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Socio-Economic Drivers of Greenhouse Gas Emissions in the Brazilian Amazon: New Evidence from Santarem, Para[1]

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Abstract

We use a novel and more precise data set on greenhouse gas (GHG) concentrations in the Amazon region to estimate the nexus between local economic indicators and GHGs. We find that urbanization and waste generation emerge as new and important drivers of observed methane emissions. Local nitrous oxides emissions seem to result mainly from agricultural production, and carbon dioxide seems to be driven by deforestation. Given the importance of the Amazon region to global climate, these findings can offer insight into the development of scientific models for the natural environment and the design of effective environmental policies for the region.

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I. Introduction

The Amazon forest is thought to play an important role in local and global climate systems (see for example Shukla et al., 1990, Artaxo, 2001, Marengo and Nobre, 2001, Betts et al., 2003, and Mahli et al., 2008). Attention to the region is further motivated by concern over climate change and how it affects and is affected by the Amazon forest (Mahli et al., 2008). An important component of the contribution of the Amazon forest to the local and global climate systems is its role as a source or sink of important greenhouse gases such as carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O). Nevertheless, still limited information exists on the contribution of the Amazon forest to the volumes of these gases in the atmosphere and "whether the Amazon is even a net source or sink of carbon remains unknown" (Gatti et al., 2010, p. 581). This data limitation, in turn, hinders the finer development of global climate models and the design of effective environmental policies for the region and the world.

In order to tackle this problem, the Instituto de Pesquisas Energeticas e Nucleares (IPEN) at the University of Sao Paulo, Brazil has started collecting air samples from selected sites in the Amazon region and measuring local concentrations of CO_2, CH_4, N_2O and other gases. The data have been collected since the year 2000 and analyzed at the National Oceanic and Atmospheric Administration (NOAA) lab in Boulder, Colorado, and more recently at a NOAA lab replica at the University of Sao Paulo. This new flow of more precise information opens up an opportunity for novel investigation of the natural and anthropogenic determinants of the flows of important greenhouse gases in the region. Analysis of the data thus far unveils perhaps unexpected emissions patterns (such as relatively high N_2O concentrations in the dry season near the town of

Santarem, in the state of Para, Brazil – D'Amelio et al., 2009), and suggests the presence important anthropogenic sources of greenhouse gases in the region in addition to natural processes determining gas concentrations (Miller et al., 2007, D'Amelio et al., 2009 and Gatti et al., 2010).

This paper takes one additional step towards understanding emissions in the Amazon region by conducting the first joint exploration of the new data and the socio-economic drivers that could be influencing the local patterns for CO_2, CH_4 and N_2O air concentrations. By doing so, we hope to offer insight into the refinement of greenhouse gases-climate models as well as into the design of policies to curb emissions and environmental degradation in this important region of the world.

This paper is organized in three sections in addition to this introduction. Section II describes the data and methods used in our analysis, whereas section III presents our results and section IV concludes.

II. Data and Methods

Primary data on CO_2, CH_4 and N_2O air concentrations were collected between the years 2000 and 2010 above the Tapajos National Forest in the state of Para, Brazil (2^{o}51.42'S, 54^{o}57.54'W), near the city of Santarem.[2] Data collection was based on aircraft vertical profile measurements with semi-automatic portable sampling systems (Miller et al., 2007, D'Amelio et al., 2009, and

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[2] Air samples are also collected near the towns of Alta Floresta, Rio Branco and Tabatinga. However, these are much shorter time series and we focus on the longer series for Santarem.

Gatti et al. 2010). Once measurements were taken, back trajectories for these gases as well as net contributions from the region were calculated.[3] Net fluxes can take either positive or negative values, indicating whether the region behaves as a source or sink of these greenhouse gases, respectively. Figure 1 plots the back trajectories for airflows for each flight measurement at 500m at the Santarem measurement site.[4] By overlapping these back trajectories with the political map of Brazil, we were able to locate the municipalities of the state of Para that were likely to have contributed to GHG concentrations at the measurement site.[5] This, in turn, allowed us to collect municipal data on socio-economic variables at the municipal level and contrast them to the primary GHG concentration data.

Data collection for greenhouse gases were not homogenous throughout the sampling period with only two flights taking place in 2000 and progressively more flights in subsequent years. Data collection frequency increased substantially starting in 2007, with information for every season and all but two months between 2007 and 2010 (with more than one sample collected in most months). Secondary, socio-economic data are collected with a lower frequency than the GHG data, and relating both sets of information requires that we take averages of the chemical measurements. When we use annual economic data, this process dramatically reduces our time series and limits our ability to conduct quantitative analysis a high degree of statistical confidence. Nevertheless, our results for both the shorter annual series and the longer monthly

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[3] Miller et al. (2007), D'Amelio et al. (2009), and Gatti et al. (2010) provide a detailed description of the method for calculation of net fluxes into the Santarem measurement site. The approach is cognizant of trade-wind easterlies coming from the tropical Atlantic Ocean depending on the seasonally varying latitude of the Inter-Tropical Convergence Zone (ITCZ). The ITCZ brings extraneous gases to the region that need to be discounted. To do so, the authors use NOAA GHG measurements to the south (Ascension Island) and north (Barbados) of the ITCZ, measurements in the Brazilian city of Fortaleza and site measurements of sulfur hexafluoride (SF_6), a purely anthropogenic gas without regional sources or sinks in the Amazon Basin.

[4] Back trajectories for airflows at higher altitudes were also calculated, but we focus on 500m, since this altitude is the one that is most likely to reflect trajectories followed by local emissions.

[5] The list of municipalities under the back trajectories appears in appendix I.

series suggest plausible relationships and interesting questions which are worth exploring as more information becomes available to policy makers.

Annual data for gross domestic product (GDP) by sector (agriculture, industry and services), number of bovines, and area planted with crops are available at the municipal level from the Brazilian Institute of Geography and Statistics (IBGE). We compiled data for these indicators for the municipalities located upwind of Santarem according to the back trajectories from figure 1. The annual data range from 2000 to 2010. Since these municipalities account for over 80% of the economic activity in the state of Para, we also use IBGE monthly data that are available at the state level to further investigate potential sources of the GHGs measured in Santarem. The monthly data refer to the physical production of the state industry and the state volume of sales from the trading sector. Since GHG data collection was irregular over time and for the different gases, we formed different time series for each gas starting at periods where data collection became more frequent, and by taking averages for those months were measurements took place more than once. Thus, our series for CH_4 emissions ranges from April, 2006 to June, 2010. Information for the months 07/2006, 11/2006, 10/2008 and 07/2009 was missing and the corresponding data were interpolated by taking simple averages from neighboring months. The monthly series for N_2O ranges from April, 2006 to May, 2010, with interpolated observations for 07/2006, 11/2006, 01/2007, 10/2008 and 07/2009. The monthly series for CO_2 ranges from 02/2007 to 12/2010, with interpolated observations for 04/2008, 07/2008, 10/2008, 07/2009 and 08/2010.

For those economic variables where monthly data are available, we estimate vector autoregression (VAR) models relating greenhouse gas measurements and local economic indicators.[6] We conduct standard model selection and diagnostics tests available in most econometric packages and present our results below.[7]

III. Socio-economic determinants of GHG emissions in Santarem

To shed light into the local emissions patterns, it is instructive to examine some of the economic changes taking place in the municipalities upwind of Santarem. Figures 2(a) through 2(d) plot the evolution of three economic variables of interest here: gross domestic product, bovine cattle and planted area. Figure 2 (b) plots services GDP (S), industrial GDP (I), government expenditures (G) and agricultural GDP (A). Aggregate GDP (figure 2 (a)) was somewhat stagnant in the early years of the sample until it started growing mainly due to an increase in the services sector. The bovine herd in the region (figure 2 (c)) grew until 2006 and remained stable afterwards. Finally, planted area (figure 2 (d)) increased until it peaked in 2005, and declined afterwards. Figure 3 plots the monthly time series on greenhouse gases measured in Santarem as well as industrial physical production and volume of sales from the trading sector in Para. Next, we explore the linkages between our pollution and local economy indicators.

Methane (CH_4)

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[6] We do not find any evidence of cointegration among our time series. We therefore do not pursue any vector error correction model estimation here.

[7] We use the freely available packages *vars* and *urca* written for the R language in our econometric estimation. All results are available from the authors upon request.

Methane (CH_4) emissions come from a variety of natural and anthropogenic sources (Cicerone and Oremland, 1988), and substantial natural emissions from the Amazonian wetlands are to be expected, especially during the raining season due to degradation of flooded organic matter. However, studies on plants as direct emitters (Keppler et al., 2006) and field measurements from Amazonian forests (do Carmo et al., 2006) suggest important sources of CH_4 other than wetlands in the Amazonian region. Furthermore, Miller et al. (2007) report measurements of methane in Santarem (and Manaus) that are almost always above the extraneous levels that are expected to be transported into the region. This, in turn, suggests the presence of important regional upwind sources. Below, we explore whether and which anthropogenic sources could be significantly contributing to Miller et al.'s findings.

CH_4 emissions due to human activities in the region come from two major sources: cattle raising and waste generation and disposal.[8] Figures 4(a) and 4(b) plot annual averages for methane emissions against annual cattle herds and services GDP in the region of interest, respectively. We notice that the urban population in the state of Para grew by 1.07 million people (26% growth) between the census years of 2000 and 2010 (IBGE 2000 and 2010),[9] and we use services GDP as a proxy for local urbanization and generation of waste. Although both graphs suggest a positive relationship between human activities and CH_4 emissions, this relationship seems to be stronger in the case of services GDP (correlation of 0.68 versus 0.39 in the case of cattle herds). This suggests that rapid urbanization and generation of human waste is a more likely cause for the increase in methane emissions in the region. To further investigate this possibility, we explore the dynamic nexus between monthly averages of CH_4 emissions and the volume of sales in the

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[8] Fossil fuel mining and distribution are also important contributors to methane emissions, but this is not a significant source in the region.

[9] Rural population grew by 317,878 people (15%) in the same period.

trading sector, our proxy for urbanization and waste generation, between April of 2006 and June of 2010.

We estimate a vector autoregression model with one lag in the endogenous variables (VAR(1)) involving Santarem measurements of CH_4 and sales for the state of Para. From figure 3 we can identify a clear seasonal pattern and a trend in the case of sales, with peaks occurring in December during the holiday season. We therefore estimate a model that includes a time trend and seasonal dummies. We also considered VAR models with higher lag orders, but chose VAR(1) as our preferred model, given model diagnostic statistics, a relatively small sample size (n = 50), and the fact that the travel time of CH_4 emissions from the surface to the measurement altitude should be relatively short.[10] Table 1 reports the estimated results for our VAR(1) model, whereas table 2 reports the post-estimation diagnostic tests. Table 1 shows lagged sales influencing emissions, but not the opposite, as one would expect. We also conduct Granger causality tests that corroborate the expected direction of causality between these two variables (table 2). Table 2 also reports the Chi square Jarque-Bera tests for normality of the model residuals, the Chi square Breusch-Godfrey Lagrange multiplier test of residual autocorrelation, and the estimated roots of the characteristic polynomials. We fail to reject the hypotheses of normality and no remaining autocorrelation, and the estimated characteristic roots are less than one.

In order to better characterize the linkages between methane emissions and sales, we estimate the orthogonalized impulse-response function (IRF) and forecast error variance decomposition (FEVD) describing how a shock in the volume of sales affects CH_4 emissions. Figure 5 plots the

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[10] Appendix II further discusses our estimation procedure and findings for different models.

estimated IRF with 95% confidence bands and shows how a one unit shock (impulse) in sales, all else constant, quickly causes an increase in methane measurements at Santarem (response) followed by a smooth decrease in subsequent months. Finally, we use the model to forecast a response of CH_4 measurements to a shock in the volume of sales, and estimate the percentage of the variance of the CH_4 forecast error as shown in figure 6: a shock in the volume of sales in the state of Para, accounts for over 10% of the variance of the error in forecasting CH_4 4 to 12 months following the initial hypothetical shock. The IRF and FEVD estimates suggest a statistically significant and non-negligible linkage between sales and methane emissions. This result highlights the role of recent urbanization trends in Para, and suggests that promising policies to curb methane emissions in the region could focus on waste generation and disposal.

Nitrous Oxide (N_2O)

Nitrous oxide is the third most important anthropogenic greenhouse gas with a warming potential 310 times bigger than that of CO_2. Furthermore, it contributes to the depletion of the stratospheric ozone layer. The main sources of anthropogenic N_2O are land use (fertilization), manure management, fossil fuel combustion and sewage disposal (US EPA, 2011), but natural processes also contribute to N_2O emissions, especially those from wet rainforest systems during the rainy season (Van Haren et al., 2005; Verchot et al., 1999; Perez et al., 2000; Garcia-Montiel et al., 2003; Wick et al., 2005; and Kiese et al., 2003) and the oceans. Whereas D'Amelio et al. (2009) observe higher N_2O fluxes during the rainy season as expected, comparison with measurements at another site in the Amazon region (Manaus) indicate an unexpectedly high flux of this GHG during the dry season. This observation suggests the presence of N_2O sources other than natural soil emissions and invites further investigation of anthropogenic processes in the region, a task we take up here.

As we would expect, N_2O emissions seem to be influenced by the use of fertilizers in agriculture as shown in figure 4(c). Because rice and cassava are two important crops in the State of Para and are planted from October through January (IBGE, Censo Agropecuario 1995/1996) we plot N_2O emissions against lagged planted area and obtain a positive relationship between these two variables (correlation coefficient $\rho = 0.71$).

Since important anthropogenic sources of N_2O emissions are fossil fuel combustion and sewage disposal, both related to urbanization and economic activity, we use monthly data on the volume of sales from the trading sector as a proxy variable to investigate whether there is an important nexus between these activities and emissions in the region. However, our estimates do not offer any support for this hypothesis.[11] For completeness, we also estimate dynamic models linking N_2O and industrial physical production for the state of Para, thus investigating another measure of local economic activity. As in the case of sales from the trading sector, we fail to find any significant linkages between this indicator and nitrous oxide emissions in Santarem.

Carbon Dioxide (CO_2)

The Amazon region is an important carbon storage area with likely significant implications to global climate. However, we know relatively little about the carbon cycles in the region, how

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[11] Two of the VAR models we estimated (5 and 6 lags) had statistically significant coefficients for sales lagged by 4 months in the equation for N_2O emissions. However, Granger causality tests provide evidence against the hypothesis that sales cause emissions, and post-estimation tests for these VAR models suggest instability and autocorrelated residuals, thus violating basic assumptions for reliable inference.

they affect global climate and how the rainforest could be affected by climate change. Attempts to build couple carbon-climate models still struggle with how to treat the Amazon region and whether it is a source or sink of CO_2 (Botta et al., 2002 and Dufresene et al., 2002). This is in part due to data constraints and in part to our limited understanding of natural and human processes that contribute to the carbon cycle in the region. Gatti et al. (2010) document important efforts to address the data issue, whereas we use their information to advance our knowledge of how socio-economic variables might be influencing carbon fluxes in the region.

We start by plotting CO_2 fluxes measured by IPEN near Santarem against economic variables that are likely to be correlated with typical anthropogenic sources of this greenhouse gas. The main culprit for CO_2 emissions worldwide is the burning of fossil fuels. This in turn is likely to be correlated with industrial and services GDP mainly through transportation activities in the region. When we compare CO_2 emissions measured in Santarem and industrial and services GDP in its upwind region, the resulting plot suggests the opposite of the expected relationship (the estimated correlation coefficients are -0.55 for industrial GDP and -0.19 for services GDP). The fact that industry and services cannot provide a good explanation for CO_2 emissions is Santarem is, however, not surprising, since deforestation is the main reason why Brazil is an important greenhouse gas polluter. Deforestation is typically the first step in the geographic expansion of the economic frontier in wooded areas. We first observe removal of timber species that are valuable enough to cover the high opportunity costs of penetrating a dense forest. This pioneer economic activity then leaves behind roads and basic infrastructure that lowers the penetration costs for other economic activities, such as small scale (slash and burn) agriculture, then cattle raising, and eventually large scale agriculture. This is a recurrent pattern in the Brazilian Amazon region and other tropical forests of the world.[12] Since we do not have reliable annual deforestation data to match our sample observations, we attempt to link CO_2 emissions in Santarem to contemporaneous deforestation by plotting emissions of the greenhouse gas in a given year against the growth rate of cattle herds three years in the future as in figure 4(d). The main idea is that current deforestation determines current CO_2 emissions and future growth of the local livestock economy. The resulting correlation is positive and relatively large ($\rho = 0.77$), thus offering support to the hypothesis that deforestation is likely the main culprit for CO_2 emissions in the region.

We further investigate the determinants of carbon dioxide emissions in Santarem, by estimating dynamic econometric models involving the greenhouse gas measurements in the region and both industrial production and the volume of sales of the trading sector. This analysis uses a larger monthly time series than the annual data described in the previous paragraph, but once again we find no evidence that the local industry or services sectors are important drivers of CO_2 emissions in the region. As noted before, monthly data are for the entire state of Para, but over 80% of the economic activity in the state comes from the municipalities that are upwind of Santarem.

The standard statistical tests we conducted to investigate whether the natural and economic series are integrated (augmented Dikey-Fuller and Johansen tests) offer support to the hypotheses that physical industrial production is integrated of order one, but not the other series. We therefore estimated VAR models both in levels and differences in the case of physical industrial

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[12] See for example, Barbier et al (1995), Stone (1998), Verissimo et al (1995) and Uhl et al (1991).

production and involving 1 to 12 lags. In neither of the estimated models,[13] we found support for the hypothesis that economic activity measured by industrial or services production caused CO_2 emissions. These findings reinforce our simple correlation results and the relative importance of deforestation in the local emissions of CO_2.

IV. Conclusion

The Amazon region is thought to play an important role in the determination of global climate and is expected to influence and be influenced by climate change. Nevertheless, limited information on greenhouse gases concentrations still hinders our knowledge of the interaction between the region and local and global climate, as well as our ability to design effective policies to protect the local environment. New data on the concentration of CO_2, CH_4 and N_2O are collected by the University of Sao Paulo and present us with a unique opportunity for novel investigation of the determinants of greenhouse gas emissions in the region. This paper analyzes economic data from the region upwind of the measurement site near the town of Santarem, in the state of Para, Brazil and investigates the causal relationship between these socio-economic indicators and local greenhouse gases concentrations.

Our results suggest that recent urbanization and waste generation patterns have emerged as important drivers of methane concentrations in the Santarem measurement site. Because of data constraints, this result relies on indirect evidence of urbanization and waste generation and further investigation of the hypothesized linkage between urbanization and methane emissions

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[13] We estimated a total of 36 models: 12 models (lag orders 1 through 12) involving levels of CO_2 and industrial production; 12 models involving differences of CO_2 and industrial production; and 12 models involving CO_2 and volume of sales of the trading sector.

seems a promising research avenue. Whereas the scientific community and policy makers often focus on bovine production as the sole significant source of anthropogenic methane emissions in the Amazon, the typical towns upwind of Santarem face severe waste management problems, and policies to efficiently manage waste disposal can have a significant impact on the quality of life for the local population as well as on the environment. Improper waste management is also pervasive in the broader Amazon region as well as many other parts of Brazil.

In the case of N_2O, our results suggest an expected positive relationship between agricultural activity and emissions, but no significant (indirect) relationship between fossil fuel burning, waste disposal and this greenhouse gas. Deforestation and expansion of agriculture in the region seems to be a leading cause of local nitrous oxide emissions.

Finally, our analysis for carbon dioxide concentrations suggests the expected result that deforestation plays a leading role in local emissions. This corroborates the view that Brazil is an important carbon emitter not so much because of its energy consumption (given the relative importance of renewable energy in the country), but because of deforestation in its territory, especially in the Amazon region. Perhaps more surprising is the finding that, despite vigorous economic growth in Brazil in recent years, the local industrial and services sectors do not seem to have significantly contributed to carbon emissions in the region.

Appendix I – Municipalities upwind of Santarem, Para

Abaetetuba
Abel Figueiredo
Acará
Afuá
Almeirim
Altamira
Anajás
Ananindeua
Anapu
Augusto Corrêa
Aurora do Pará
Bagre
Baião
Barcarena
Belém
Belterra
Benevides
Bom Jesus do Tocantins
Bonito
Bragança
Brasil Novo
Brejo Grande do Araguaia
Breu Branco
Breves
Bujaru
Cachoeira do Piriá
Cachoeira do Arari
Cametá
Capanema
Capitão Poço
Castanhal
Chaves
Colares
Concórdia do Pará
Curralinho
Curuçá
Dom Eliseu
Garrafão do Norte
Goianésia do Pará
Gurupá
Igarapé-Açu
Igarapé-Miri
Inhangapi
Ipixuna do Pará
Irituia
Itupiranga
Jacundá
Limoeiro do Ajuru
Mãe do Rio
Magalhães Barata
Marabá
Maracanã
Marapanim
Marituba
Medicilândia
Melgaço
Mocajuba
Moju
Monte Alegre
Muaná
Nova Esperança do Piriá
Nova Ipixuna
Nova Timboteua
Novo Repartimento
Oeiras do Pará
Ourém
Pacajá
Palestina do Pará
Paragominas
Peixe-Boi
Placas
Ponta de Pedras
Portel
Porto de Moz
Prainha
Primavera
Quatipuru
Rondon do Pará
Salinópolis
Salvaterra
Santa Bárbara do Pará
Santa Cruz do Arari
Santa Isabel do Pará
Santa Luzia do Pará
Santa Maria do Pará
Santarém
Santarém Novo
Santo Antônio do Tauá
São Caetano de Odivelas
São Domingos do Araguaia
São Domingos do Capim
São Francisco do Pará
São João da Ponta
São João de Pirabas
São João do Araguaia
São Miguel do Guamá
São Sebastião da Boa Vista
Senador José Porfírio
Soure
Tailândia
Terra Alta
Tomé-Açu
Tracuateua
Tucuruí
Ulianópolis
Uruará
Vigia
Viseu
Vitória do Xingu

Appendix II – VAR estimation procedure

To select the VAR model for CH_4 we first tested for unit roots in the series for CH_4 and volume of sales for the trade sector. Augmented Dikey-Fuller tests based on a drift process or drift and trend process suggest that both series are stationary. We then estimated a VAR model in levels of the variables with a lag order $p = 1$. The choice of $p = 1$ for the lag order is due to the fact that surface CH_4 emissions are expected to quickly affect measurements. Furthermore, inclusion of additional lags restricts our already relatively small time series. Nevertheless, we also estimated VAR models with higher lag orders. For $p = 1$ through 4, the models exhibit characteristic roots that are less than one and residuals that are not autocorrelated, and we fail to reject normality of the residuals. These models produced qualitatively similar impulse-response functions. For $p = 5$ through 12, the corresponding models produced autocorrelated residuals, and for $p = 7$ through 12 some of the estimated characteristic roots are greater than 1, thus violating the stability assumption of the estimated models. A similar procedure was adopted for the analysis of the N_2O and CO_2 series.

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Table 1: CH4-Sales VAR(1) estimates

	CH4 Equation		Sales Equation	
CH4.l1	0.1629		-0.03796	
	(0.1565)		(0.0438)	
Sales.l1	0.8355	**	0.70671	****
	(0.4039)		(0.11305)	
Constant	-87.4663		53.76551	***
	(66.623)		(18.64672)	
Trend	-1.1801	**	0.20097	
	(0.4723)		(0.13219)	
SD1	-61.638	***	-30.653	****
	(20.8834)		(5.84494)	
SD2	-45.4353	**	-2.56638	
	(19.3463)		(5.41473)	
SD3	-78.2669	***	-26.31984	****
	(23.5382)		(6.58796)	
SD4	-59.6527	**	-17.66953	**
	(23.9599)		(6.706)	
SD5	-41.7553	*	-14.34058	**
	(23.928)		(6.69708)	
SD6	-31.384		-14.50608	**
	(23.5295)		(6.58553)	
SD7	-46.9639	*	-14.10141	**
	(23.2335)		(6.50268)	
SD8	-54.7114	**	-22.38214	***
	(24.1021)		(6.7458)	
SD9	-36.9494		51.7153	****
	(22.9615)		(6.42657)	
SD10	-72.9396		-74.66569	****
	(44.3004)		(12.39897)	
SD11	-3.8255		-38.15405	****
	(19.9621)		(5.58707)	
R2	0.581		0.9479	
Adj R2	0.4134		0.9271	
F(14,35)	3.466		45.5	
	[0.001412]		[< 2.2e-16]	
N	50		50	

Notes: standard errors in parenthesis, p-values in square brackets, '****' p<0.001 ,'***' p<0.01, '**' p<0.05, '*' p<0.1

Table 2: CH4-Sales VAR(1) post-estimation tests

H0: Normally distributed errors		
J-B Chi2(4)	Skewness Chi2(2)	Kurtosis Chi2(2)
6.1202	2.0032	4.117
[0.1903]	[0.3673]	[0.1276]
H0: Errors are not autocorrelated		
B-G Chi2(20)		
21.9476		
[0.3434]		
Granger causality tests		
H0: CH4 does not cause Sales	**H0: Sales do not cause CH4**	
F(1,70)	F(1,70)	
0.7509	4.2789	
[0.3892]	[0.04228]	
Roots of characteristic polynomial		
0.6403		
0.2294		

Note: P-values in square brackets.

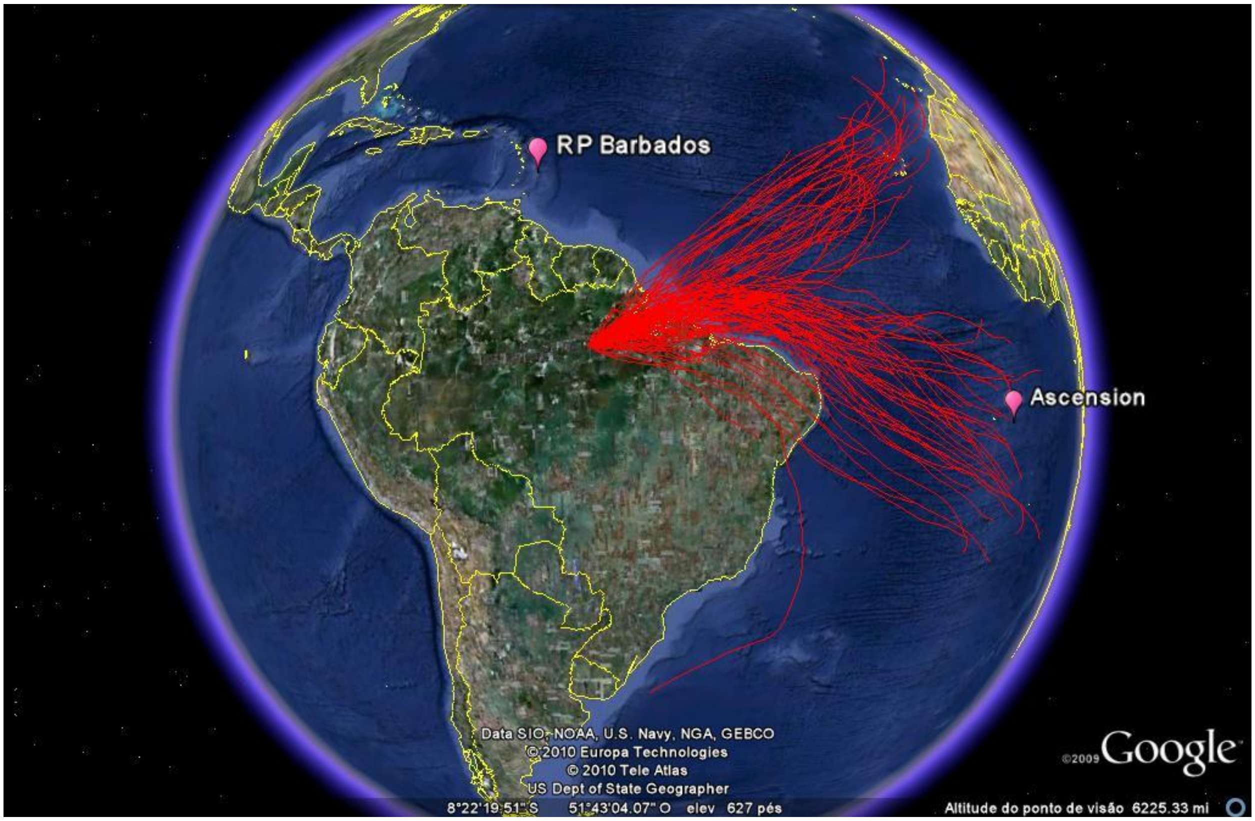

Figure 1: Back trajectories for air flows arriving at the Santarem measurement site at 500m and obtained with the Hysplit back-trajectory model (Draxler, 2011).

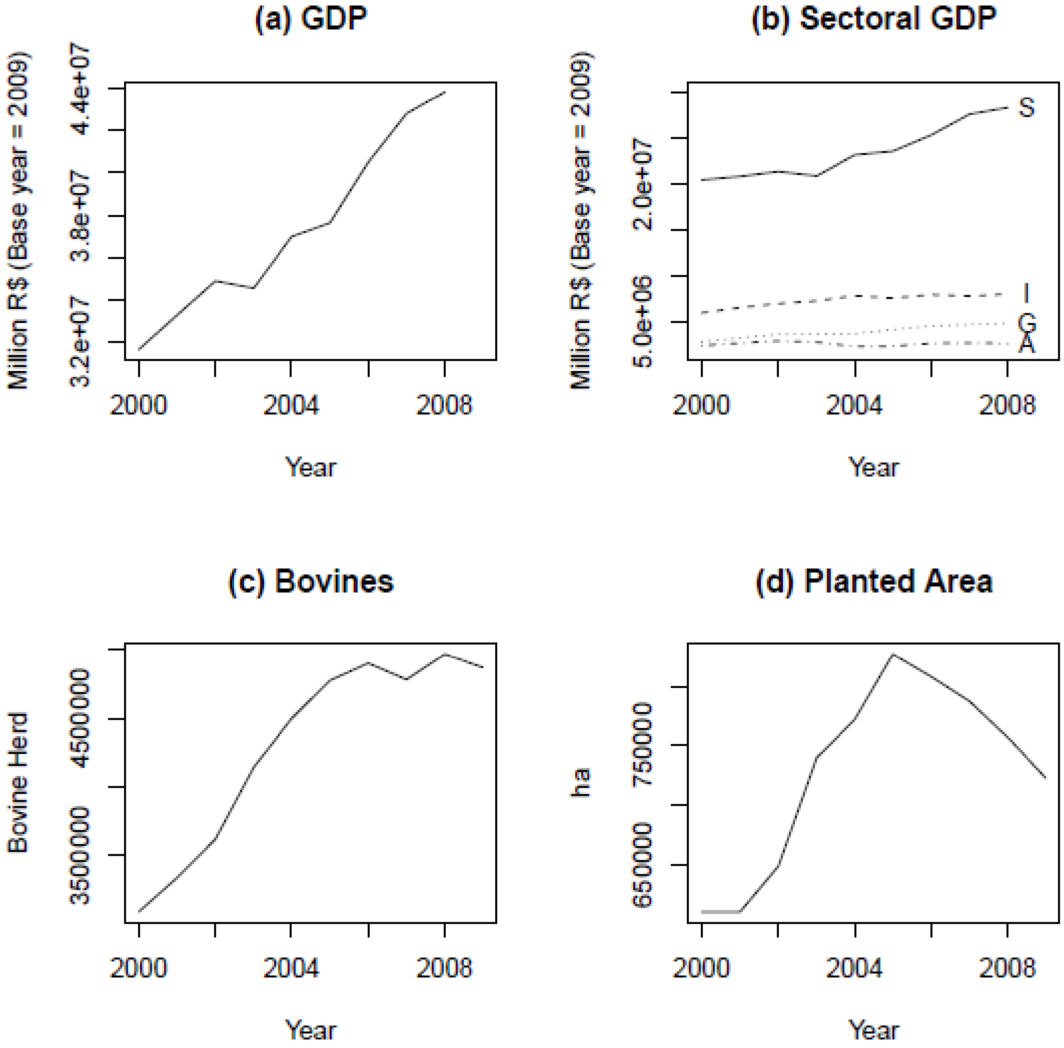

Figure 2: Economic indicators for municipalities upstream of Santarem, Para – annual data.

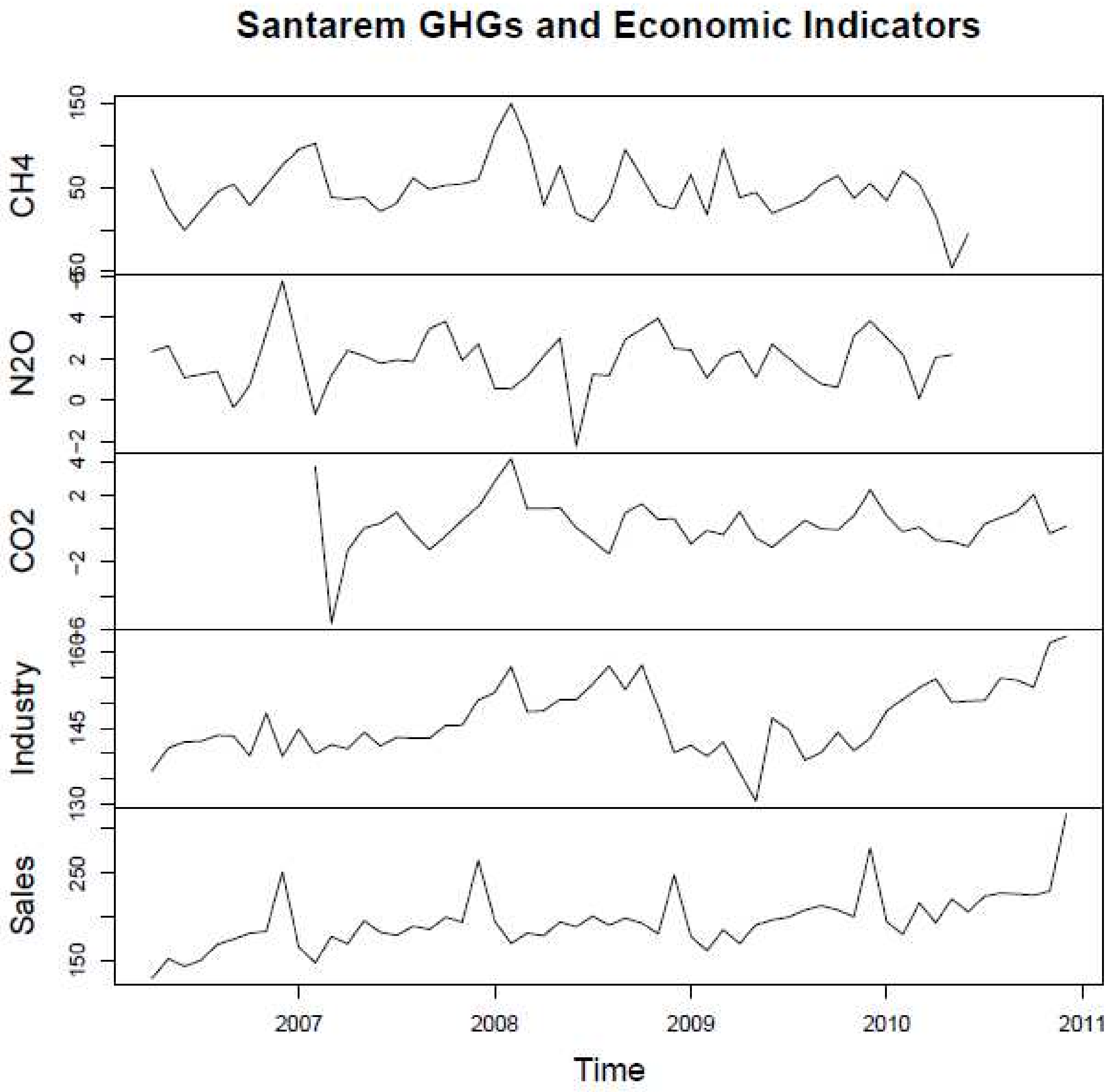

Figure 3: Greenhousegases in Santarem and Para economic indicators – monthly observations.

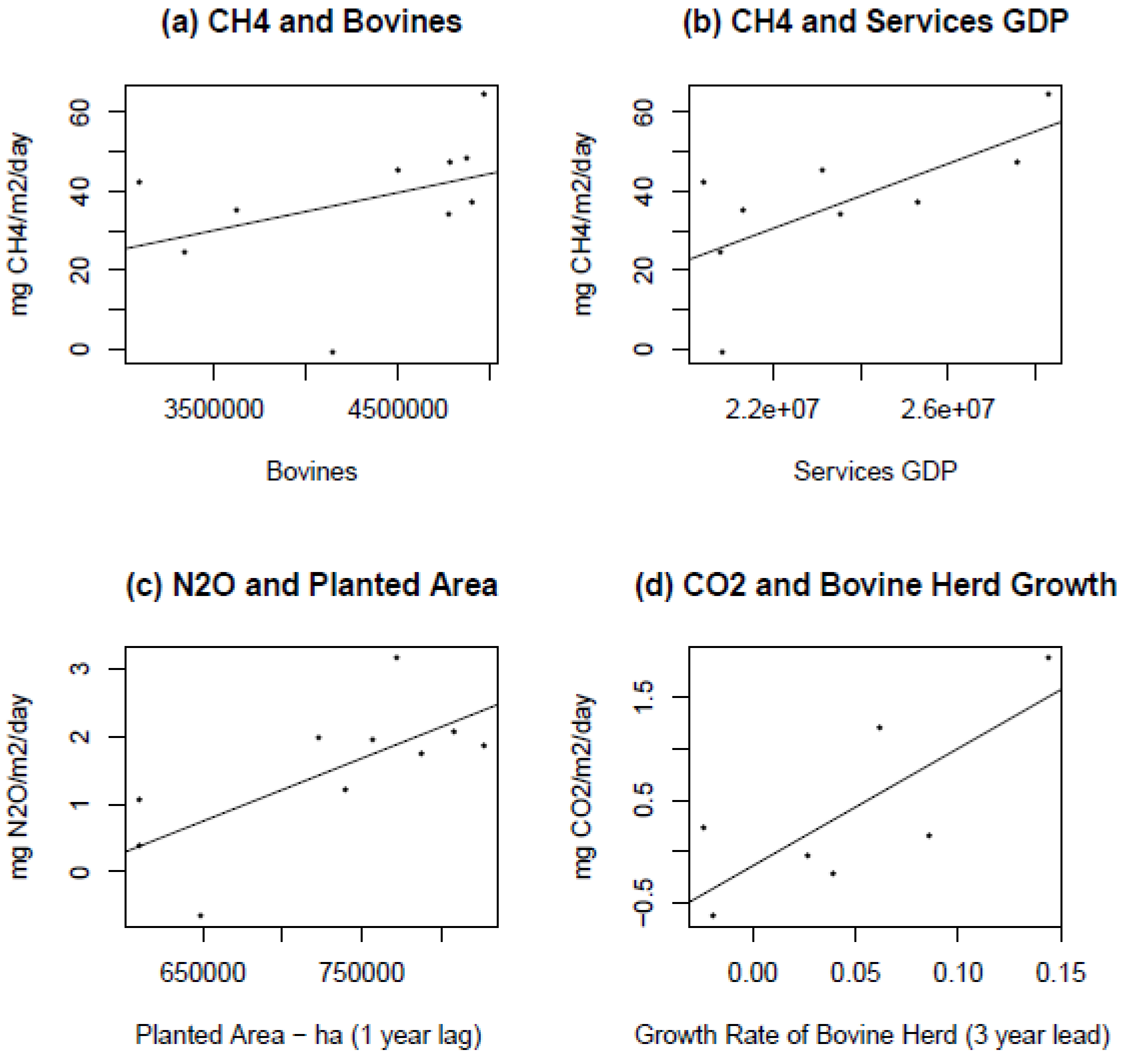

Figure 4: Greenhouse gases and economic indicators for municipalities upstream of Santarem, Para – annual data.

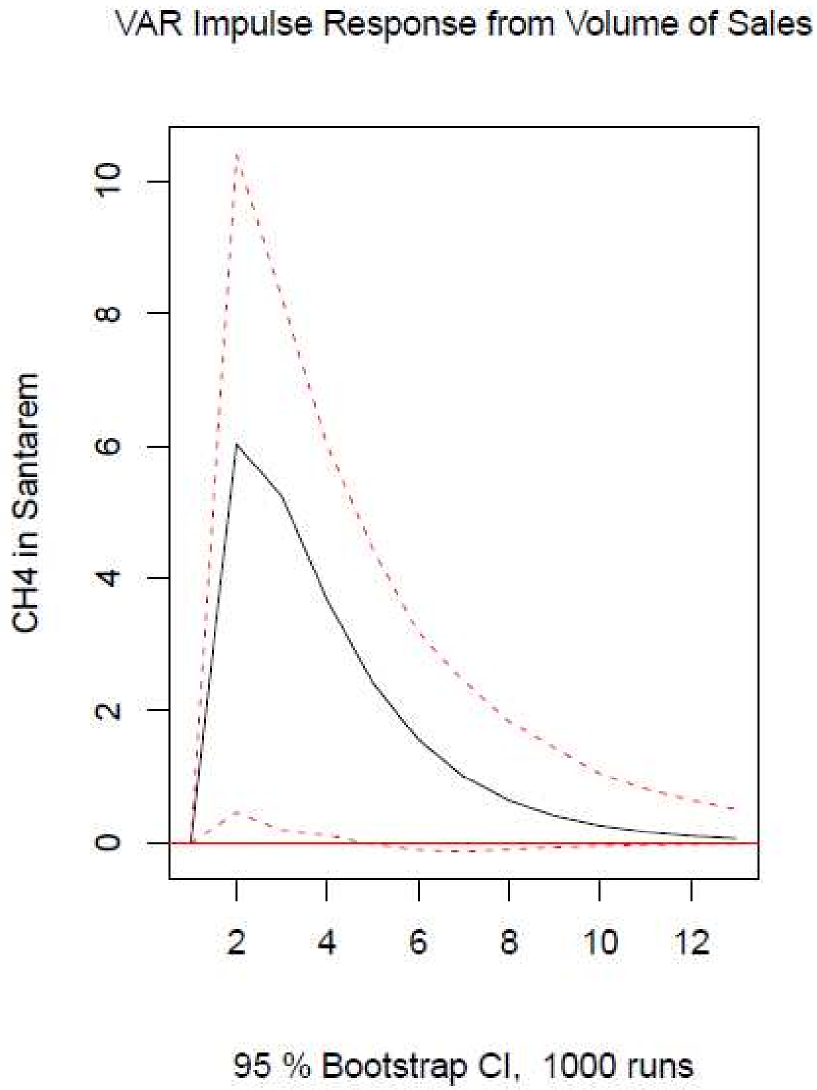

Figure 5: Impulse-response function. Impulse = Sales; Response = CH_4. Dashed lines are 95% bootstrap confidence intervals.

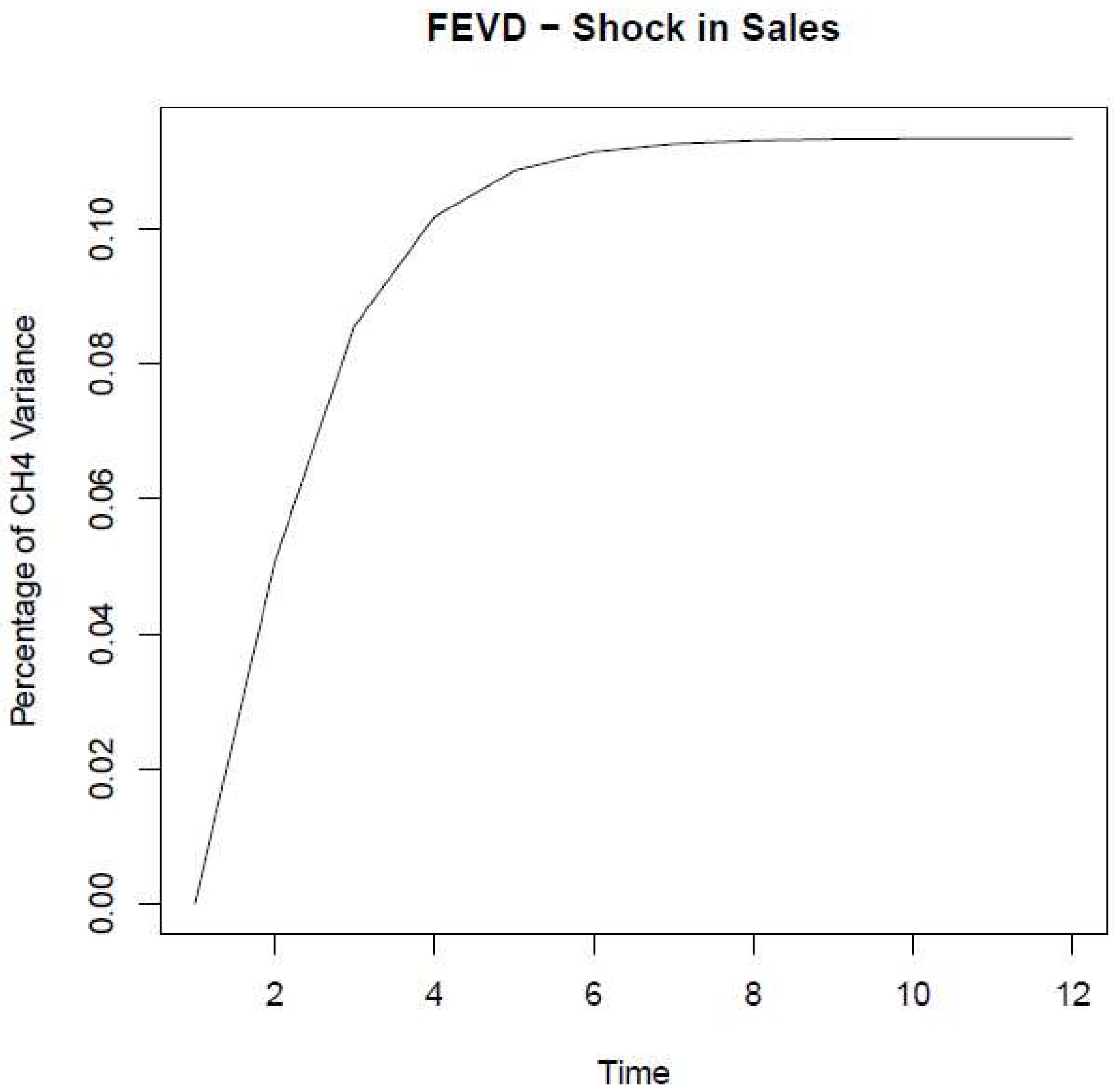

Figure 6: Forecast error variance decomposition. Impulse = Sales; Response = CH_4.