

Environmental policy and health: Evidence from the reduction of sugarcane burning in Brazil

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Last Version

Abstract

São Paulo, the major sugarcane-producing state in Brazil, commands over a fifth of the world's sugarcane production. This paper explores the health impacts of an environmental policy that has reduced pre-harvest sugarcane burning in the state, the Green Ethanol Protocol. By analyzing birth outcomes, hospitalizations, and mortality data, our preferred estimates suggest that a one standard deviation increase in exposure to the policy caused a 7% decrease in hospitalizations due to respiratory diseases, a 4% reduction in hospitalizations due to circulatory system diseases, and a 14% lower likelihood of birth anomalies. These results are robust across several econometric specifications and remain consistent when excluding data from the COVID-19 outbreak period. We find no clear evidence that the pre-harvest sugarcane burning ban affects birthweight or mortality due to respiratory or circulatory diseases. Based on 2019 costs, we estimate lower bound cost savings from this environmental policy to be 217 million BRL, 54 million USD, between 2011 and 2021, solely in terms of hospitalization costs.

Keywords: Sugarcane Smoke; Environmental Policy; Health Outcomes.

JEL Codes: Q52, I18, K32.

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Resumo

São Paulo, o maior estado produtor de cana-de-açúcar do Brasil, responde por mais de um quinto da produção mundial de cana-de-açúcar. Este artigo explora os impactos na saúde de uma política ambiental que reduziu a queima de cana-de-açúcar antes da colheita no estado, o Protocolo Etanol Verde. Ao analisar os resultados de saúde no nascimento, hospitalizações e dados de mortalidade, nossas estimativas preferenciais sugerem que um aumento de um desvio padrão na exposição à política causou uma redução de 7% nas hospitalizações por doenças respiratórias, uma redução de 4% nas hospitalizações por doenças do sistema circulatório e uma probabilidade 14% menor de anomalias congênitas. Esses resultados são robustos em várias especificações econométricas e permanecem consistentes mesmo quando excluimos dados do período de surto de COVID-19. Não encontramos evidências claras de que a proibição da queima de cana-de-açúcar antes da colheita afete o peso ao nascer ou a mortalidade por doenças respiratórias ou do sistema circulatório. Com base nos custos de 2019, estimamos que a economia mínima gerada por essa política ambiental seja de BRL 217 milhões, USD 54 milhões, entre 2011 e 2021, apenas em termos de custos de hospitalização.

Palavras-chave: queima de cana-de-açúcar, política ambiental, indicadores de saúde.

1 Introduction

Agricultural fires have several drawbacks during and after burning, including alterations to the soil's physical, chemical, and biological characteristics, and significant local air pollution (Andreae & Merlet, 2001; Santín & Doerr, 2016). Despite these disadvantages, fires remain widely used in agriculture because they reduce labor costs associated with clearing bushes, removing crop residues, and controlling invasive plant species (Levine, 1991; Radosevich et al., 2007). This cost reduction is particularly important for smallholders practicing traditional agriculture while managing their land (Morello et al., 2019). However, it is also common in large-scale agriculture – *e.g.*, the pre-harvest sugarcane burning in Brazil (Uriarte et al., 2009). The trade-off between more sustainable yet costly farming practices hinders the voluntary reduction of agricultural fires in sugarcane production. It highlights the need for additional incentives, such as environmental regulations and agreements, to foster and promote change towards sustainability. In this regard, São Paulo introduced the Green Ethanol Protocol (GEP) in 2007 to reduce pre-harvest burning in sugarcane production – the primary crop used for ethanol in Brazil. The GEP has proven effective: between 2010 and 2015, the area permitted for pre-harvest burning decreased by over 80% (SAA-SP, 2023).

The goal of this paper is to examine how the Green Ethanol Protocol (GEP) impacts public health outcomes by reducing exposure to smoke. São Paulo alone commands over a fifth of the world’s sugarcane production¹. Nevertheless, this production is far from evenly distributed across the state. While half of São Paulo’s municipalities allocate minimal or no land to sugarcane cultivation, the other half dedicates at least 5% of their territory to this crop. A quarter of all municipalities utilize over 20% of their land for sugarcane production, and the top decile utilizes over 40%². This variation in land use helps quantify to what extent people are exposed to the GEP. We assert that individuals in municipalities with more land allocated to sugarcane production were more exposed to sugarcane smoke before the environmental agreement. Consequently, they are likely to experience greater health improvements due to the GEP.

We analyzed varying levels of exposure to the environmental policy in relation to several health outcomes. We first examine whether exposure affects birth outcomes, including birthweight, the probability of low or very low birthweight, and the incidence of birth anomalies. Second, we analyze hospitalization records detailed by diseases to determine whether individuals more exposed to the GEP reduced the probability of being hospitalized for respiratory or circulatory diseases. Finally, we investigate whether increased exposure influences mortality rates from respiratory and circulatory diseases, using detailed mortality records also detailed by disease type in Brazil.

The analysis confirms that exposure to the environmental policy generally improves residents’ health, except mortality rates, where no significant effects were found. The findings are discussed regarding an additional standard deviation of exposure, cities with 18% of land allocated to sugarcane, and the top decile of exposure, cities where at least 40% of land is used for sugarcane production. The results can be summarized as follows.

Newborn Health Outcomes: For every one standard deviation increase in GEP exposure, birth anomalies decreased by 14%, with a more pronounced reduction of 31% among individuals in the top decile of exposure. We found no impact on birth weight outcomes, including birth weight levels or the likelihood of having low birth weight (less than 2500 grams) or very low birth weight (less than 1500 grams) infants.

Hospitalizations: The studied environmental agreement reduces hospitalizations due to both respiratory and circulatory diseases. For each standard deviation increase in GEP exposure, hospitalizations for respiratory diseases decreased by 7%. Among the most exposed group (top decile of exposure), the reduction was around 15%. Hospitalizations for circulatory diseases decreased by 4% for every additional standard deviation

¹Brazil dominates the world sugarcane market, accounting for 37% of global production in 2022. São Paulo, as Brazil’s primary producer, contributes 58% to the nation’s output, representing 21% of the world’s sugarcane production (FAO, 2023).

²Figure 2 illustrates the spatial distribution of land allocated to sugarcane production in São Paulo.

of exposure, with a 9% reduction for the most exposed group.

Mortality: We found no clear evidence that mortality related to respiratory diseases changed due to the GEP. While some evidence suggests a reduction in infant mortality from respiratory diseases, these findings are not robust when accounting for the COVID-19 outbreak period or changes in the metrics used. The reduction in mortality due to circulatory system diseases appears robust, showing a 1.5% decrease in deaths for each additional standard deviation in exposure to the GEP. However, we did not conduct statistical inference on this mortality effect due to the lack of power in these estimates combined with the small effect size.

Lower hospitalization rates and a decrease in the number of babies born with anomalies represent significant cost savings for the government. In Brazil, severe anomalies can incur additional expenses, such as lifelong social protection equivalent to at least one minimum wage and increased healthcare costs. The direct cost of less hospitalization is more straightforward to quantify. By estimating the reduction in hospitalizations resulting from the GEP and applying 2019 hospitalization cost data, we determined that São Paulo saved at least 217 million BRL, 54 million USD, between 2011 and 2021 due to this environmental policy.

Our research relates to papers investigating how environmental agreements affect health outcomes (Isen et al., 2017; McCarty et al., 2007). More specifically, we build on a well-developed body of literature linking air pollution to newborn health (Currie & Schmieder, 2009; Sram et al., 2013; Greenstone & Hanna, 2014; Van Rossem et al., 2015), respiratory diseases (Mo et al., 2018; Simkovich et al., 2019; Tran et al., 2023), and circulatory diseases (Franchini & Mannucci, 2007; Lee et al., 2014; Franklin et al., 2015). Previous research has investigated the impacts of pre-harvest sugarcane burning in Brazil, but without focusing on health outcomes. For instance, Valente & Laurini (2021) studied the reduction in the number of observed fires associated with sugarcane burning, while Cristale et al. (2012), Souto-Oliveira et al. (2023), and França et al. (2014) investigated the pollution reduction related to it.

There are also some studies that explicitly examine the relationship between sugarcane smoke and health outcomes. Several papers focus on the health of workers more directly exposed to smoke (Prado et al., 2012; Abreu et al., 2011; Ribeiro & Ficarelli, 2010). Other research investigates the effects of sugarcane smoke in specific municipalities. For example, Arbex et al. (2000) explores the correlation between daily counts of inhalation therapy and sugarcane smoke in Araraquara, a municipality in São Paulo, while Cançado et al. (2006) examines the relationship between sugarcane smoke and respiratory diseases in Piracicaba, another municipality in the state. Rangel & Vogl (2019) conducted an insightful study examining the impact of agricultural fires on birth outcomes, focusing

on the state of São Paulo.

In contrast, our study is the first to measure how the Green Ethanol Protocol (GEP) has mitigated various health drawbacks associated with sugarcane smoke for the general population of São Paulo state, rather than focusing solely on a specific municipality or workers with higher exposure to the sugarcane smoke. By doing so, we provide solid empirical evidence of the health benefits of transitioning from the less sustainable practice of manual harvesting with pre-harvest burning to the more environmentally friendly technology of mechanical harvesting. This evidence is important for similar transitions in other Brazilian states that continue to use sugarcane burning and for reductions in such practices in different countries – *e.g.*, pre-harvest sugarcane burning is still used in Florida, United States (Nowell et al., 2022) in 2024.

The remainder of this paper is structured as follows: The second section overviews sugarcane production in Brazil and introduces the Green Ethanol Protocol. The third section details the data collection process and the empirical strategy employed in the analysis. The fourth section presents our findings. Finally, the paper concludes by discussing policy implications based on our results.

2 Sugarcane Production in Brazil

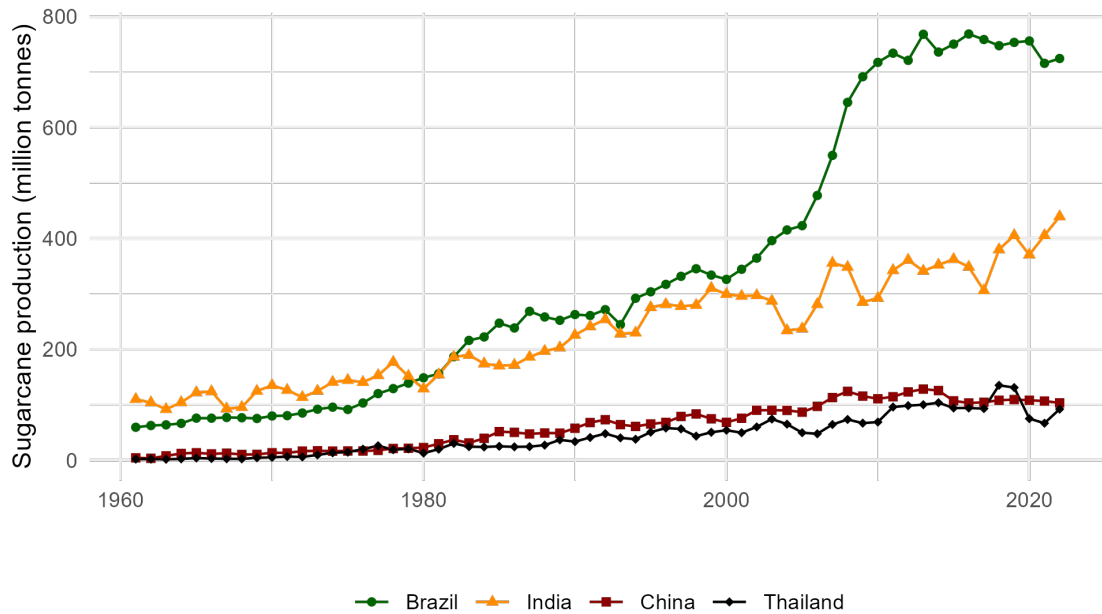
2.1 Overview

Brazil is the world’s leading producer of sugarcane, harvesting 720 million tonnes in 2022, which accounts for 37% of global output (see Figure 1) (FAO, 2023). Before 2000, India, the second-largest producer, had output levels comparable to Brazil. However, Brazil’s production surged in the 2000s, doubling between 2000 and 2010. This growth was primarily driven by the country’s biofuel policies, including increased ethanol mandates, lower taxation on ethanol compared to gasoline, and the introduction of flex-fuel vehicles in 2003 (Cardoso et al., 2019).

São Paulo alone produced 420 million tonnes of sugarcane in 2022, representing 58% of Brazil’s total output (IBGE, 2024). If São Paulo were a country, its production would nearly match India’s, the world’s second-largest sugarcane producer. São Paulo’s production is unevenly distributed within the state, with the majority concentrated in the northeastern cities. In contrast, the state’s southern regions contribute almost nothing to sugarcane production. Figure 2 shows the share of land allocated to sugarcane production in each municipality of São Paulo between 2002 and 2010.

We used variations in the share of land dedicated to sugarcane cultivation to assess

Figure 1: Sugarcane Production Trends for the Top 4 Producing Countries



Author’s elaboration using data from [FAO \(2023\)](#), with significant processing by Our World in Data.

each municipality’s exposure to sugarcane smoke. It follows that municipalities with higher relative levels of sugarcane production experience greater exposure to smoke from sugarcane burning. Therefore, any environmental policy aimed at reducing sugarcane burning would likely have a more significant impact on residents in cities with higher relative sugarcane production than in areas with lower relative cultivation.

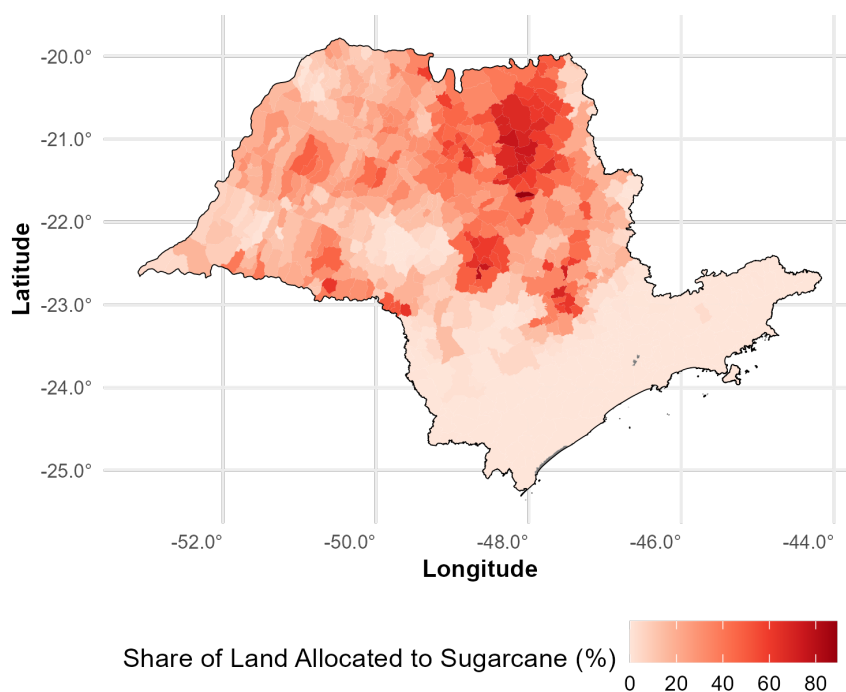
2.2 The Green Ethanol Protocol

Although sugarcane production in Brazil is predominantly a modern, high-productivity industry rather than smallholder-driven, fire has been widely used to facilitate manual harvesting, raising significant concerns about the environmental sustainability of ethanol production – sugarcane is the primary crop for ethanol production in Brazil³. Consequently, ensuring the sustainability of ethanol production is crucial for this debate, as any shortcomings could hinder the growth of domestic and international biofuel markets and delay the implementation of biofuel mandates and policies ([Oliveira et al., 2017](#)).

In this context, São Paulo state transitioned from labor-intensive manual harvesting, which relied on fire, to capital-intensive mechanical harvesting, thereby eliminating the need for agricultural fires. This transition was driven by two environmental policies:

³Ethanol is still predominantly produced from sugarcane in Brazil. However, since 2018, corn has increasingly contributed to ethanol production, accounting for 15% of the total in 2023 ([Unicadata, 2024](#)).

Figure 2: Spatial Distribution of Land Allocated to Sugarcane Cultivation in São Paulo (2002-2010)



Data from IBGE-Sidra, Pesquisa Agrícola Municipal (IBGE, 2024). The figure shows the share of land allocated to sugarcane cultivation in each municipality of the state of São Paulo between 2002 and 2010.

i) a law mandating the adoption of cleaner, albeit more costly, technology; and ii) an environmental agreement that employed alternative incentives to promote the shift toward this cleaner technology.

The State Law No. 11.241/2002⁴ established a gradual ban on sugarcane straw burning. Although the law includes specific provisions for areas based on slope and farm size, its overall goal was to progressively reduce the areas where burning is permitted. Specifically, it aimed to ban burning in 20% of the area by 2002, 30% by 2006, 50% by 2011, 80% by 2016, and 100% by 2021.

The Green Ethanol Protocol⁵, signed in 2007, advanced the deadlines established by State Law No. 11.241/2002 from 2021 to 2014 in areas that can be mechanized and from 2031 to 2017 in other regions. Participation in the GEP is voluntary for refineries. Producers are incentivized by the opportunity to access markets with stringent environmental standards, as well as by improved financing conditions and technical assistance. In addition to accelerating the timeline for eliminating pre-harvest sugarcane burning, the environmental agreement also aims to achieve other environmental goals, such as reducing water usage and preserving forests, protecting riparian forests, reusing and recycling waste and adopting best practices in the use of agrochemicals. Regarding water,

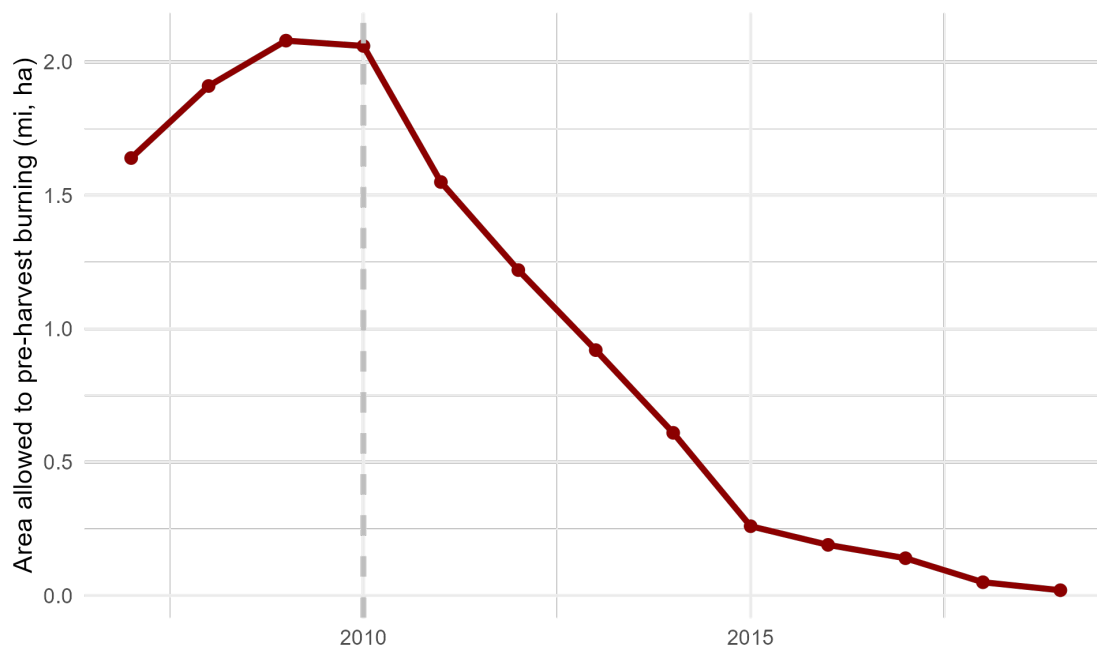
⁴The original law can be found [here](#).

⁵In Portuguese, Protocolo Agroambiental Etanol Verde or Protocolo Etanol Mais Verde after 2017.

for example, consumption in sugarcane production decreased by 52% between 2010 and 2022, from $1.5 m^3$ to $0.7 m^3$ (Unica, 2022).

The Green Ethanol Protocol (GEP) was signed in 2007, coinciding with Brazil's significant increase in sugarcane production during the 2000s, driven by biofuel policies and the expansion of land allocated to sugarcane in São Paulo. Between 2007 and 2010, the harvested sugarcane area in São Paulo increased by over 30% (see Figure 4 in the Appendix), while the share of manually harvested sugarcane decreased from 67% to 37% (see Figure 5 in the Appendix). As the GEP and State Law No. 11.241/2002 set limits on the use of pre-harvest burning as a share of the harvested area, the total amount of land where burning occurred still increased due to the overall expansion in sugarcane cultivation (see Figure 3). Consequently, it was only after 2010 that the total area allowed for pre-harvest burning began to decrease, marking the point where any improvements in health outcomes related to reduced smoke exposure could be expected. Hence, 2010 marks when policies aimed at lowering sugarcane smoke began to take effect, which is central to our empirical strategy, as outlined in the next section.

Figure 3: Land Permitted for Pre-Harvest Burning in São Paulo



Data from SAA-SP (2023). The graph illustrates the total area permitted for pre-harvest sugarcane burning. The gray dashed line marks when a significant reduction in these areas began.

3 Data and Empirical Strategy

In this paper, we combine four different datasets to construct a municipality-year panel⁶. We first collected data on the area dedicated to sugarcane planting as a share of the total area of each municipality. This data is sourced from the Municipal Agricultural Production (PAM) maintained by the Brazilian Institute of Geography and Statistics (IBGE). Figure 2 illustrates this variable, and we used the average share from 2002 to 2010 – the pre-treatment period – in our regressions. Next, we merged this level of exposure with our outcomes of interest:

Rate of hospitalizations primarily caused by respiratory diseases: The number of hospitalizations per municipality population. We utilized data from hospitalization records across municipalities, documented in the Sistema de Informação de Agravos de Notificação (SINAN) database from Datasus, available from 2008 to 2022. We extracted all hospitalizations with International Classification of Diseases (ICD-10) codes between J00 and J99, focusing specifically on respiratory diseases.

Rate of hospitalizations primarily caused by diseases of the circulatory system: The Number of hospitalizations per municipality population. We used data from SINAN-Datasus, available from 2008 to 2022, with ICD-10 codes between I00 and I99.

Mortality primarily caused by respiratory diseases: The Number of deaths caused by respiratory diseases divided by the total population. This data is available from 2002 to 2023 from the Sistema de Informações sobre Mortalidade (SIM) and Datasus.

Mortality primarily caused by circulatory diseases available from 2002 to 2023 from SIM-Datasus.

Birthweight in grams, sourced from the Sistema de Nascidos Vivos (SINASC) from Datasus, available from 2002 to 2023. We used the average value for each municipality.

Number of anomalies: The share of babies with anomalies per thousand births. This data is also from SINASC-Datasus.

Lastly, we used some information regarding cities to be used as control or to weight regressions. **Population** data from IBGE population estimates, except for census years where we used data from the census. **GDP** Data on GDP per capita per municipality, data also from IBGE.

Our empirical strategy exploits the timing of the reduction in pre-harvest sugarcane

⁶The R codes for downloading, cleaning, merging datasets, conducting regressions, and creating visualizations can be found on this [link](#).

burning (Figure 3) and the cities most exposed to this reduction (Figure 2), and estimate a specification of the following form:

$$\ln(Y_{it}) = \underbrace{\text{Land}_i \times D_{2010t}}_{\alpha \cdot \text{Exp}_{it}} + \theta_i + \gamma_t + \epsilon_{it} \quad (1)$$

Where Y_{it} represents our health outcomes (rate of hospitalizations, mortality, or birth outcomes) and θ_i and γ_t are the municipality and year fixed effects, respectively. α is our parameter of interest, measuring how exposure to the Green Ethanol Protocol affects health outcomes. The exposure (Exp_{it}) is captured by the interaction between the share of land allocated to sugarcane (Land_i) and the dummy variable indicating when the GEP began to reduce sugarcane burning (D_{2010} , which is one if year > 2010 , zero otherwise).

4 Results

4.1 Birth outcomes

The results for birth outcomes indicate that the reduction of pre-harvest sugarcane burning did not significantly affect birthweight or the probability of having a low or very low birthweight baby (see Table 1). However, the number of anomalies was considerably reduced due to the GEP. An additional standard deviation of exposure is associated with a 14% reduction in anomalies ($0.18 \times 0.79 = 0.14$, see Table 1, Panel A). For municipalities in the top decile of exposure to the GEP, where at least 40% of the land is allocated to sugarcane production, the reduction is approximately 31% (0.40×0.79). The results remain consistent when excluding the COVID-19 outbreak period from the analysis: there are no effects on birthweight variables, and there is a significant improvement in anomaly reduction for mothers residing in municipalities most affected by the GEP.

4.2 Hospitalizations

The number of hospitalizations related to circulatory and respiratory diseases decreased significantly (see Table 2). The effect of exposure to environmental agreement (the GEP) is more pronounced for respiratory diseases. Specifically, an increase of one standard deviation in exposure is associated with a 7% reduction (0.38×0.18) in the per capita number of hospitalizations for respiratory diseases. In municipalities with higher exposure, the reduction in hospitalizations reaches 15% (0.4×0.38).

The environmental agreement also improves health outcomes related to circulatory

Table 1: Birth Outcomes

	ln(birthweight)	ln(lbw)	ln(vlbw)	ln(anomalies)
<i>Panel A – Full sample (2002-2023)</i>				
Exp	−0.002 (0.003)	0.027 (0.023)	−0.067 (0.056)	−0.795** (0.311)
Num.Obs.	15,484	15,485	15,485	9,766
<i>Panel B – Exclusion of Covid Period (2002-2019)</i>				
Exp	−0.002 (0.004)	0.027 (0.023)	−0.028 (0.054)	−0.789** (0.317)
Num.Obs.	12,905	12,906	12,906	8,163
Std.Errors by municipality	✓	✓	✓	✓
FE: municipality	✓	✓	✓	✓
FE: year	✓	✓	✓	✓
Weights	Births	Births	Births	Births

Robust standard errors are in parentheses, adjusted for clustering by municipality. The symbols *, **, and *** denote rejections of the null hypothesis at significance levels of 10%, 5%, and 1%, respectively. Panel A displays results for the full sample (births between 2002 and 2023). Panel B excludes births during the COVID-19 outbreak, considering only births before 2020. The regressions are weighted by the number of births in each municipality. The first regression is for birthweight, the second for the probability of having a birthweight lower than 2500 grams (LBW), the third for the probability of having a birthweight lower than 1500 grams (VLBW), and the fourth for the number of anomalies (1000 × number of anomalies per municipality per year). Except for the first column, we added 0.001 to the dependent variable to avoid dropping observations with zero values.

diseases (Table 2, Panel B). An additional standard deviation of exposure to the GEP is associated with a 4% reduction in hospitalizations primarily caused by circulatory diseases. Municipalities in the top decile of exposure experienced at least a 9% reduction in such hospitalizations.

The introduction of flex-fuel cars in 2003 and the expansion of ethanol mandates increased demand for ethanol, benefiting municipalities with intensive sugarcane production. To ensure robustness, we included per capita GDP in our analysis to account for potential improvements in health due to better economic status. The results remained consistent, with only marginal changes. Excluding the COVID-19 outbreak period resulted in slightly lower effect estimates, but the overall conclusions remained the same.

4.3 Mortality

Regarding mortality results, we found no significant effects on deaths related to respiratory diseases. Still, there is a reduction in mortality primarily due to circulatory diseases (see Table 3). Overall, we report no significant effects on mortality for either category.

Table 2: Hospitalizations primarily caused by respiratory and circulatory diseases

	ln(hosp)	ln(hosp)	ln(hosp)	ln(hosp)
<i>Panel A – Respiratory Diseases</i>				
Exp	−0.380*** (0.114)	−0.287** (0.111)	−0.369*** (0.112)	−0.286** (0.111)
ln(gdp)			−0.146* (0.083)	−0.036 (0.071)
Num.Obs.	4,739	4,081	4,739	4,081
<i>Panel B – Circulatory Diseases</i>				
Exp	−0.239*** (0.078)	−0.222*** (0.075)	−0.234*** (0.078)	−0.221*** (0.075)
ln(gdp)			−0.077 (0.063)	−0.056 (0.063)
Num.Obs.	4,689	4,039	4,689	4,039
Std.Errors by municipality	✓	✓	✓	✓
FE: municipality	✓	✓	✓	✓
FE: year	✓	✓	✓	✓
Weights	Population	Population	Population	Population
Period	2008-2021	2008-2019	2008-2021	2008-2019

Robust standard errors, adjusted for clustering by municipality, are presented in parentheses. The symbols *, **, and *** indicate rejection of the null hypothesis at significance levels of 10%, 5%, and 1%, respectively. The regressions are weighted by the population of each municipality. The dependent variable in the regressions is the logarithm of the number of hospitalizations primarily caused by respiratory diseases (Panel A, ICD-10 codes J00 to J99) or the number of hospitalizations primarily caused by circulatory diseases (Panel B, ICD-10 codes I00 to I99).

This conclusion is drawn from the minimal impact observed (less than a 2% reduction from an extra standard deviation of exposure) and the limited statistical power of our estimates, many of which are only significant at the 10% confidence level. Further investigation is likely needed. Or disaggregating results for more specific subgroups of diseases could provide clearer evidence of which conditions are directly impacted by the environmental policy under study.

4.4 Discussion

After demonstrating that exposure to the environmental agreement is associated with fewer hospitalizations, a natural question arises: How much does the reduction in exposure to sugarcane smoke save on hospitalization costs? To estimate this, we calculated the average reduction in hospitalizations due to the GEP in each exposed city for the two studied diseases. This reduction is represented by the formula:

Table 3: Mortality primarily caused by respiratory and circulatory diseases

	ln(deaths)	ln(deaths)	ln(deaths)	ln(deaths)
<i>Panel A – Respiratory Diseases</i>				
Exp	−0.010 (0.042)	−0.009 (0.042)	0.031 (0.041)	0.033 (0.041)
log(gdp)		0.015 (0.017)		0.027* (0.015)
Num.Obs.	12,840	12,840	11,556	11,556
<i>Panel B – Circulatory Diseases</i>				
Exp	−0.083* (0.050)	−0.081* (0.047)	−0.100** (0.044)	−0.096** (0.042)
log(gdp)		0.090*** (0.024)		0.078*** (0.018)
Num.Obs.	12,808	12,808	11,527	11,527
Std.Errors by municipality	✓	✓	✓	✓
FE: municipality	✓	✓	✓	✓
FE: year	✓	✓	✓	✓
Weights	Population	Population	Population	Population
Period	2002-2021	2002-2021	2002-2019	2002-2019

Robust standard errors, adjusted for clustering by municipality, are presented in parentheses. The symbols *, **, and *** indicate rejection of the null hypothesis at significance levels of 10%, 5%, and 1%, respectively. The regressions are weighted by the population of each municipality. The dependent variable in the regressions is the logarithm of the number of deaths primarily caused by respiratory diseases (Panel A, ICD-10 codes J00 to J99) or circulatory diseases (Panel B, ICD-10 codes I00 to I99), both divided by the total population.

$$\text{Total Savings} = \sum_i \sum_d (\alpha_d \times \text{Exp}_i) \times \text{Cost}(2023)_d \times \text{Hospitalizations}_{dit} \quad (2)$$

Where α is the effect size from the first column of Table 2 (our preferred estimation) and Exp is the level of exposure. We then aggregated these reductions for the post-treatment period (year > 2010) and multiplied them by the average cost of hospitalizations in 2023 for each of our two group of diseases.

The total reduction of 217 million BRL (54 million USD) between 2011 and 2021 represents a conservative estimate. This number reflects the minimum savings attributed to reduced smoke from sugarcane burning in São Paulo, as it only considers anomalies within two groups of diseases – circulatory and respiratory.

5 Final Remarks

In this study, we investigated the effects of an environmental agreement aimed at enhancing the sustainability of Brazilian ethanol production by reducing the use of fire in sugarcane harvesting. Our findings indicate a significant reduction in birth anomalies and hospitalizations related to respiratory and circulatory diseases. However, no apparent effects on mortality or birth weight were observed. These results provide empirical evidence that regions heavily reliant on agricultural fires face negative public health impacts.

This is a warning for other Brazilian states that continue to use fire in sugarcane pre-harvesting. For example, the state of Pernambuco still relies predominantly on manual harvesting, with over 90% of its sugarcane harvested manually (Conab, 2024). Transitioning to mechanical harvesting could yield substantial health benefits for these regions. This insight is also relevant for sugarcane cultivation in other global regions, such as India and South Florida, where pre-harvest burning remains a common practice.

Another important policy implication is that, considering shifts from fossil fuels to biofuels, the sustainability of biofuels matters. While Brazilian sugarcane ethanol is recognized for its favorable energy balance, the production method significantly impacts its sustainability with mechanical harvesting being superior in several aspects, including better public health.

There are additional considerations when substituting manual with mechanical harvesting in São Paulo, such as the effects on the low-skilled workforce, including wages, job-related accidents, and migration patterns. These aspects are part of our future research agenda.

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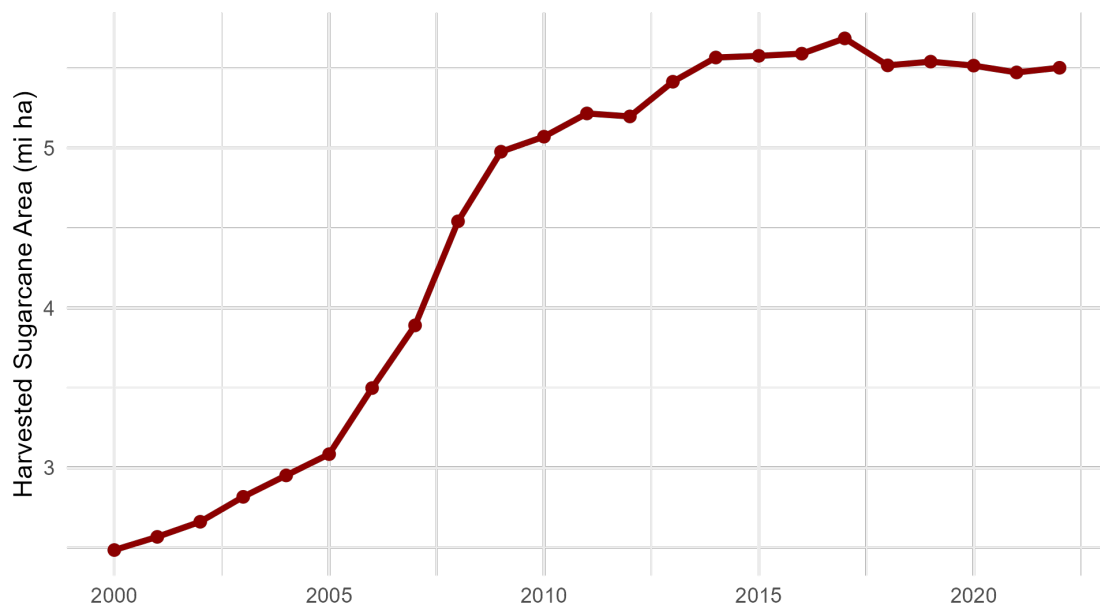
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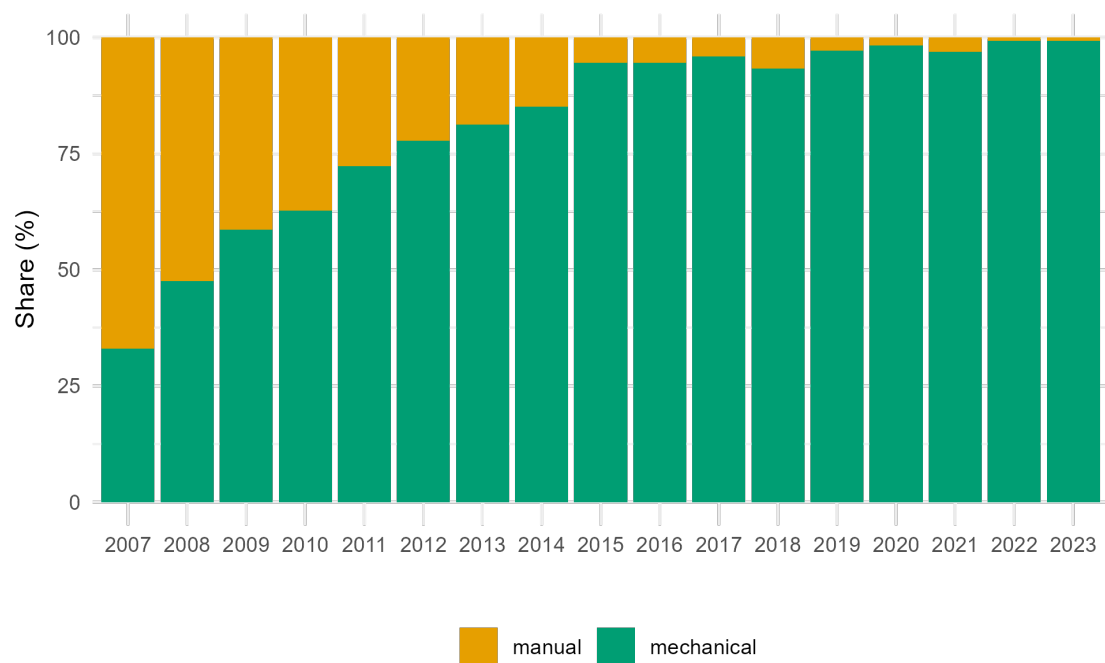
Appendix

Figure 4: Harvested Sugarcane Area in São Paulo



Data from IBGE-Sidra, Pesquisa Agrícola Municipal (IBGE, 2024). The figure depicts the harvested sugarcane area in São Paulo state, measured in million hectares.

Figure 5: Distribution of Sugarcane Harvesting Methods in São Paulo State (Mechanical vs. Manual)



Data from Conab (Conab, 2024). The figure illustrates the distribution of harvested sugarcane in São Paulo state by harvesting method (mechanical or manual).