental Kuznets Curve and the Pollution-Halo/Haven Hypotheses: An Investigation in Brazilian Municipalities

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**Abstract:** There is much discussion on the non-linear relationship between economic growth and carbon dioxide ($CO_2$) emissions. Additionally, the effects of Foreign Direct Investment (FDI) on the environment are ambiguous, as both beneficial (i.e., pollution-halo) and harmful (i.e., pollution-haven) effects were found. Therefore, the literature presents no consensus on either of these topics. This is especially problematic for developing regions, as these regions represent growing economies interested in receiving foreign investments, and their $CO_2$-related research is limited. This study aims to understand the impacts of economic growth and FDI on the $CO_2$ emissions of São Paulo state, Brazil. To perform this study, a unique dataset on regional FDI was built, and 592 municipalities were included. The analyses combine linear and non-linear estimations, and the results suggest a non-linear relationship between Gross Domestic Product (GDP) per capita and $CO_2$ emissions, along with a negative association between FDI and $CO_2$. Finally, this study discusses possible policy implications and contributes to the international literature.

**Keywords:** foreign direct investment; FDI; economic growth; $CO_2$ emissions; pollution; São Paulo; Brazil



**Citation:** Polloni-Silva, E.; Ferraz, D.; Camioto, F.d.C.; Rebelatto, D.A.d.N.; Moralles, H.F. Environmental Kuznets Curve and the Pollution-Halo/Haven Hypotheses: An Investigation in Brazilian Municipalities. *Sustainability* **2021**, *13*, 4114. https://doi.org/10.3390/su13084114

Academic Editors: Andrzej Cieślik and Michael Ryan

Received: 23 February 2021
Accepted: 11 March 2021
Published: 7 April 2021



## 1. Introduction

Economic growth plays a vital role in countries' economic and human development. Over the past 40 years, the world economy has more than tripled [1]. Despite economic growth raising living standards in most countries, it was also responsible for an increase in $CO_2$ emissions and a depletion of natural resources. The results presented in the IPCC report confirm that global warming is largely attributed to human activities, especially those related to $CO_2$ emissions [2].

According to Mardani et al. [3], the majority of previous studies for the past two decades have been intensively focused on the study of the nexus between economic growth and energy use and their effects on $CO_2$ emissions.

Dinda [4] and Liu et al. [5] states that the investigation of the relationship between economic growth and $CO_2$ emissions mainly focuses on whether this relationship follows the Environmental Kuznets Curve (EKC) hypothesis. According to this hypothesis, the environmental quality deteriorates in the early stage of economic development/growth and improves in a later stage as the economy develops.

Most studies following this approach confirm the existence of an inverted U-shaped (and other curve shapes) for the relationship between growth and emissions (i.e., EKC) in many countries and regions [6–9]. Still, Al-mulali et al. [10] and Sadik-Zada and Ferrari [11] state that this transition in the GDP–$CO_2$ relationship depends on the region's economic development stage and technology adoption, which arguably explains how the EKC theory still generates debate across distinct regions/countries.

Accordingly, pollutant emissions are the most critical environmental problem worldwide, and their reduction is part of the political agenda and international organizations debate, such as the Paris Agreement and the 2030 Agenda for Sustainable Development [12]. According to the Sustainable Development Goals (SGD), countries and local governments must foster climate action (SGD-13) and global partnerships (SGD-17), as well as inclusive industrialization, innovation, and economic growth (SGD-8 and SGD-9) to achieve a better stage of sustainable development.

Moreover, policies must be adequate to deal with the reduction of $CO_2$ emissions without affecting economic growth, especially in developing countries, which have been stressing efforts to promote and upgrade their industrial activity [13,14]. Generally, productivity growth is associated with growth in real wages, and ultimately an improve-ment in living standards [14].

In this sense, Foreign Direct Investment (FDI) is a remarkable phenomenon for both developed and developing countries due to its notorious effects on globalization [15] and economic growth [16]. Bakhsh et al. [17] state that FDI contributes to the host economy by stimulating its economic development, by being a source of external finance, and by reducing the bridge between domestic savings and target investment. In sum, FDI facilitates local development, which further encourages employment opportunities for skilled and unskilled labor in the host country [17].

However, there is still some debate on the effects of FDI on carbon emissions. In sum, a multitude of studies argues FDI may negatively affect the environment due to its impact on economic growth [7,8,16,18,19]. While FDI inflows may rapidly affect the host economy and bring hope to the deprived populations, they may also increase environmental degradation and pollution [16]. In other terms, the promotion of economic growth by inward FDI is not free from environmental costs [20], which is alarming considering that nations, especially developing countries, are eager to attract foreign investments [21]. Indeed, He and Yao [16] assert that emerging countries may trade off FDI's financial benefits against environmental losses.

Nonetheless, other studies pointed out that FDI may bring green technologies, which could improve the host country's environmental quality and boost productivity [17,21]. Also, foreign investments might create new investments in the energy sector, promoting alternative energy resources such as wind turbines and photovoltaic cells [22]. These cleaner resources can reduce pollution caused by coal and diesel consumption Moreover, Shahbaz et al. [20] argue that the effect of FDI on the environment depends on the group of analyzed countries. For example, Yi et al. [23] found that green FDI has significantly reduced China's carbon emissions.

In addition to the current lack of consensus on the FDI–$CO_2$ relationship, a major limitation is the lack of regional studies. Research on FDI usually employs country-level data, with a few exceptions. For instance, He and Yao [16] studied FDI in 29 Chinese provinces to avoid significant regional disparities across the country. A similar approach was presented by Hille et al. [24] and their research in Korea. Zhang and Zhou [25] also argue that FDI studies rarely consider regional differences, although these differences may alter results. In fact, the international business literature recognizes the importance of regional or "subnational" differences in FDI activities [26,27], and claim that these subnational differences are particularly relevant for large emerging economies like the BRICS [28]. Specifically, Brazil's inequality and regional differences are well documented [29].

To fill this gap, our study aims to analyze the impact of inward FDI on $CO_2$ emissions in Sao Paulo state, Brazil. We employed advanced econometric models and a unique panel dataset regarding FDI within 592 municipalities in São Paulo state ranging from 2010 to 2016. This dataset is the first and only regional FDI database available for Brazil, which implies an extensive manual check of approximately 22,000 export records to identify the source of capital of a company in a given municipality. Such data allows an indepth analysis of FDI in the region and may serve as a base for future research worldwide.

We choose Sao Paulo for three reasons. First, Brazil has received little attention from the international literature. The absence of empirical studies in Brazil is particularly worrisome considering the country's inward FDI stock. The Sao Paulo state is particularly relevant for a more in-depth analysis of FDI in Brazil due to foreign investments in the region. According to the Central Bank of Brazil [30], the state accounted for roughly 39% of foreign investments in the country, at least considering industrial enterprises. Besides, Sao Paulo presented the highest Gross Domestic Product (GDP) in 2016 and is the richest and most economically complex region in Brazil [31]. Second, Brazil is the leading air polluter in Latin America and is a country that experienced significant growth in recent years [32,33], with 441.8 million tons of $CO_2$ emissions in 2018 [34]. Sao Paulo state is responsi-ble for 71.50 × 106 $tCO_2$/year [35], which is remarkable to control environmental damage in the country. In addition, Brazilian policymakers do not fully understand the environmental impacts of such investments. Third, there is an absence of studies using subnational data for developing countries.

Accordingly, our study presents three contributions to the literature. First, we present an in-depth $CO_2$-related analysis in a developing region, which is important for local policymaking, especially for policymakers being pressured to promote economic growth with minimum environmental damage. Policymakers in other parts of Brazil and the world may access our policy recommendations. Second, due to the scarcity of data, we built a unique dataset with information about multinational companies located in Sao Paulo state using an export-oriented FDI measure similar to Moralles and Moreno [36] and Polloni-Silva et al. [37]. Third, our findings reveal the impact of FDI on $CO_2$ emissions at a municipal level, therefore contributing to the international debate on this issue.

The rest of this paper is organized as follows. The literature review on the impacts of FDI and the possible non-linear relationship between economic growth, FDI, and emissions is presented in Section 2. Section 3 focuses on the data gathering process and the estimation strategy. Section 4 presents the main findings. Section 5 presents the robustness checks. Finally, Section 6 presents the policy implications of our findings, along with a brief conclusion.

## 2. Literature Review and Hypotheses Development

### *2.1. Pollution-Halo and Pollution-Haven*

According to the literature, FDI may boost the host country's economic growth while putting the environment at risk [16,20,38]. Although previous research has found inconclusive results, scholars have attempted to explain the influence of FDI on the environ-ment, as it is often assumed to be connected to economic growth [39,40].

Nonetheless, the literature points to two alternative theories that associate FDI and the environment. Namely, the "pollution-haven" and "pollution-halo" theories. The pollution-haven hypothesis defends that inward FDI is attracted to weak regulatory and environmental laws presented by the host country [17,41]. Thus, FDI should negatively affect the environment, especially in developing economies with weaker environmental standards [42]. In fact, several countries are eager to attract FDI [21] and may use their lax environmental regulations to compete in the "FDI tournament" [38]. On the contrary, the pollution-halo hypothesis claims that foreign firms, especially from developed economies, arrive with newer and cleaner technologies and better management practices capable of improving the environmental quality of the host country [17,21]. The pollution-halo hypothesis is especially relevant when domestic firms are considered pollution-intensive when compared to international standards [17].

Concerning the pollution-haven and pollution-halo studies, the results are debatable, once again. Zafar et al. [21] found evidence of FDI bringing advanced technology and in-novative products in the United States, which decreased environmental pollution as the pollution-halo theory suggests. Additionally, Jiang et al. [43] claim that FDI improved air quality in China, especially in populated cities.

By employing cointegration analysis, Nepal et al. [44] found that an increase in FDI inflows may reduce energy use, evidencing that energy-efficient techniques through FDI can reduce carbon emissions, which reinforces the importance of policies that encourage FDI inflow in renewable energy sectors. Evidence of pollution-halo in developing economies is also found by Tiba and Belaid [15] and Yi et al. [23].

However, FDI may present a significant positive impact on environmental degradation, thus supporting (especially in developing economies) the pollution-haven hypothesis. In this sense, He and Yao [16] found (at least to some extent) evidence to pollution-havens in China, while similar results are also presented by Jiang [8], Shahbaz et al. [20], and Opoku and Boachie [19]. Furthermore, Kastratović [42] studied 63 different de-veloping countries, including Brazil, and found evidence of pollution-havens. Zakarya et al. [45] studied the BRICS and also found evidence of pollution-havens, as FDI increased $CO_2$ emissions in the selected countries.

Yet, the results presented by Shao et al. [46] refuted the pollution-haven hypothesis for the BRICS. Thus, in essence, the literature still lacks conclusive results. As Nasir et al. [18] declared, FDI may have either a positive or negative impact on the host's environ-ment. It depends on the research method, timeframe, and region [16,18,25]. *De facto*, in-conclusive or mixed results for developing countries were also found by Nadeem et al. [47], Chen and Yang [48], and Xu et al. [49]. Therefore, further research is essential to better comprehend the link between FDI and the environment.

Thus, considering the current literature on FDI, environment, and location choice, we formulate the following hypothesis:

**Hypothesis 1 (H1).** *The effect of FDI on $CO_2$ emissions is statistically significant.*

Which can be partitioned into:

**Hypothesis 1a (H1a).** *FDI is negatively associated with $CO_2$ emissions (pollution-halo behavior);*

**Hypothesis 1b (H1b).** *FDI is positively associated with $CO_2$ emissions (pollution-haven behavior).*

### *2.2. Non-Linear Relationship between Economic Growth, FDI, and $CO_2$ Emissions*

Global warming is one of the main concerns of world globalization in terms of industrial development. There has been a steady growth in energy demands to sustain the development of countries. At the same time, there are increasing concentrations of greenhouse gases (GHGs) in the atmosphere, particularly carbon dioxide ($CO_2$), intensifying the natural greenhouse effect and the heat it generates. According to IPCC [2], human activities are estimated to have caused approximately 1.0 °C of global warming above preindustrial levels.

Since the 1990s, some authors have come to defend that the interaction between economic growth and environmental problems has a certain regularity. This empirical evidence first emerged by Grossman and Krueger [50,51], in which the relationship between GDP per capita and emission of pollutants takes the form of a "U-inverted" or Environmental Kuznets Curve (EKC). Therefore, their work linked economic growth to environmental degradation in a non-linear way.

The EKC theory asserts that environmental degradation increases in the early stages of economic growth, and decreases when the income surpasses a certain threshold level [16,50]. In other words, the EKC theory suggests that at an early stage of economic development, people will demand more energy and natural resources, while neglecting the environment. However, at a later stage of development, people may present a different mindset and demand a cleaner environment, energy-efficient products, and the protection of natural resources, as well as the environment, in general [18,21]. In summary, EKC represents the notion that despite the environmental degradation at first, economic growth can improve the environmental quality in the long-run [18]. As FDI is often assumed to be connected to economic growth [39,40], multiple scholars are now analyzing FDI and its effects on the environment from the EKC perspective.

However, results are still inconclusive [18]. Both country-specific and diversified studies have been published. Fosten et al. [52] found significant evidence of EKC in the UK. Esteve and Tamarit [53] studied Spain and found that, in the long-run, economic growth reduces $CO_2$ emissions. However, Ghosh [54] found no conclusive evidence of this long-run relationship between growth and emissions in India, and similar results were found for Turkey [55], where pollution was not found to be associated with FDI or economic growth. Instead, Haug and Ucal [56] examines the effects of foreign trade and FDI on $CO_2$ emissions in Turkey and the results show that FDI has no statistically significant long-run effects and $CO_2$ intensity is not influenced by FDI, but an environmental Kuznets curve is present for $CO_2$.

More recently, Nasir et al. [18] found evidence of EKC in Asia, although their results were not statistically significant. Contrarily, the authors of [57] validated the EKC phenomenon in Malaysia. Furthermore, Onafowora and Owoye [58] analyzed the EKC phenomenon in selected economies such as Brazil, Mexico, China, Japan, and South Korea (among others) and only found evidence of EKC in developed economies. Malik et al. [59] studied the case of Pakistan and confirms the EKC hypothesis, and the symmetric results show that economic growth and FDI intensify carbon emission in both the long and short-run and Pakistan is a pollution haven for FDI.

The results of Liu et al. [5] revealed that there is a reverse U-shape relationship be-tween economic growth and carbon dioxide emissions in China, and an inverted N-shaped relationship between FDI and carbon dioxide emissions. However, he suggested reexamining the results by grouping different regions.

Considering the literature, it is possible to infer that the results on the non-linear relationship between economic growth and environmental degradation are still inconclusive [16].

Considering the current literature on economic growth, EKC, and FDI, the following hypotheses were formulated:

**Hypothesis 2 (H2).** *Economic growth presents a non-linear relationship with $CO_2$ emissions;*

**Hypothesis 3 (H3).** *FDI presents a non-linear relationship with $CO_2$ emissions.*

## 3. Data and Method

Our sample includes 592 out of the 645 municipalities in São Paulo state. We excluded 1 municipality for the lack of industry-related data and 52 small-sized municipalities (i.e., averaging 3000 inhabitants each) for the lack of energy-related data. Consequently, the employed sample comprises roughly 99.3% of the state's population. Also, the data ranges from 2010 to 2016, resulting in a seven-year period and 4144 observations.

### *3.1. $CO_2$ Emissions*

This study employs $CO_2$ emissions per capita as the dependent variable. However, a detailed (i.e., municipal-level) $CO_2$ database is not available at this moment. Previous scholars also faced this issue when studying $CO_2$ at a more micro-level. For this reason, we manually calculate the emissions from energy consumption for the municipalities of São Paulo, which is a common procedure in $CO_2$-related studies.

Therefore, we use data on electricity consumption and fossil fuels. Namely, the calculation includes gasoline, diesel, liquefied petroleum gas, fuel oil, aviation gasoline, and aviation kerosene. By following this calculation, this study is aligned with previous research, employing data from the Brazilian Energy Research Office (EPE) and the National Agency for Petroleum, Natural Gas and Biofuels (ANP). Yet, the Brazilian fuel legislature makes it inappropriate to calculate $CO_2$ emission directly. Thus, this study followed the IPCC [60] guidelines and subtracted the volume of ethanol added to gasoline C, which is commonly commercialized in the country, to use gasoline A in our calculations. The volume of biodiesel added to diesel oil was also subtracted.

Finally, the $CO_2$ emissions are calculated using the conversion factors presented in Table 1.

**Table 1.** $CO_2$ conversion factors for various energy sources.

| Type of Energy | Conversion Factor | Description |
|---|---|---|
| Electricity * | 0.0512 (2010); 0.0292 (2011); 0.0653 (2012); 0.096 (2013); 0.1355 (2014); 0.1244 (2015); 0.0817 (2016) | $tCO_2$/Mwh |
| Automotive gasoline | 69.3 | $tCO_2$/TJ |
| Diesel oil | 74.1 | $tCO_2$/TJ |
| Liquefied petroleum gas | 63.1 | $tCO_2$/TJ |
| Fuel oil | 77.4 | $tCO_2$/TJ |
| Aviation gasoline | 70 | $tCO_2$/TJ |
| Aviation kerosene | 71.5 | $tCO_2$/TJ |

Source: Ministry of Science, Technology, Innovation, and Communications (MCTIC) and IPCC (2006). * The Brazilian government considers all electricity sources (i.e., hydro, natural gas, oil, biomass, coal, wind, nuclear, and solar) contributing to the national grid to define the $CO_2$ conversion factor.

### 3.2. Explanatory and Control Variables

This study is interested in better understanding the general effects of the development of São Paulo state on the environment. Accordingly, the regions' GDP per capita is employed as a measure for economic growth, as done by previous $CO_2$-studies [7,61,62]. Although alternative variables (e.g., income levels) could provide valuable information on the overall richness of a region, there is a general consensus on the importance of GDP as the primary measure of how an economy or region is performing.

Additionally, in recent years, FDI received considerable recognition in many $CO_2$-related studies [5,15,62]. However, similar to the $CO_2$-issue presented earlier, São Paulo state does not present a regional FDI database. De facto, there are no governmental statistics on FDI at the state or city-levels [36], and this lack of data virtually explains the current absence of Brazilian studies on FDI and its regional effects, except for Moralles and Moreno [36] and Polloni-Silva et al. [37].

Therefore, we build a proxy for the regional FDI presence in each municipality using export-data from the Brazilian Integrated System of Foreign Trade (SISCOMEX). This sys-tem provides information on all exporting companies operating in São Paulo state, including their names, addresses, and export band value (e.g., up to 1 million BRL, between 1 and 5 million BRL, between 5 and 10 million BRL). With this information, a research group manually verified if these companies presented international origins (i.e., if the headquarters is located in a foreign country). For the whole São Paulo state during the 2010–2016 period, the research group performed approximately 22,000 individual checks. Hence, we follow Moralles and Moreno [36] in building a proxy variable for the intensity of FDI in a region, following Equations (1) and (2) below.

$$FDI_{jt} = W_{jt} \times \left( \frac{MNC_{jt}}{TC_{jt}} \right) \tag{1}$$

And,

$$W_{jt} = \frac{SFE_{jt}}{STE_{jt}} \tag{2}$$

where $FDI$ is the intensity of FDI for every region $j$ at the year $t$, $W$ is the adjustment weight regarding the exports from foreign companies, $MNC$ is the number of multinational companies (i.e., foreign companies), $TC$ is the total number of exporting companies, $k$ is the number of foreign companies, $SFE$ is the sum of exports from foreign companies, and $STE$

is the sum of total exports (including national and foreign companies). The export band values (i.e., 1 million; 5 million; 10 million; 50 million, 100 million, and 320 million) are used to calculate *SFE* and *STE*, similar to Moralles and Moreno [36].

This FDI measure varies from 0 (no foreign companies) to 1 (all exports are dependent upon foreign companies). Thus, this measure represents the intensity of FDI for every municipality in every year of the sample and shows the relative importance of FDI for each region. With this information, our study will be the first to evaluate the municipal-level effects of FDI on the environment in a Brazilian region.

It should be noted that this FDI measure is not perfect as it excludes foreign companies commercializing their products exclusively within the country. However, this measure is arguably a valuable proxy for FDI considering that many foreign companies use Brazil as an export station to other Mercosul (*Mercado Comum do Sul*) countries [63]. As an example, roughly 22% of Paraguay's imports and 24% of Argentina's imports come from Brazil, and these products involve a multitude of industrial sectors (e.g., machinery, chemicals, clothing, cars) [64]. As the SISCOMEX system presents data on all exporting companies from all sectors, our FDI measure is arguably capable of including a considerable share of all foreign companies in the country. Additionally, a similar export-oriented proxy for FDI was already employed by Moralles and Moreno [36] and Polloni-Silva et al. [37].

Furthermore, regarding the control variables, previous scholars have employed a multitude of demographic, economic, and technology-related variables in previous studies. For this study, the models include the industrial and service sectors' share of total GDP, the share of electricity consumption in total consumption, and the population density. Therefore, our model is similar to previous employed models [9,61,62,65]. Table 2 presents the descriptive statistics and the sources used.

**Table 2.** Descriptive statistics and variables description.

| Variable | Description | Source | Observations | Mean | S.D. | Min. | Max. |
|---|---|---|---|---|---|---|---|
| $CO_2$ | $CO_2$ per capita (tons) | - | 4144 | 2.055 | 2.540 | 0.105 | 34.413 |
| GDPPC | GDP per capita (2010 values; given in 1000 BRL) | Brazilian Institute of Geography and Statistics (IBGE) | 4144 | 20.197 | 16.578 | 4.780 | 278.840 |
| FDI | Foreign Direct Investment | - | 4144 | 0.046 | 0.144 | 0.000 | 1.000 |
| IND | Industrial sector (value added to total GDP; %) | IBGE | 4144 | 19.365 | 13.303 | 2.224 | 85.966 |
| SERV | Service sector (value added to total GDP; %) | IBGE | 4144 | 39.147 | 11.086 | 7.412 | 75.640 |
| RES | Share of residential electricity consumption in total consumption (%) | Secretary of Energy and Mining of the State of São Paulo | 4144 | 34.679 | 12.072 | 0.177 | 66.417 |
| DENS | Population density (population per square kilometer) | IBGE | 4144 | 342.577 | 1301.545 | 3.698 | 13,534.820 |

### 3.3. Explanatory and Control Variables

We start the analysis by verifying the linear effects of the explanatory variables on the regions' $CO_2$ emissions. Thus, the primary model can be written as:

$$\ln CO2_{jt} = \beta_0 + \beta_1 \ln GDPPC_{jt} + \beta_2 FDI_{jt} + \beta_3 \ln{}' \mathbf{X}_{jt} + a_j + e_{jt} \quad (3)$$

where $CO_2$ is the dependent variable for every municipality $j$ at time $t$, $GDPPC$ is the real GDP per capita, $FDI$ is the aforementioned proxy for regional FDI intensity, $\mathbf{X}$ is the set of control variables, $a_j$ is the regional fixed effect, and $e$ is the error term. All variables are employed in their natural-log form, except for $FDI$ as the variable is already in percentage form. In addition to the linear effects of the other explanatory variables, this model formulation allows us to verify if FDI presents a pollution-haven or pollution-halo behavior.

However, this study also aims to test for possible non-linear relationships between economic growth, FDI, and $CO_2$ emissions. Thus, by following many previous scholars, we add quadratic terms to our model:

$$\ln CO_{2_{jt}} = \beta_0 + \beta_1 \ln GDPPC_{jt} + \beta_2 \ln GDPPC_{jt}^2 + \beta_3 FDI_{jt} + \beta_4 \ln{}' \mathbf{X}_{jt} + a_j + e_{jt} \quad (4)$$

And,

$$\ln CO_{2_{jt}} = \beta_0 + \beta_1 \ln GDPPC_{jt} + \beta_2 FDI_{jt} + \beta_3 FDI_{jt}^2 + \beta_4 \ln{}' \mathbf{X}_{jt} + a_j + e_{jt} \quad (5)$$

with these models, it is possible to test for U or inverted-U curves between GDP, FDI, and the $CO_2$ emissions, thus verifying the existence of EKC curves and better understanding how future development may affect the environment if São Paulo continues to grow and attract foreign investments.

Furthermore, it is necessary to consider possible non-spherical disturbances that are commonly found in panel datasets. Initially, we verified if our baseline models present collinearity issues (see Appendix A), which is a common issue in environmental studies [66]. Moreover, the Hausman test was employed to examine which specification (i.e., random or fixed-effects) was better suited for our models. Additionally, the modified Wald test for group-wise heteroscedasticity [67], the Wooldridge test for autocorrelation [68], and the Pesaran test for cross-sectional dependence [69] were used. In sum, these tests' results show that the fixed-effects model was the preferable specification and that the sample shows heteroscedasticity, autocorrelation, and cross-sectional dependence problems.

To deal with these issues, $CO_2$-studies have been using the Driskoll–Kraay [70] estimator [9,61,71], as this technique deals with heteroscedasticity and autocorrelation problems and is robust to general forms of cross-sectional (spatial) and temporal dependence with panels of all sizes, including an N > T dataset [72]. Therefore, the fixed-effects Driscoll–Kraay (DK) estimator is the main technique employed in the analyses. Yet, the sam-ple is limited as a higher time frame is not available at the moment. Thus, to take ad-vantage of the higher degrees of freedom as the random-effects specification has, the Feasible Generalized Least Squares (FGLS) technique was employed to double-check our findings. FGLS is usually a random-effects estimator capable of dealing with heterosce-dasticity, autocorrelation, and cross-sectional correlation [68,73].

## 4. Main Results

Our main findings are presented in Table 3, which shows the linear and quadratic relationships between our explanatory variables and the regions' $CO_2$ emissions. As shown, economic growth increases $CO_2$ emissions, as expected. Moreover, Table 3 shows that a non-linear relationship between GDP per capita and $CO_2$ emissions exists, as the quadratic term for GDP per capita is significant and negative. Thus, Table 3 suggests that after a certain threshold, the overall growth/richness of a region, here represented by the GDP per capita, helps to decrease the emission level.

Additionally, FDI has a linear and negative relationship with $CO_2$ emissions, which indicates that FDI presents a pollution-halo behavior. Thus, these results are aligned with some previous studies defending the pollution-halo hypothesis for FDI such as Jiang et al. [74], Zhang and Zhou [25], and Shao et al. [46]. Indeed, FDI seems to be environmentally beneficial to the region. Furthermore, a non-linear relationship between FDI and $CO_2$ is not found, as the quadratic term is not significant. Yet, before declaring support for any hypothesis, further tests will be made.

**Table 3.** DK and FGLS estimations for the whole sample.

| **Variables** | **(1)** | **(2)** | **(3)** | **(4)** | **(5)** | **(6)** |
|---|---|---|---|---|---|---|
| | **DK** | **FGLS** | **DK** | **FGLS** | **DK** | **FGLS** |
| GDPPC | 0.309 *** | 1.372 ** | 0.901 *** | 5.518 ** | 0.308 *** | 0.913 *** |
| | (0.0251) | (0.685) | (0.120) | (2.457) | (0.0252) | (0.306) |
| GDPPC$^2$ | | | −0.0916 *** | −0.729 ** | | |
| | | | (0.0164) | (0.348) | | |
| FDI | −0.0614 * | −2.563 ** | −0.0553 * | −0.636 | −0.00806 | −2.278 |
| | (0.0336) | (1.265) | (0.0319) | (1.177) | (0.0975) | (9.335) |
| FDI$^2$ | | | | | −0.0551 | 0.324 |
| | | | | | (0.0762) | (9.171) |
| IND | 0.0458 *** | 1.340 ** | 0.0427 ** | 0.607 | 0.0459 *** | 1.721 *** |
| | (0.0138) | (0.535) | (0.0182) | (0.477) | (0.0137) | (0.591) |
| SERV | 0.503 *** | 2.033 ** | 0.489 *** | −0.584 | 0.503 *** | 1.662 ** |
| | (0.0872) | (0.859) | (0.0985) | (1.020) | (0.0871) | (0.784) |
| RES | −0.221 *** | −0.250 | −0.218 *** | −0.152 | −0.221 *** | 1.383 |
| | (0.0381) | (0.364) | (0.0390) | (0.328) | (0.0380) | (1.409) |
| DENS | 0.990 ** | −1.376 * | 1.048 *** | −0.0203 | 0.988 ** | −0.947 |
| | (0.401) | (0.778) | (0.403) | (0.736) | (0.401) | (0.638) |
| Constant | −5.800 *** | −7.787 ** | −6.909 *** | −7.523 * | −5.792 *** | −13.43 * |
| | (2.130) | (3.648) | (2.270) | (4.055) | (2.128) | (7.236) |
| F | 228.10 *** | | 193.48 *** | | 728.43 *** | |
| Wald Chi2 | | 33.97 *** | | 27.99 *** | | 41.45 *** |
| Hausman | 117.64 *** | | 200.59 *** | | 114.69 *** | |
| Mod. Wald. | 190,000 *** | | 200,000 *** | | 190,000 *** | |
| Wooldridge | 343.60 *** | | 328.73 *** | | 340.18 *** | |
| Pesaran | 294.31 *** | | 290.91 *** | | 294.45 *** | |
| Observations | 4144 | 4144 | 4144 | 4144 | 4144 | 4144 |
| Municipalities | 592 | 592 | 592 | 592 | 592 | 592 |

*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$. Standard errors in parentheses. DK: Fixed-effects regression with Driscoll–Kraay standard errors. FGLS: Feasible Generalized Least Squares.

Regarding the control variables, Table 3 shows that both the industrial and the service sectors contribute to higher emission levels. Again, this demonstrates that economic growth is environmentally costly. The results demonstrate that the industrial sector is positive and significant, while FDI is negative and significant. Thus, the overall industrial sector increases the emission levels, while a higher FDI intensity is beneficial.

Likewise, the service sector, which is ignored by many scholars, also increases pollution. This result is expected considering that the $CO_2$ measure employed by our study is calculated using energy consumption. De facto, the service sector is expanding in the region, and many services, particularly in highly urbanized regions, involve road transportation, which generates higher levels of pollution [75]. In addition, a higher share of residential electricity consumption in the total consumption presents negative coefficients, indicating that higher shares of consumption by other sectors (e.g., industry) result in higher $CO_2$ than the residential sector. In other words, the impact from the residential sector is lower than other sectors. Also, regions with higher population density levels present higher emissions, as these regions are arguably larger and more populated.

To further evaluate if the results from Table 3 are reliable, we split the sample into subsamples. First, we estimated the models exclusively with the municipalities with foreign companies operating during the 2010–2016 period, therefore excluding smaller (i.e., less populated/developed) regions. Moreover, we excluded the city of São Paulo and the São Paulo metropolitan region, as these municipalities represent significantly well-developed and populated regions. São Paulo city and its neighborhood are responsible for a significant share of the state's GDP and $CO_2$ emissions and therefore represent dissident regions compared to the rest of the state. In sum, results from Table 4 confirm the effects of GDP and FDI on the environment and are aligned with Table 3.

**Table 4.** DK estimations for the sub-samples.

| Variables | Municipalities with FDI during the 2010–16 Period | | | Excluding São Paulo City | | | Excluding São Paulo Metropolitan Region | | |
|---|---|---|---|---|---|---|---|---|---|
| | (7) | (8) | (9) | (10) | (11) | (12) | (13) | (14) | (15) |
| GDPPC | 0.182 *** | 1.714 *** | 0.180 *** | 0.182 *** | 1.714 *** | 0.179 *** | 0.210 *** | 2.048 *** | 0.207 *** |
| | (0.0477) | (0.125) | (0.0465) | (0.0477) | (0.125) | (0.0464) | (0.0524) | (0.280) | (0.0506) |
| $GDPPC^2$ | | −0.214 *** | | | −0.214 *** | | | −0.254 *** | |
| | | (0.0229) | | | (0.0230) | | | (0.0418) | |
| FDI | −0.120 *** | −0.123 *** | 0.0884 | −0.120 *** | −0.123 *** | 0.0886 | −0.120 *** | −0.125 *** | 0.102 |
| | (0.0324) | (0.0305) | (0.0841) | (0.0324) | (0.0305) | (0.0844) | (0.0324) | (0.0310) | (0.0892) |
| $FDI^2$ | | | −0.211 *** | | | −0.211 *** | | | −0.221 *** |
| | | | (0.0740) | | | (0.0742) | | | (0.0841) |
| IND | 0.00849 | −0.00715 | 0.00931 | 0.00822 | −0.00755 | 0.00907 | 0.0127 | 0.000710 | 0.0149 |
| | (0.0342) | (0.0420) | (0.0329) | (0.0348) | (0.0427) | (0.0335) | (0.0384) | (0.0474) | (0.0377) |
| SERV | 0.234 *** | 0.218 *** | 0.228 *** | 0.234 *** | 0.218 *** | 0.229 *** | 0.309 *** | 0.307 *** | 0.302 *** |
| | (0.0616) | (0.0478) | (0.0632) | (0.0617) | (0.0484) | (0.0633) | (0.0772) | (0.0471) | (0.0791) |
| RES | −0.0748 *** | −0.0720 *** | −0.0752 *** | −0.0744 *** | −0.0717 *** | −0.0748 *** | −0.0669 *** | −0.0648 *** | −0.0667 *** |
| | (0.0148) | (0.0145) | (0.0145) | (0.0149) | (0.0145) | (0.0146) | (0.0171) | (0.0170) | (0.0169) |
| DENS | 0.726 | 0.782 | 0.726 | 0.722 | 0.779 | 0.722 | 0.565 | 0.623 | 0.560 |
| | (0.657) | (0.605) | (0.654) | (0.657) | (0.605) | (0.653) | (0.682) | (0.613) | (0.676) |
| Constant | −4.993 | −7.883 ** | −4.985 | −4.951 | −7.840 ** | −4.942 | −4.074 | −7.569 ** | −4.041 |
| | (3.939) | (3.741) | (3.910) | (3.928) | (3.729) | (3.898) | (3.684) | (3.703) | (3.647) |
| F | 51.36 *** | 1189.08 *** | 14.29 *** | 50.86 *** | 1189.18 *** | 55.28 *** | 23.90 *** | 1329.63 *** | 10.30 *** |
| Hausman | 63.40 *** | 37.74 *** | 78.87 *** | 62.50 *** | 32.85 *** | 77.97 *** | 43.59 *** | 93.89 *** | 61.90 *** |
| Mod. Wald. | 4516 *** | 18185 *** | 4584 *** | 4503 *** | 18120 *** | 4576 *** | 4067 *** | 9411 *** | 4344 *** |
| Wooldridge | 58.98 *** | 47.52 *** | 58.76 *** | 58.67 *** | 47.29 *** | 58.45 *** | 56.56 *** | 43.60 *** | 56.77 *** |
| Pesaran | 128.97 *** | 120.66 *** | 128.38 *** | 127.32 *** | 119.04 *** | 126.74 *** | 94.41 *** | 87.71 *** | 93.73 *** |
| Observations | 1001 | 1001 | 1001 | 994 | 994 | 994 | 784 | 784 | 784 |
| Municipalities | 143 | 143 | 143 | 142 | 142 | 142 | 112 | 112 | 112 |

*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$. Standard errors in parentheses. DK: Fixed-effects regression with Driscoll-Kraay standard errors. Sub-sample 1: only municipalities with FDI during the whole time period. Sub-sample 2: São Paulo city excluded. Sub-sample 3: São Paulo metropolitan region excluded.

The results from Table 4 confirm the findings in Table 3. In sum, GDP seems to present a non-linear relationship with $CO_2$. An inverted U-shaped relationship between GDP and $CO_2$ seems to represent the Brazilian reality similar to the original Simon Kuznets [76] curve. Moreover, FDI is, again, linear and negatively associated with emissions, thus being environmentally beneficial. Once more, before declaring support for the hypotheses, we perform robustness checks.

## 5. Robustness Checks

The robustness checking section is twofold. First, we verify if endogeneity is an issue. Second, we evaluate if a non-linear relationship is significant using the threshold regression technique, as some scholars presented criticism towards the use of quadratic varia-bles to test for non-linearity.

The main explanatory variables (GDP per capita and FDI) were tested for endogeneity. Sustainability studies showed that economic growth and environmental degradation may suffer from simultaneity problems. Additionally, the international business literature argues that foreign companies do not choose their subsidiaries' locations randomly. Foreign firms may be attracted to some of the host's characteristics [26]. If foreign firms are choosing to invest in more developed regions, and these regions generate more pollution, then the model may suffer from reverse causality.

Therefore, the C-statistic test (also known as the difference-in-Sargan test) was employed to verify endogeneity issues [77] and we employed the lagged values as instruments, following Yue et al. [78] and Song [79]. Previous scholars argue that finding instruments to employ in $CO_2$-related studies is difficult, but defend that past outputs should not impact present emissions. Therefore, one-year lagged values of GDP per capita and FDI were used. Results (see Appendix B) show that FDI is exogenous, but endogeneity is significant for GDP per capita.

To mitigate this issue, we employed the Limited Information Maximum Likelihood (LIML) estimation technique. Previous studies commented that the LIML technique is better than the traditional Two-Stages Least Squares (2SLS) technique, and more capable of ensuring consistency and asymptotic normality [80]. LIML presents good results even in smaller samples [81] and reduces the bias of the estimations [82].

The results presented in Table 5 demonstrate that our linear results are consistent, as they are aligned with the previous estimations in Table 3. GDP per capita is positively associated with $CO_2$ emissions. Conversely, FDI is negatively associated with emissions.

Furthermore, there is the issue of possible non-linear relationships between our explanatory variables and $CO_2$ emissions. Previously, we employed the quadratic forms of GDP and FDI in the models, as it is done by the majority of EKC studies [7,15,62]. Recently, however, scholars have commented on the limitations of this method. Girma [83] argues that, although the quadratic specification tends to be more informative than the linear model, it establishes a very specific functional form on the non-linearity that may not be a good representation of the pattern in the data. He and Yao [16] pointed out that, although EKC is traditionally measured in quadratic or even cubic forms, this specification is arbitrary and subjective. For these reasons, scholars are now using more novel methods such as nonparametric regressions and the Non-linear Autoregressive Distributed Lag (NARDL) in non-linear studies [84]. Particularly, the threshold regression is being employed by $CO_2$-related studies [16,85,86].

Thus, this study also investigates the non-linear behavior of the variables using the fixed-effect panel threshold regression proposed by Hansen [87] as presented in Equations (6) and (7).

$$\ln CO_{2_{jt}} = \beta_0 + \beta_1 \ln GDPPC_{jt}\, I\big(GDPPC_{jt} \le \lambda\big) + \beta_2 \ln GDPPC_{jt}\, I(GDPPC_{jt} > \lambda) + \beta_3 FDI_{jt} + \beta_4 \ln{}' \mathbf{X}_{jt} + a_j + e_{jt} \quad (6)$$

And,

$$\ln CO_{2_{jt}} = \beta_0 + \beta_1 \ln FDI_{jt}\, I\big(FDI_{jt} \le \lambda\big) + \beta_2 \ln FDI_{jt}\, I(FDI_{jt} > \lambda) + \beta_3 GDPPC_{jt} + \beta_4 \ln{}' \mathbf{X}_{jt} + a_j + e_{jt} \quad (7)$$

where $I(\cdot)$ is an indicator function. We follow Girma [83] and employ a set of quantiles (1%, 1.25%, 1.50%, ... , 98.75%; 99%) to estimate the threshold parameter (λ). Then, we test the null hypothesis of no non-linearity ($H_0$: $\beta_1 = \beta_2$) using the likelihood ratio test statistics and their bootstrapped $p$-values.

Table 6 shows that a non-linear relationship is only significant for the GDP–$CO_2$ relationship, with one significant threshold point.

**Table 5.** LIML estimations.

| Variables | Whole Sample | | | Municipalities with FDI during the 2010–16 Period | | | Excluding São Paulo City | | | Excluding São Paulo Metropolitan Region | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | (16) | (17) | (18) | (19) | (20) | (21) | (22) | (23) | (24) | (25) | (26) | (27) |
| GDPPC † | 0.526 *** | 1.356 ** | 0.527 *** | 0.696 ** | 0.649 | 0.696 ** | 0.695 ** | 0.649 | 0.696 ** | 1.002 ** | 0.785 | 1.002 ** |
| | (0.105) | (0.592) | (0.106) | (0.289) | (0.552) | (0.290) | (0.290) | (0.552) | (0.290) | (0.504) | (0.596) | (0.505) |
| $GDPPC^{2}$ † | | −0.127 | | | 0.00735 | | | 0.00733 | | | 0.0253 | |
| | | (0.115) | | | (0.118) | | | (0.118) | | | (0.106) | |
| FDI | −0.0989 ** | −0.130 ** | −0.169 | −0.139 * | −0.136 * | −0.0115 | −0.139 * | −0.135 * | −0.0106 | −0.168 * | −0.151 * | −0.118 |
| | (0.0451) | (0.0567) | (0.153) | (0.0783) | (0.0821) | (0.207) | (0.0782) | (0.0821) | (0.207) | (0.0899) | (0.0841) | (0.244) |
| $FDI^{2}$ | | | 0.0712 | | | −0.128 | | | −0.128 | | | −0.0485 |
| | | | (0.144) | | | (0.183) | | | (0.183) | | | (0.207) |
| IND | −0.00756 | −0.0952 | −0.00779 | 0.0155 | 0.0128 | 0.0170 | 0.0154 | 0.0126 | 0.0168 | 0.0517 | 0.0342 | 0.0524 |
| | (0.0240) | (0.0826) | (0.0241) | (0.0746) | (0.0680) | (0.0748) | (0.0749) | (0.0683) | (0.0751) | (0.106) | (0.0811) | (0.106) |
| SERV | 0.551 *** | 0.980 *** | 0.552 *** | 0.454 * | 0.433 | 0.452 * | 0.454 * | 0.433 | 0.453 * | 0.759 * | 0.636 | 0.758 * |
| | (0.0796) | (0.320) | (0.0799) | (0.255) | (0.304) | (0.256) | (0.256) | (0.305) | (0.257) | (0.404) | (0.406) | (0.406) |
| RES | −0.237 *** | −0.254 *** | −0.237 *** | −0.0940 *** | −0.0928 *** | −0.0939 *** | −0.0934 *** | −0.0922 *** | −0.0933 *** | −0.0952 *** | −0.0893 *** | −0.0951 *** |
| | (0.0706) | (0.0773) | (0.0706) | (0.0256) | (0.0280) | (0.0257) | (0.0256) | (0.0280) | (0.0256) | (0.0277) | (0.0277) | (0.0278) |
| DENS | 0.450 *** | 0.0114 | 0.452 *** | 0.246 | 0.245 | 0.245 | 0.240 | 0.239 | 0.239 | −0.0767 | −0.0434 | −0.0781 |
| | (0.164) | (0.416) | (0.165) | (0.339) | (0.327) | (0.340) | (0.340) | (0.327) | (0.340) | (0.453) | (0.407) | (0.453) |
| F | 17.59 *** | 10.56 *** | 15.17 *** | 3.19 *** | 4.28 *** | 2.98 *** | 3.17 *** | 4.26 *** | 2.97 *** | 2.24 ** | 3.17 *** | 2.09 ** |
| Observations | 3552 | 3552 | 3552 | 858 | 858 | 858 | 852 | 852 | 852 | 672 | 672 | 672 |
| Municipalities | 592 | 592 | 592 | 143 | 143 | 143 | 142 | 142 | 142 | 112 | 112 | 112 |

*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$. Standard errors in parentheses. † Predicted using one-year lagged values as instruments.

**Table 6.** Test results for the threshold effects.

| Variables | Threshold | RSS | MSE | *F* | *p*-Value |
|---|---|---|---|---|---|
| GDPPC | Single (λ1) | 154.769 | 0.037 | 20.300 | 0.077 |
| | Double (λ2) | 154.374 | 0.037 | 10.580 | 0.340 |
| | Triple (λ3) | 154.037 | 0.037 | 9.050 | 0.573 |
| GDPPC † | Single (δ1) | 102.709 | 0.029 | 24.930 | 0.054 |
| | Double (δ2) | 102.410 | 0.028 | 10.350 | 0.636 |
| | Triple (δ3) | 102.186 | 0.028 | 7.780 | 0.858 |
| FDI | Single (ϕ1) | 155.377 | 0.038 | 4.040 | 0.773 |
| | Double (ϕ2) | 155.250 | 0.038 | 3.370 | 0.760 |
| | Triple (ϕ3) | 155.178 | 0.038 | 1.920 | 0.937 |

† Predicted using one-year lagged values as instruments.

Therefore, the threshold tests confirm the linear relationship between FDI and $CO_2$, and FDI seems to be negatively associated with emissions. Therefore, the results support H1a and reject H1b.

Table 7 shows the estimated coefficients for GDP following two distinct regimes: lower and higher levels of GDP. These results suggest that, indeed, there is a non-linear relationship between GDP and $CO_2$. After the threshold point, the impact of GDP on the environment is lower, meaning that richer regions (i.e., more developed) tend to have a smaller environmental impact, which is beneficial to the region.

**Table 7.** Panel threshold estimations.

| Variables | (28) | (29) |
|---|---|---|
| GDPPC (≤λ1) | 0.351 *** | |
| | (0.0543) | |
| GDPPC (>λ1) | 0.307 *** | |
| | (0.0508) | |
| GDPPC † (≤δ1) | | 0.636 *** |
| | | (0.117) |
| GDPPC † (>δ1) | | 0.574 *** |
| | | (0.108) |
| FDI | −0.0585 | −0.0874 |
| | (0.0792) | (0.0581) |
| IND | 0.0456 * | 0.0536 ** |
| | (0.0247) | (0.0209) |
| SERV | 0.493 *** | 0.279 *** |
| | (0.0655) | (0.0483) |
| RES | −0.218 ** | −0.222 ** |
| | (0.0952) | (0.104) |
| DENS | 1.022 *** | 0.753 *** |
| | (0.211) | (0.197) |
| Constant | −6.018 *** | −4.925 *** |
| | (0.711) | (0.718) |
| F | 23.47 *** | 13.33 *** |
| Observations | 4144 | 3552 |
| Municipalities | 592 | 592 |

*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$. Robust standard errors in parentheses. † Predicted using one-year lagged values as instruments.

Nonetheless, the threshold regression does not support the EKC hypothesis, as GDP still presents positive effects in both regimes. Hence, Table 7 shows support for H2 and rejects H3. São Paulo state does not present the inverted-U curve that European [88] and Asian [5,7,62] regions present. In sum, the GDP–$CO_2$ relationship is not linear or quadratic. The policy implications of these findings will be discussed in the next section.

## 6. Conclusions and Policy Implications

The findings show that the relationship between economic growth and emissions is environmentally costly and non-linear. To some extent, GDP increases $CO_2$ emissions, which corroborates with previous studies' understanding [21,89]. Other studies proposed an inverted U-shape curve between economic growth and emissions [5,8,15,19]. Our study contributes by showing that GDP is non-linear with $CO_2$ emissions, although this relationship did not present the U-shape form previously proposed. In this sense, we found that GDP becomes less environmentally damaging after a certain threshold point. This result supports hypothesis 2 (*H2: Economic growth presents a non-linear relationship with $CO_2$ emissions*).

Additionally, the results reveal a negative impact of FDI on $CO_2$ emissions, therefore supporting hypothesis 1 (*H1a: FDI is negatively associated with $CO_2$ emissions*). This result corroborates with previous studies that advocate in favor of FDI to reduce pollutant emissions [6,21,23,78]. In contrast, our main finding presents evidence against studies arguing that foreign investments increase environmental damage [7,8,16,19,62,90]. The dataset we employed shows that the majority of foreign companies operating in São Paulo state have origins in developed economies (e.g., United States, Germany, and Japan), and are operating in medium and high-tech sectors (e.g., cars, energy, mobile technologies, and electronics). Therefore, the negative impact of FDI on $CO_2$ emissions might result from multinational companies with green practices and higher levels of productivity. This is relevant because public authorities in developing regions must create specific policies to attract international enterprises to generate green growth conditions. We argue that FDI must be one of the major drivers to promote economic growth along with sustainable development.

There are two main useful contributions for policymakers. First, the non-linear effect of GDP on emissions might encourage public authorities to find alternative economic growth strategies. Arguably, local policymakers have an essential role in boosting economic growth while reducing power consumption, as energy policies should be managed at the local level [91]. Second, FDI is an essential policy tool to create green development paths in Sao Paulo state. In this sense, local policies must focus on strategies to attract green technologies [92], clean energy sources [93], green jobs and products [94], and higher productivity [95]. Note that FDI is crucial to promote economic growth because it guarantees access to foreign firms' knowledge and technologies to transform the economic structure. For example, the industry is a relevant sector to the Sao Paulo region. Public authorities could reduce taxes to national and multinational companies that emit less $CO_2$. A tax policy could also lead green companies to regions that are already presenting higher levels of $CO_2$, such as the Sao Paulo city and densely populated regions [96]. New firms might also create local new jobs, increase the local income, and generate green economic growth paths. This new cycle would generate development with lower $CO_2$ emissions. Besides, alternative transport policies are required in metropolitan areas, such as efficient public transport for passengers, vehicle utilization improvements, and fuel efficiency to reduce pollutant emissions [75,97]. The public sector might invest in environmental projects to develop national green products, such as photovoltaic cells, smart grids, bioplastics, among others [98]. Also, the vast regions in Sao Paulo countryside could focus on alternative energy resources [99], such as the electric energy from sugarcane mills or by building photovoltaic power plants.

Noteworthy, Sao Paulo is the most developed state in Brazil. It means that Sao Paulo has adequate infrastructure (roads, railways, ports, and airports) to connect the region with the entire world. Also, Sao Paulo presents one of the highest human development in Brazil, which is crucial to create human capital (education, health, income, among others). These conditions favor the attraction of FDI to Sao Paulo state. Other emerging regions may use the policy recommendations presented here to facilitate their development.

Finally, some limitations of this study are expected to open multiple avenues for future research. First, this study measures $CO_2$ emissions through consumption. Future studies are encouraged to examine the impact of FDI and GDP on other types of emissions (e.g., sulfur dioxide emissions ($SO_2$), air quality, or ecological footprint). Second, this study did not verify how renewable and non-renewable energy sources can individually affect São Paulo state's emissions. Third, we did not control the effect of economic structure and the type of FDI on pollution.

Despite these limitations, this study contributes to the literature on growth, foreign investments, and $CO_2$ emissions. As previously described, there is no consensus on the effects of growth and FDI on the environment, particularly in emerging economies. To the best of our knowledge, this is the first study to apply Brazilian regional FDI data to better comprehend its environmental consequences. To perform such an analysis, a handmade and unique dataset was built, and more novel econometric techniques were employed. Our findings have important policy implications and are arguably capable of guiding future research in developing regions.

**Author Contributions:** Conceptualization, E.P.-S., H.F.M. and D.A.d.N.R., writing—original draft preparation, E.P.-S., D.F., F.d.C.C., and H.F.M.; methodology and software, E.P.-S. and H.F.M.; writing—review and editing, D.A.d.N.R. and E.P.-S.; project administration, H.F.M. All authors have read and agreed to the published version of the manuscript.

**Funding:** This study was financed in part by the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior—Brasil (CAPES). This study was also supported by the São Paulo Research Foundation (FAPESP) (Process no. 2019/19905-0). The first author acknowledges the financial support from the Brazilian National Council for Scientific and Technological Development (CNPq, 140263/2020-9).

**Institutional Review Board Statement:** Not applicable.

**Informed Consent Statement:** Not applicable.

**Data Availability Statement:** Data will be made available upon reasonable request, following the embargo period on the FDI-related dataset, which will make the dataset publicly available on 30/11/2023.

**Conflicts of Interest:** The authors declare no conflict of interest.

## Appendix A

**Table A1.** Variance Inflation Factor (VIF).

| Variables | Whole Sample | | Municipalities with FDI during the 2010–16 Period | | Excluding São Paulo City | | Excluding São Paulo Metropolitan Region | |
|---|---|---|---|---|---|---|---|---|
| | VIF | 1/VIF | VIF | 1/VIF | VIF | 1/VIF | VIF | 1/VIF |
| GDPPC | 1.850 | 0.541 | 1.330 | 0.752 | 1.330 | 0.752 | 1.550 | 0.645 |
| FDI | 1.090 | 0.917 | 1.140 | 0.877 | 1.140 | 0.877 | 1.130 | 0.885 |
| IND | 1.810 | 0.552 | 1.750 | 0.571 | 1.740 | 0.575 | 1.860 | 0.538 |
| SERV | 1.500 | 0.667 | 2.050 | 0.488 | 2.200 | 0.455 | 2.200 | 0.455 |
| RES | 1.390 | 0.719 | 1.580 | 0.633 | 1.570 | 0.637 | 1.530 | 0.654 |
| DENS | 1.720 | 0.581 | 1.140 | 0.877 | 1.260 | 0.794 | 1.400 | 0.714 |
| Mean | 1.560 | - | 1.520 | - | 1.510 | - | 1.610 | - |

## Appendix B

**Table A2.** Endogeneity tests.

| Variable | Sample | C-Statistic | *p*-Value | Result |
|---|---|---|---|---|
| GDPPC | Whole sample | 12.442 | 0.0004 | Endogenous |
| | Municipalities with FDI during the 2010–16 period | 5.741 | 0.0166 | Endogenous |
| | Excluding São Paulo city | 5.713 | 0.0168 | Endogenous |
| | Excluding São Paulo metropolitan region | 5.917 | 0.0150 | Endogenous |
| FDI | Whole sample | 0.096 | 0.7571 | Exogenous |
| | Municipalities with FDI during the 2010–16 period | 0.008 | 0.9299 | Exogenous |
| | Excluding São Paulo city | 0.008 | 0.928 | Exogenous |
| | Excluding São Paulo metropolitan region | 0.843 | 0.3584 | Exogenous |

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