IMPACTO DOS PROJETOS DE ABATE DE METANO DO MECANISMO DE DESENOLVIMENTO LIMPO PARA OS OBJETIVOS DE DESENVOLVIMENTO SUSTENTÁVEL NO BRASIL
IMPACT OF CLEAN DEVELOPMENT MECHANISM METHANE AVOIDANCE PROJECTS TO SUSTAINABLE DEVELOPMENT GOALS IN BRAZIL

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Resumo
O Mecanismo de Desenvolvimento Limpo (MDL) foi criado para reduzir as emissões globais de gases de efeito estufa a baixo custo, permitindo que países desenvolvidos implementem projetos em países em desenvolvimento. O Brasil é o terceiro maior país em relação à implementação de projetos de MDL. O setor de metano evitado, principalmente responsável pela produção de suínos, é o mais lucrativo em termos de RCE e número de projetos. Assim, o estudo tem como objetivo avaliar a contribuição de projetos MDL de prevenção de metano para o desenvolvimento sustentável em municípios brasileiros usando uma abordagem Diferença em Diferença. Os dados utilizados consistiram em uma amostra de 291 municípios, sendo 148 em tratamento e 143 servindo como grupo controle. Os resultados mostraram que há um efeito decrescente nas emissões de manejo de dejetos animais para os municípios que foram beneficiados com projetos de MDL durante 2006 e 2016.
Palavras-chave: Diferença-em-Diferenças. Gases de efeito estufa. Desenvolvimento sustentável.

Abstract
The Clean Development Mechanism (CDM) was created to reduce global greenhouse gas emissions at low cost by allowing developed countries to implement projects in developing countries. Brazil is the third largest country in respect to CDM project implementation. The methane avoidance sector, mostly accounted for swine production is the most lucrative in terms of CER and number of projects. Thus, the study aims to evaluate the contribution of CDM methane avoidance projects to sustainable development in Brazilian municipalities using a Difference-in-Difference approach. The data used consisted in a sample of 291 municipalities, with 148 receiving treatment and 143 serving as a control group. The results showed that there is a decreasing effect on animal waste management emissions for the municipalities that were benefited with CDM projects during 2006 and 2016.
Key words*: Difference-in-differences. Greenhouse gases. Sustainable development.*

1. Introduction

The Clean Development Mechanism (CDM) is one of the economic instruments created under the Climate Convention, by the Kyoto Protocol, with the aim of reducing global greenhouse gas (GHG) emissions at low cost. The Protocol established that developed countries could partially comply with their emission targets by implementing projects in developing countries, that would be the low-cost mechanism (UNEP, 2005).

CDM has several stages in which a project is designed. The host government states its national approval, validation and registration, monitoring, verification/certification and issuance of Certified Emission Reductions (CER). The impact of CDM is way beyond emission reduction. The way in which it is promoted can promote the development growth by the generation of employment, transference of technologies, reduction of poverty, etc. It also has a unique financing source, where it can receive funding from both government and foreign sources, primarily subsidized by corporations. This financing approach reduces the burden on the government budget while enabling companies to play a significant role in the CDM process. According to Luedemann et al. (2023), the government source is responsible for only a small portion of the total budget for CDM projects.

Brazil is the third largest country regarding the number of registered CDM projects. Mori-Clement (2019) and Luedemann et al. (2023) point out the importance of CDM projects to the methane avoidance agenda, both for the number Certified Emission Reduction (CER) issued and also for the high number of projects implemented, second only to energy projects. Luedemann et al. (2023) argue that there was a greater abatement from Certified Emission Reduction revenue through methane avoidance projects compared to other types of projects. The implementation of CDM projects across Brazil may have the potential to contribute to the design and development of a methane credit market proposed by the Ministry of Environment in 2022. Such grant would represent a technology transfer in line with the designs of CDM frameworks.

The authors additionally note a distinct feature regarding methane avoidance CDM projects, which is the uniformity in the types of methodologies that are implemented. Specifically, all executed projects focus on swine production and manage manure waste through the production of biogas, including many alternatives such as biodigesters, anaerobic digestion, etc.

Given the importance of CDM projects in Brazil, especially swine production, we aim to evaluate the contribution of CDM methane avoidance projects to sustainable development in Brazilian municipalities. For that, we implemented a Difference-in-difference (DiD) approach using an individual-level panel data (2006 to 2016) with propensity score matching to correct parallel trends assumption and evaluate the three dimensions of sustainable development (economic, social and environmental) during the years of 2006 and 2016.

2. Literature review

Several authors have explored the impacts of CDM through different methodologies. For instance, Zhang and Wang (2011) conducted an econometric analysis of CDM effects on sulfur dioxide emissions in China, but found no statistically significant impact. Xie et al. (2014) used an input-output model to evaluate the employment impacts of CDM projects in China and found that although some projects caused direct job losses, they also created a significant number of indirect jobs, especially in the solar sector. However, the results of these studies may not be generalizable to other contexts, such as Brazil.

Mori-Clement (2019) observed that CDM projects contributed to the creation of new jobs, especially hydropower initiatives, which had a positive impact in poverty alleviation in the municipalities where the projects were implemented. The author implemented a Difference-in-Difference model using data from registered CDM projects in Brazil. The outcome variables for Brazil included Municipal Human Development Index: Overall MHDI (UNDP), Municipal Human Development Index: Income MHDI (UNDP), Firjan Municipal Development Index: Overall (Firjan), Firjan Municipal Development Index: Labour and income (Firjan), Per capita income - Reals (IBGE), Percentage of poor households (IBGE), Percentage of population vulnerable to poverty (IBGE), Theil index (IBGE)[1] and Unemployment rate (IBGE). Matching techniques were also included.

To examine the local employment impacts of CDM projects in Brazil, Mori-Clement and Bednar-Friedl (2019) used a dynamic panel regression analysis across municipalities. The results indicated mixed effects depending on the sector, which varied from positive to negative. They also noted that revenues from Certified Emission Reductions (CER) had little impact on sectoral employment, what would corroborate with Luedemann et al. (2023).

Olsen and Fenhann (2008) argue that there is a need for an international standard for sustainability assessment in CDM projects. The idea of the authors come from a major concern regarding CDM project implementation in respect to additionality and co-benefits. Also, there is a concern about how to achieve both carbon reduction and sustainable development goals in which the CDM framework proposes. According to Mori-Clement and Bednar-Friedl (2019) while there is an extensive literature concerning climate change mitigation and environmental benefits of CDM, there is a relatively limited portion of research focusing on the various dimensions of sustainable development.

Du and Takeuchi (2019) also applied a Diff-Diff model to evaluate CDM renewable energy projects in rural China and have discovered that this kind of projects increased income, employment and industry in the communities included. In contrast, Pécastaing et al. (2018) discovered that while CDM projects in Peru may have a slight effect on household consumption, no noticeable effects were observed in employment or poverty alleviation. The different outcomes among countries suggest that the effect of CDM may be particular to each project type, rather than an overall estimate.

Regarding sustainability management, the Clean Development Mechanism (CDM) provided the design of a regulatory institutional infrastructure with capabilities to "measure, report, and verify results of the emissions reduction process within projects and programs," serving as a facilitator of a range of opportunities for actions and projects aimed at reducing greenhouse gas emissions (Gutierrez, 2018, p.276), including voluntary forms of emission offsetting. Specific to swine production in Brazil, Oliveira et al (2018) points out that there is a potential to promote “responsible project management and awareness of the business community to make their businesses executive” (OLIVEIRA et al. 2018, p. 32). Also, data from Brazilian Institute of Geography and Statistics points out a quarterly increase in the total weight of swine carcasses in the South region (IBGE, 2021).

3. Methods

3.1 Analytical assumptions

The methodology approach is similar to what is adopted in Mori-Clement (2019). A Difference-in-Differences (DiD) approach combined with matching techniques was applied. The DiD is a technique commonly applied in policy impact analysis and experimental analysis since its straightforward implementation. It refers to the average change in Y for those in the treatment group minus the average change in Y for those in the control group.

[1] Theil index is a statistical measure of income distribution.

One way to adjust for those remaining differences between the two groups is to compare not the outcomes Y, but the change in the outcomes pre- and post-treatment, thereby adjusting for differences in pretreatment values of Y in the two groups (STOCK; WATSON, 2003). Thus, Equation 1 demonstrates the estimator of impact from DiD.

$$\hat{\beta}_1^{diff-in-diffs} = \Delta\overline{Y^{treat}} - \Delta\overline{Y^{control}} \tag{1}$$

One of the major problems in DiD estimators refers to parallel trends assumptions which means that the treatment group, absent the intervention, would have followed the same trends as the control group (FREDRIKSSON; OLIVEIRA, 2019; WOOLDRIDGE, 2012). Fredrikson & Oliveira (2019) and Lechner (2011) discuss that matching techniques may give robustness in DiD, reducing bias. In this way, we followed a similar approach as Du and Takeuchi (2019) and adopted a propensity score matching, a one-dimensional measure representing the probability a given municipality would belong to the treatment groups.

Matching is a powerful nonparametric preprocessing method that is widely used to reduce selection bias and estimate treatment effects. The primary benefit of matching is that it can be used to estimate a wide range of treatment effects, regardless of the functional form of the outcome or the treatment effect (STUART et al., 2011; ZHAO et al. 2021).

The baseline year used was 2006, which is a year before the first project implementation related to methane avoidance in Brazil, an approach similar to what was adopted in Du and Takeuchi (2019).

Using a n-nearest neighbor matching with predate observations the weights generated in this regression were integrated to our panel dataset. Equation (2) shows the model predicted in this stage.

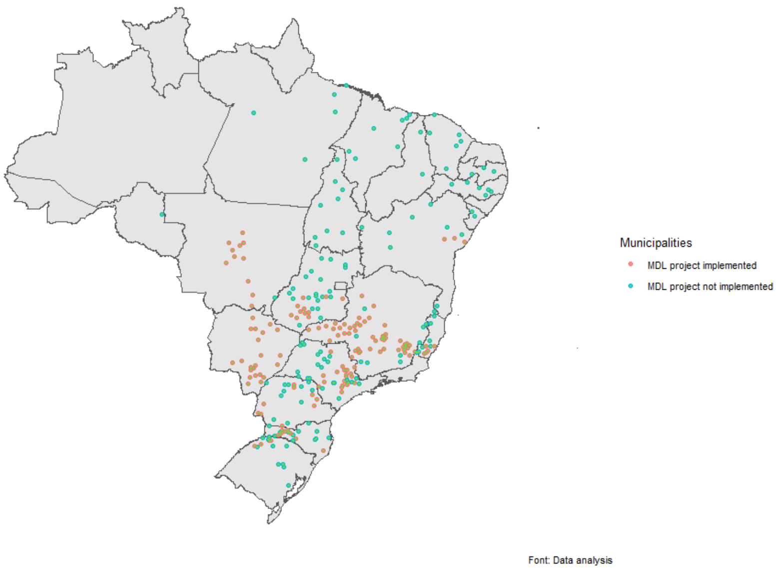
$$W_{i,t} = \alpha + \beta_1 GDP_{i,1} + \beta_2 POP_{i,1} + \beta_3 GEO_{i,1} + \beta_4 ANIMALS_{i,1} + \beta_5 IFDM_{i,1} + \mu_i \tag{2}$$

The variables used to match municipalities were GDP, overall Firjan Municipal Development Index (FMDI) and swine production in all municipalities selected, with and without CDM projects. In this case, the dependent variable is a binary indicating treatment status. The output of this model is the distance between each municipality from the socioeconomic variables in the treatment group. Therefore, distance values equal to one, would represent the treatment group itself, the closer to one, the more alike in terms of parallel trends.

3.2 Data

Figure 1 shows the map of Brazil with the respective municipalities included in the matched sample performed by the n-nearest neighbor estimator. In total, there are 291 municipalities, with 148 receiving the treatment and 143 not receiving it.

Figure 1. Map of municipalities in the sample analysis



Source: Elaborated by the authors.

In Figure 1, the orange dots represent the municipalities that received MDL projects. The blue dots are the municipalities that were matched in the model that will be compared in the Difference-in-Difference modeling.

The independent variables include a binary variable indicating treatment status, a continuous variable indicating time, and an interaction term between treatment and status. Also, the model includes a control variable for fertilizers (Fert) in the states during the years 2007 and 2016. Table 1 shows in details all variables included.

Table 1. Variables from municipalities in Brazil used in the model

Variable	Description	Source
gdpc	GDP per capita calculated using population from 2010 (2006 to 2008). GDP per capita in monetary values (2009 to 2018).	IBGE (2023a,b)
fert	Control variable - Tons of fertilizers delivered to the final consumer for each Brazilian state (2007 and 2014).	IBGE (2023)
fmdi_e	Firjan Municipal Development Index on employment (20006 to 2016)	IFDM (2022)
em	Animal waste management emissions from municipalities (2000 to 2016).	SEEG (2022)

Source: Elaborated by the authors.

The Firjan Municipal Development Index (FMDI) assesses and describes the formal job market in a given locality through the use of five indicators. The FMDI draws on official data sources such as the Ministry of Labour and Employment, Ministry of Education, and Ministry of Health, and is calculated by the Industry Federation of the State of Rio de Janeiro (Firjan) (MORI-CLEMENT, 2019).

4. Results

The data is composed by a treatment sample representing 148 municipalities of the 291 municipalities of the total sample. Table 2 displays the descriptive statistics of the dataset used in the model.

Table 2. Descriptive statistics of the dataset used in DiD model

Statistic	**N**	**Mean**	**S.D.**	**Min.**	**Max.**
Treatment and control	3196	0: 1568 1:	-	-	
Years (categorical)	11	-	-	2006	2016
GDP *per capita*	3196	22.279,5	29.029,21	395,8	447.786,9
FIRJAN employment	3196	0,6322	0,1176	0,2627	0,8983
Emissions	3196	6,56e+10	3,61e+10	1,64e+03	1,15e+13
Fert	216	711.707	668.159,5	0	2.455.688

Source: Elaborated by the authors.

From the 11 years estimated, there were a total of 3196 observations in the model. GDP per capita is a monetary value with standard deviation varying more than its mean, this indicates a large heterogeneity in the sample, which is explained by the municipalities in different Brazilian regions (North, South, Center-West, North-East and South-East). South-East region, especially, has a historical accumulation of income. Despite this fact, FIRJAN employment index does not have a larger standard deviation than its mean, indicating a level of homogeneity in the sample regarding employment. However, the minimum and maximum values are further apart. The same logic applies to the value of animal waste management emissions.

The minimum value for fertilizers is reflecting the lack of data throughout the series analyzed. The addition of a control variable is to reduce the error variance and it is expected that the missing parts of fertilizers' historic trend would not affect the control. The large number for the maximum level of fertilizer used is related to the data from each state throughout the years.

Table 3 displays the results of a multiple regression analysis with the three dependent variables explained in the section before: FIRJAN employment, Emissions, and GDP *per capita*. The table shows the estimates and p-values for each of the coefficients in the model.

Table 3. Results from the Difference-in-Difference model

	FMDI employment and income		**Emissions**		**GDP/capita**	
	Estimate	**P-value**	**Estimate**	**P-value**	**Estimate**	**P-value**
Intercept	5.58e-01	<2e-16***	4.71	0.001***	1.65e+04	<2e-16***
Treated	8.01e-02	<2e-16***	9.41	9.16e-11***	1.15e+04	<2e-16***
Time	9.65e-03	0.1596	-3.41	0.14	-5.54e+03	0.002**
Treated:time	5.71e-09	0.5517	-9.47e+10	0.003841**	1.07e+03	0.67
Fert	4.29	<2e-16***	-3.76e+04	0.001***	9.01e-04	0.25
GDP/capita	-	-	5.54e+05	0.012*	-	-
FIRJAN	-	-	-	-	-	-

Source: Elaborated by the authors.

The "Treated:time" interaction term is the compound effect of the treatment over time, and it is the coefficient that we examined to determine the impact of CDM methane avoidance projects. The effect is positively significant to animal waste management emissions. This represents an important result for understanding the impact of CDM initiatives, as the literature review reveals that emission reduction outcomes have not been very promising. However, this can be explained by the use of a highly specific breakdown of emissions at the municipal level. Therefore, although methane avoidance may not account for the overall emission reduction of CDM projects, the one in question, which is a specific share for swine production, has demonstrated positive effects

The Employment and income FMDI index does not present a statistically significant value in the model. The results found in Mori-Clement (2019) for methane avoidance projects differ from the present results, since the result was positive and statistically significant. This can be explained by the use of control variables, as well as the limited historical trend used in the present study.

It is important to note that FIRJAN and GDP per capita represented endogenous effects, therefore they were not included in all of the predicted models. Carrying on with the other coefficients, “Time” has a significant negative effect to GDP per capita, which is an interesting result despite the positive effect in all dependent variables related to “Treated”, representing a total increase of the variables in the treatment sample. This could point out that CDM initiatives were biased, regarding the choice of the municipalities. The model is not computing the relevance in which CDM projects played in each of the cities, as it is noted that some cities have been contemplated by more than 5 projects during the time (all sectors) (COELHO et al., 2022).

5. Conclusions

The objective of this study was to measure the impacts of three aspects of sustainable development: economic through per capita GDP, social through Employment and income Firjan Municipal Development Index, and finally, environmental through emissions. The results showed that methane avoidance projects under the CDM between 2006 and 2016 had significant effects on reducing emissions from animal waste management, but did not have significant effects on the other variables.

The main contribution of this study relies on the effect of emission reduction in Brazilian municipalities referred directly to swine production in Brazil. Also, there is a window to articulate to the government in respect to the soon to be methane credit in Brazil, that could be learned from the experience generated of the CDM projects. The Brazilian Methane Zero Program, launched in 2022 by the Ministry of the Environment mentions, without giving further details, the promotion of lines of credit and financing of biomethane projects.

For future studies, it would be beneficial to conduct a regional analysis to determine any variations in project implementations and add more variables to the model, such as credit. The ampliation of the historical trend would also be needed.

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