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Sectoral Offsets in the Mexican Oil and Gas Industry

Developing a Credible Baseline via Econometric Methods

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RESOURCES FOR THE FUTURE

Sectoral Offsets in the Mexican Oil and Gas Industry: Developing a Credible Baseline via Econometric Methods

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Abstract

Sectoral greenhouse gas offsets can provide the same incentives for emissions reductions as a carbon tax or a cap-and-trade program, with a focus on rewards rather than costs. This paper develops a pilot analysis of such offsets using relatively transparent quantitative methods to estimate a business-as-usual (BAU) emissions path for the gas and basic petrochemical subsidiary of Mexico's national oil company, Pemex. This BAU path, in turn, may be used as a basis for monetizing emissions reductions via bilateral or international offset transactions, with potentially low transaction costs. Overall, the analysis finds that a 10 percent emissions reduction below baseline would yield about US$40 million in additional revenue over a 13-year period for this Pemex subsidiary at a price of US$10 per ton of carbon dioxide (CO_2). Larger emissions reductions, higher offset prices, or expansion to other, larger company units could generate correspondingly higher revenues.

Key Words: greenhouse gas emissions, sectoral offsets, baselines

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Richard Morgenstern, Alexander Egorenkov, and Daniel Velez-Lopez*

1. Introduction

Mexico continues to make progress in efforts to reduce the energy and carbon intensity of its economy through a variety of energy efficiency and regulatory programs, as well as through energy infrastructure modernization. Market-based policies such as a cap-and-trade program or the recently introduced coal and oil tax of US$3.50 per ton of carbon dioxide (CO_2) are other possible options. Not surprisingly, developing a broad-based carbon pricing system is a nontrivial undertaking with its own set of institutional and political challenges. For example, under cap and trade, even when emissions allowances are initially given away for free, emitters may bear costs if the cap is less than the expected business-as-usual (BAU) emissions path. However, one can develop a sectoral carbon emissions reduction program that has all the building blocks of a cap-and-trade system—and, importantly, provides comparable incentives for the affected sector—but is based on a model of rewards rather than costs. Such a program differs from project-oriented approaches like the Clean Development Mechanism (CDM) in that the focus is on relatively large-scale emissions reductions with low transaction costs. As in the CDM, emissions reductions in a sectoral offset program would be financed by a foreign buyer and likely credited in a foreign emissions reduction program.

A key issue in developing a sectoral offset program is the definition of the BAU or baseline emissions path—that is, the reference point reflecting the emissions that would occur in the absence of any effort to create an offset. Although by its very nature the baseline is a hypothetical construct, it is critical that the underlying analysis represent a careful and credible statement about the conditions that would apply in a BAU world. Because every extra ton of emissions included in the baseline represents a ton of emissions reductions that could potentially be sold in bilateral or international markets, great care must be taken to avoid bias. Clearly, it would be unacceptable on both environmental and ethical grounds to market as offsets those

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emissions reductions that would have occurred in the absence of an offset program, sometimes referred to as “anyway tons.”

Even though the basic notion of sectoral offsets is reasonably straightforward, they are not currently used in Mexico or elsewhere. The overall aim of this paper is to support the development of a sectoral offset program, focusing on a segment of the Mexican national oil and gas company, Pemex, as a pilot study. The immediate goal is to analyze historical CO_2 emissions from the Pemex Gas and Basic Petrochemicals (PGBP) subsidiary and, using simple statistical methods, estimate future emissions based on company projections about future production levels. The estimated baseline emissions projections, in turn, could be used as a basis for discussions with potential buyers of international offsets. The selection of PGBP for this pilot study was based on the assumptions that Pemex is seeking to reduce its greenhouse gas (GHG) emissions, that the historical PGBP data hold the promise of being useful for estimating baseline emissions, and that the scale of likely emissions reductions in PGBP is sufficiently large to attract potential international buyers.

The analytical challenge is to develop a simple statistical model to explain PGBP emissions when the quality of inputs, the production volumes of various outputs, and the technology, scale, and efficiency of the different plants are all changing over time. Beyond simple graphical analysis, our approach involves performing time-series regression analyses on key inputs and outputs.

Following this brief introduction, Section 2 provides background information on Pemex and, more generally, on sectoral offsets. Section 3 presents a descriptive analysis of emissions and output at PGBP over the period 2004–13, based on monthly data in Pemex’s Information System of Industrial Safety and Environmental Protection (SISPA).[1] Section 4 develops a simple statistical model to estimate the amount of CO_2 emissions reductions attributable to system-wide efficiency improvements occurring at PGBP over the study period. The results of this exercise are then used to project BAU emissions paths out to 2026. Section 5 summarizes the lessons learned from this effort and offers a series of conclusions and recommendations for next steps. The Appendix contains a detailed summary of the data.

[1] A description of SISPA may be found in Carrisoza et al. (2002).

2. Background

2.1. Pemex

Pemex is a large, integrated, state-owned oil company, with operations involving upstream oil and gas development and extraction, refining, petrochemical production, and downstream refined products. Overall, there are tens of thousands of point and nonpoint sources of GHG emissions within the company. These sources could, in principle, be regulated using traditional, prescriptive regulations, although that would likely be a highly inefficient approach. The vast number of individual sources involved and the inherent complexity of the regulatory process needed to address the multiple sources cry out for a market-based approach. In fact, a within-company cap-and-trade program did operate in Pemex in 2001–05 on a demonstration basis. That program was designed to stimulate competition among Pemex subsidiaries to identify cost-effective abatement options and operational best practices. Twenty-five individual company units participated in the voluntary market, including the company's four regional exploration and production units, the well-drilling and maintenance unit, six refineries, seven gas-processing centers, and eight petrochemical centers. By the end of 2004, 3.64 million metric tons (MMT) of CO_2 had been traded, with a virtual market value of 198 million pesos (Burtraw et al. 2010). The market's nonobligatory nature and capital budget constraints limited the program's effectiveness, but the fact that a comprehensive internal market framework that considers business-unit baselines, pricing, and verification has already been developed could facilitate creation of a sectoral offset program within Pemex.

Although it is responsible for less than 10 percent of Pemex's overall GHG emissions, PGBP is an attractive subject for pilot analysis because its operations are relatively simple and transparent compared with those of other Pemex subsidiaries. Arguably, one could analyze a larger, more complex subsidiary, such as refining. However, in consultation with Pemex and World Bank officials, and with an emphasis on the use of available data to demonstrate feasibility, the decision was made to focus on PGBP for the initial study. The analysis presented here is based strictly on combustion-related CO_2 emissions. Fugitive emissions of methane or other greenhouse gases are not considered. The rationale for the exclusion of fugitives, also made in consultation with Pemex and bank officials, is twofold. First, although there has been some recent monitoring of fugitives, to our knowledge no systematic monitoring has been conducted over a long enough period to incorporate into our statistical analyses.[2] Second, the limited

[2] For a description of the available fugitives monitoring data, see Pemex (2013).

information that is available on fugitives, based on US Environmental Protection Agency emissions factors for the years 2009–11, suggests that such emissions are a relatively small portion of the totals.

2.2. Sectoral Offsets

At the outset, it is important to distinguish between a sector-based offset program—the boundary of which is either an entire industrial sector or, more likely, a subsector within a broader industrial classification—and project-level emissions reduction activities of the type considered by the CDM.[3] By their very nature, project-level activities do not typically encompass multiple processes within a firm and generally focus on a single process or narrowly defined industrial activity. The limits of the CDM are well known. Even before the 2010 declines in international allowance prices, experts identified problems with the CDM, including issues of environmental integrity, weak governance, inefficient operation, high transaction costs, the limited size and scope of the incentives, and the small-scale nature of the projects.[4] In contrast, the strengths of the sector-based approach—still to be demonstrated—are the potentially lower transaction costs and larger-scale emissions reductions that could be obtained by system-wide investments.

The metric of success in a sector-based program is total emissions reduced rather than individual technology or engineering improvements adopted. From the company's perspective, however, reduced emissions *intensity*—synonymous with improved efficiency—is the principal factor under its direct control, as demand for the company's output is usually considered to be exogenous. Thus there is a certain tension between the social goal of reducing total emissions and the more tractable management challenge of reducing emissions intensity. Although firms are generally more comfortable with intensity targets rather than an absolute cap, intensity reductions could be readily translated into an absolute tonnage reduction.

Scale is important for two reasons. First, if the goal is to ready Pemex for a future economy-wide carbon pricing program, it is important to involve as much of the company as possible in these early efforts to reduce emissions and to begin to develop a corporate culture that

[3] In the case of Pemex, we treat PGBP as a potential candidate for sectoral offsets because it represents a distinct, fairly broad set of activities and is also a separate business unit within the (monopoly) company. Many of the activities conducted in PGBP would fall under category 486210 in the North American Industry Classification System, Natural Gas Gathering and Processing Systems.

[4] For example, see World Bank (2010), 265–67.

seeks out low-cost emissions reduction opportunities throughout the company. The best way to accomplish that goal is to look at emissions across an entire Pemex business unit. Second, potential international buyers, such as the state of California, are likely interested in bulk purchases of tons rather than small-scale CDM project-level transactions. Japan, which does not have an official emissions target beyond 2013, is also a potential buyer, although the current focus of Japanese efforts is on promoting exports of environmental technologies and influencing the design of future carbon markets.

A future Mexican program might work as follows. Pemex would signal to potential international buyers that it wished to enter into bilateral negotiations regarding sector-based offsets for its entire petroleum sector or a major subsidiary, such as PGBP. Especially since petroleum is one of the covered sectors in most major emissions control programs, those potential international buyers would likely welcome engagement with this sector, as they could rely on their own domestic experience in structuring the transaction.

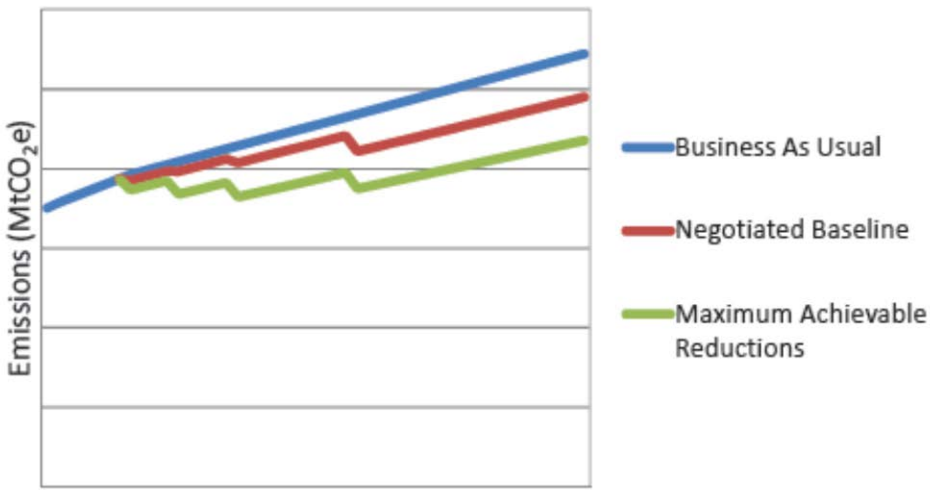
As part of a Pemex initiative in this area, it would be necessary to undertake several activities, including the following:

- development of credible estimates of a BAU emissions path for relevant business lines for a major sector or subsector over a significant time frame;
- analysis of emissions reduction options (costs and benefits);
- discussion with potential offset buyer(s) concerning BAU emissions and the nature and terms of possible offset transactions; and
- negotiation over the specific terms, including the amount and timing of both emissions reductions and payments, as well as the monitoring, reporting, and enforcement mechanisms.

As noted, this report looks only at the first of these activities—namely, the development of a credible BAU path using PGBP as a pilot study.

The top curve in Figure 1 represents a hypothetical BAU path. As shown, BAU emissions are projected to rise continuously over time for this hypothetical sector or subsector. The standard advice when entering any negotiation is to understand one’s own reward structure, options, and reservation price. Therefore, it is crucial for Pemex to know with a high degree of confidence the maximum achievable emissions reductions that can be implemented through politically and economically acceptable actions. This will involve the analysis of both the benefits and the costs of the emissions reduction options. The company can then negotiate a baseline with confidence and know what specific actions it must undertake to achieve the terms of the international agreement. The bottom curve in Figure 1 is a hypothetical representation of the maximum achievable reductions.

Figure 1. Hypothetical Business-as-Usual Forecast, Negotiated Baseline, and Maximum Achievable Reductions



Source: Burtraw et al. (2010, 6).

The middle curve in Figure 1, labeled “Negotiated Baseline,” represents the results of the international negotiations. Part of those negotiations would involve ensuring stringent monitoring, reporting, and verification such that actual emissions from covered sources are achieved. The negotiations will also involve agreement on the precise amount and timing of emissions reductions and payments for those reductions. To the extent that sector or subsector emissions are below the negotiated baseline, offset credits may be generated and sold.

Clearly, establishing the baseline is at the heart of the bilateral negotiations. The value of the offsets generated by the program equals the area between the negotiated baseline and the actual emissions (not shown in the diagram) multiplied by the market price for offset credits.

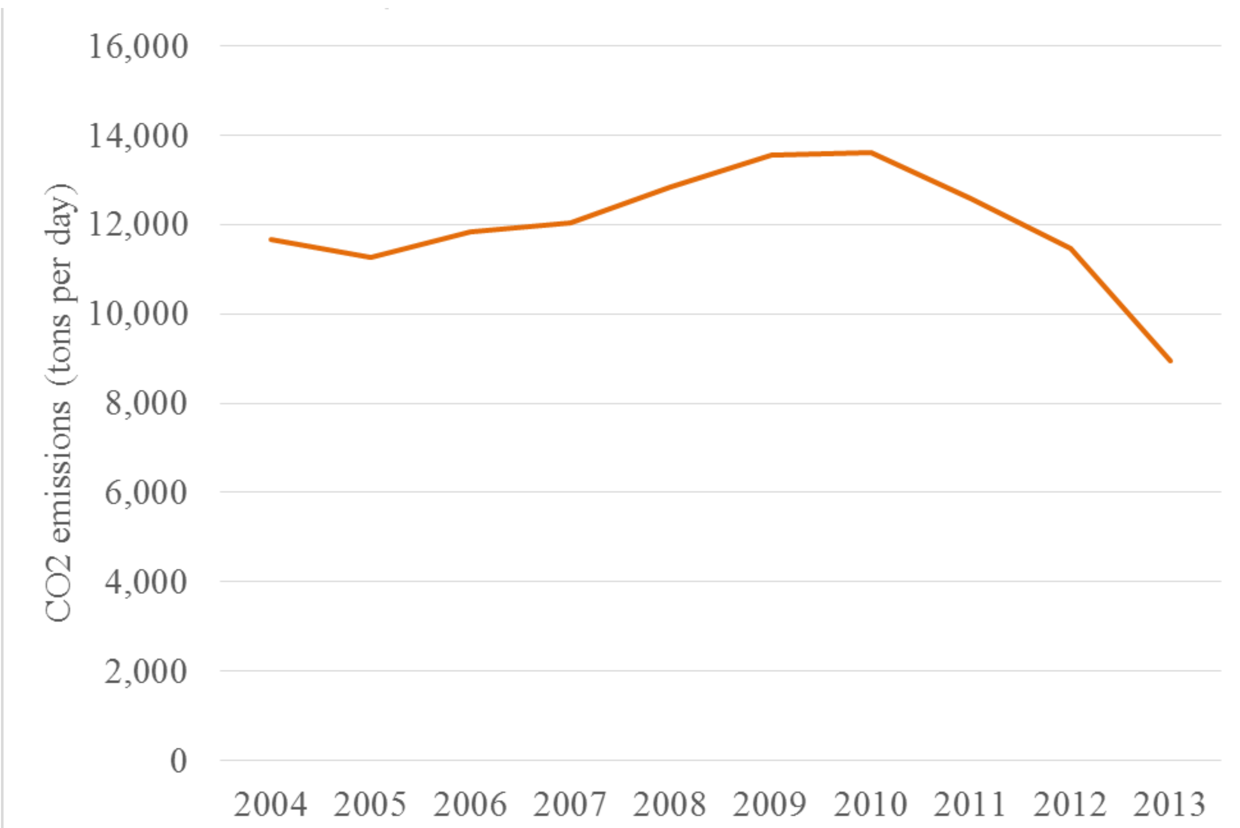
With the aim of developing a credible BAU emissions path for PGBP as a precursor to future negotiations, we review the performance of the company’s nine gas-processing centers (GPCs). Specifically, we examine the available information on historical emissions and the relationship between emissions and production as we seek to forecast a BAU path for future PGBP emissions.

3. Initial Analysis of Emissions and Output, 2004–13

3.1. Total CO_2 Emissions

To gain insight into the future path of CO_2 emissions at PGBP, we examine past emissions patterns. Figure 2 displays aggregate PGBP emissions from the nine GPCs, 2004–13, as reported in SISPA. Total emissions are calculated as the sum of emissions from natural gas combustion and from net electricity purchases, the latter based on average emissions per kilowatt-hour generated in Mexico. As shown, over the 10-year period, emissions have fallen at an annual rate of 2.9 percent, although the pattern is decidedly nonlinear. Emissions grew steadily between 2005 and 2009 at an annual rate of 4.7 percent per year. Since 2009, emissions have fallen at an annual average rate of 9.9 percent, with the largest decline occurring in 2013.

Figure 2. PGBP CO_2 Emissions

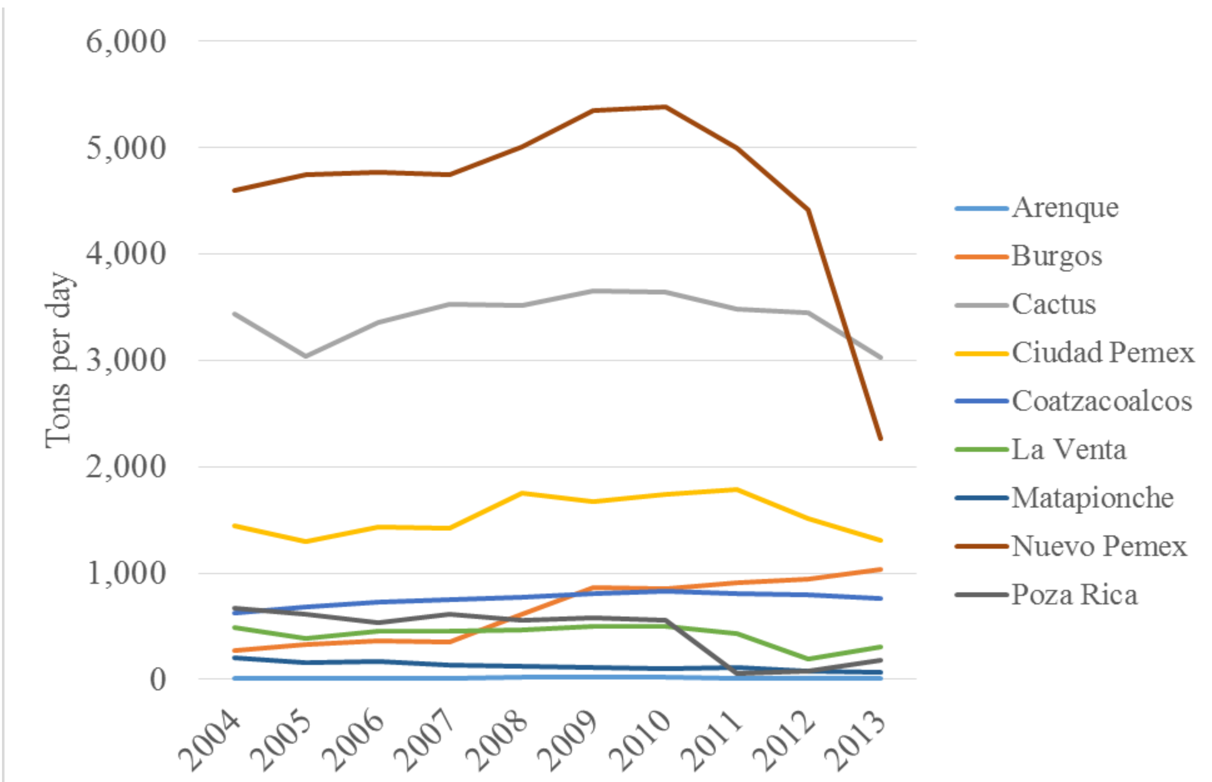


Source: SISPA, PGBP Gas Combustion Data.

Looking at emissions trends at individual GPCs, displayed in Figure 3, does little to clarify the picture. Most GPCs show a similar increase in emissions in 2009, followed by a gradual decrease, although smaller emitters like Poza Rica, Matapionche, and Arenque, which make up only about 6 percent of emissions, do not follow that path.[5]

The single largest emitter, representing about 40 percent of the total, is Nuevo Pemex, followed closely by Cactus. Not surprisingly, the emissions paths for both of these GPCs are quite similar to those for PGBP as a whole up through 2012. In 2013, we see a major drop in emissions at Nuevo Pemex. As described below, the 2013 decline reflects completion of a 300 megawatt (MW) cogeneration project involving water flows from the Mezcalapa River. Poza Rica, a very small unit, shows a decline from 2010 to 2011, reflecting the upgrade of a major compressor.

Figure 3. CO_2 Emissions by GPC



Source: SISPA, PGBP gas combustion data

[5] Discussions with Pemex staff suggest that the observed emissions increases in 2009 may be associated with the short-lived practice of injecting nitrogen into certain wells as a means of increasing recovery rates.

3.2. PGBP Production and Its Relationship to Emissions

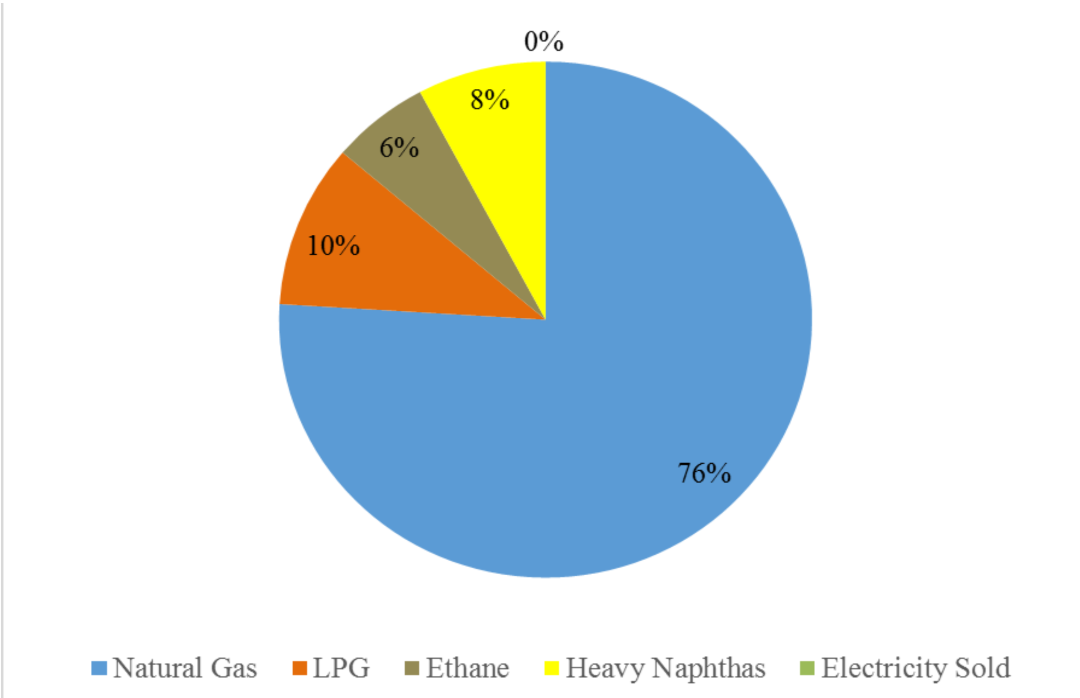
PGBP's production is centered on processing the different outputs from raw natural gas, which enters one of PGBP's gas sweeteners found in Cactus, Nuevo Pemex, Ciudad Pemex, Matapionche, Poza Rica, or Arenque. These sweeteners use a chemical process to remove "sour" gases (H_2S and CO_2) from the stream of raw natural gas. Elemental sulfur is recovered from the sour gases and sold. Once the sour gases are removed, the remaining sweet gas goes through a cryogenic expansion process to recover natural gas liquids (NGLs). The two outputs from that process are pipeline-ready dry natural gas and NGLs, which are taken to fractionators, where each of the marketable NGLs is separated by boiling point. C_2 (or ethane) is sold either into the pipeline with natural gas or to Pemex Petroquimica, where it is used for ethylene production. LPGs are marketed separately, as are heavier naphtha liquids such as C5+ and C6+, which are often mixed with crude oil. Concurrent with this process, condensed sour gas goes into different sweeteners, where NGLs are recovered while the gas is sweetened.

Each of PGBP's five petrochemical outputs—natural gas, ethane, LPG, C5+, and naphtha—differs in its energy content. Depending on whether aggregate production is measured in revenue or energy terms (dollars or BTUs), the relative importance of the different products varies.

Figure 4 displays production shares on the basis of energy, and Figure 5 shows production shares measured on the basis of revenue. In terms of energy, natural gas makes the greatest contribution to production, with 76 percent of total energy produced over the period 2004–13. However, looking at the shares in terms of revenue yields quite different results. As shown in Figure 5, natural gas, LPG, and heavy naphthas contribute nearly a third of revenue each, while other outputs have relatively minor values. Using either dollars or BTUs as the metric, electricity sold is a relatively minor output, accounting for less than 0.5 percent of the totals.

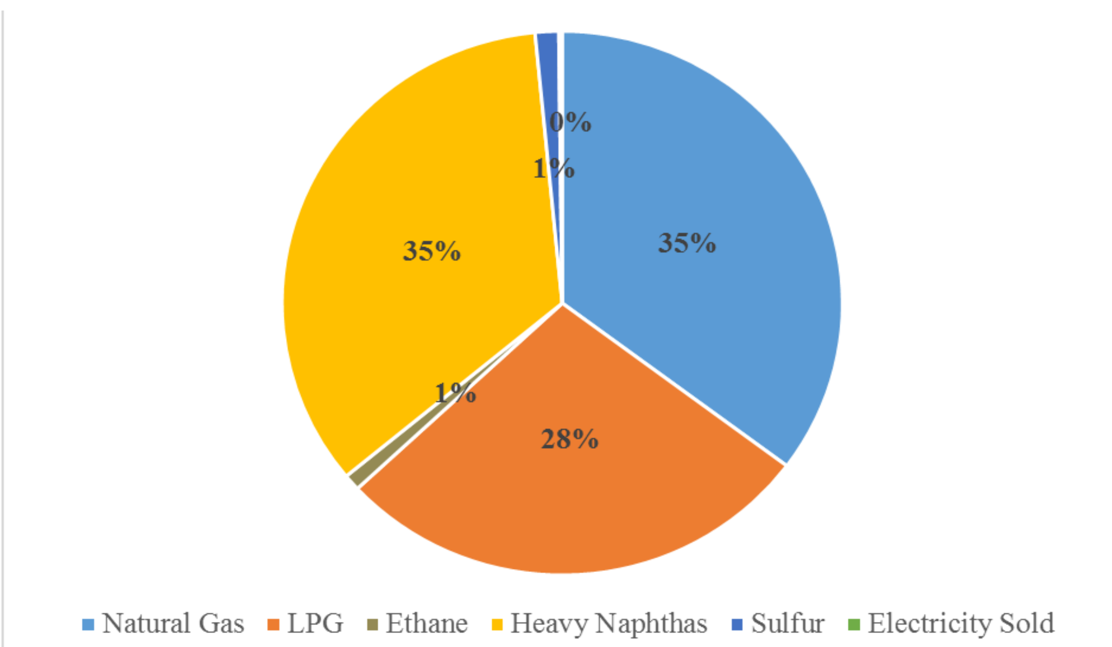
Analyzing the relationship between emissions and output can take various forms. Focusing on the production of high-volume or high-value outputs such as natural gas, LPG, or heavy naphtha liquids may be instructive. Looking at the path of production of these different outputs could reveal a relationship between production and CO_2 emissions. However, such an analysis will, by definition, yield an incomplete picture. Thus we aggregate outputs based on either BTUs or value in an attempt to understand the trends in efficiency. Unsurprisingly, because of the substantial differences in the relative BTU versus dollar valuations of the various outputs, the two metrics yield quite different results.

Figure 4. Share of Energy from Each Type of Output



Note: Outputs are weighted based on MMBtu.
Source: SISPA, PGBP production data.

Figure 5. Shares of Revenue from Each Type of Output (based on 2012 prices)

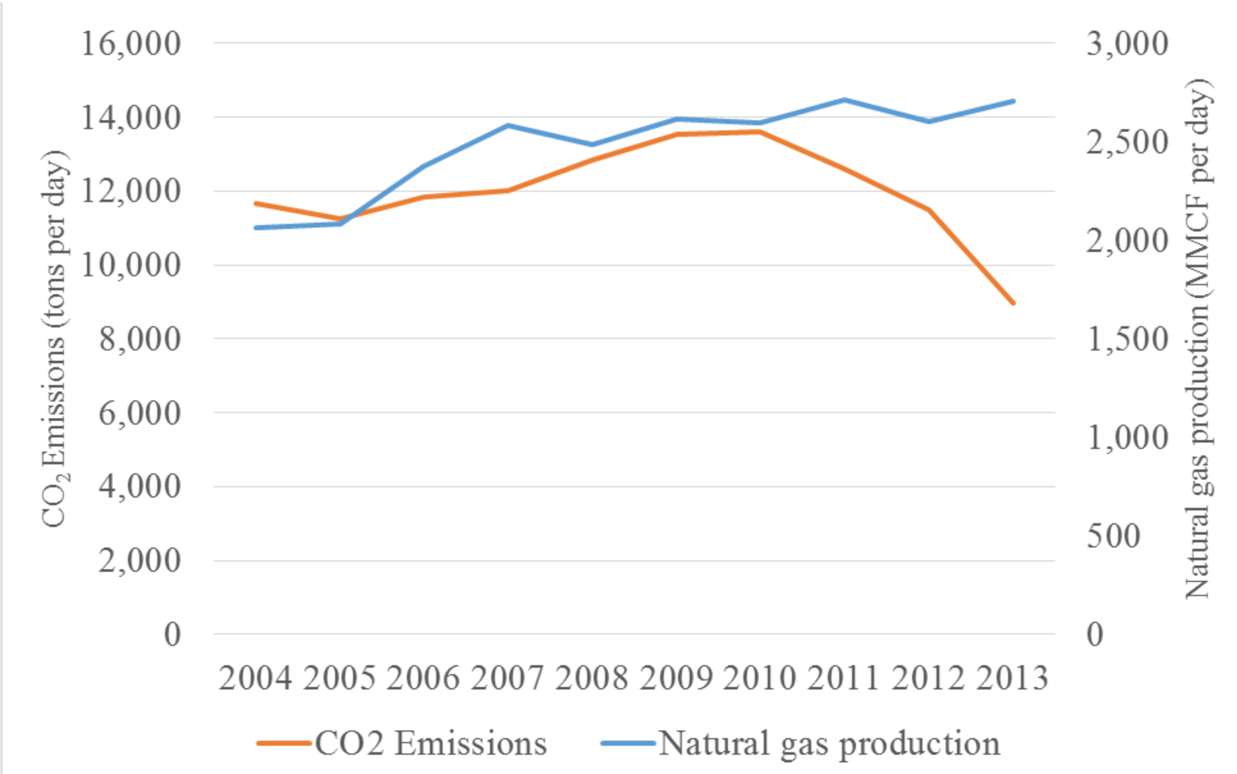


Note: Outputs are weighted based on 2012 Pemex prices.
Source: SISPA, PGBP production and price data.

3.3. The Path of Natural Gas, LPG, and Heavy Naphthas

Since natural gas is PGBP's most important product, both as a revenue stream and as an energy source, examining the path of natural gas production may provide some clues about the changes in CO_2 emissions over the period 2004–13. Figure 6 displays total CO_2 emissions alongside natural gas production. Although both show a general increase during the period, the shapes of the two curves differ. Production of natural gas increased by 3.1 percent per year over the entire period, whereas CO_2 emissions peaked in 2010 before declining below 2004 levels. As noted, over the entire 10-year period, total CO_2 emissions fell by an average of 2.9 percent per year.

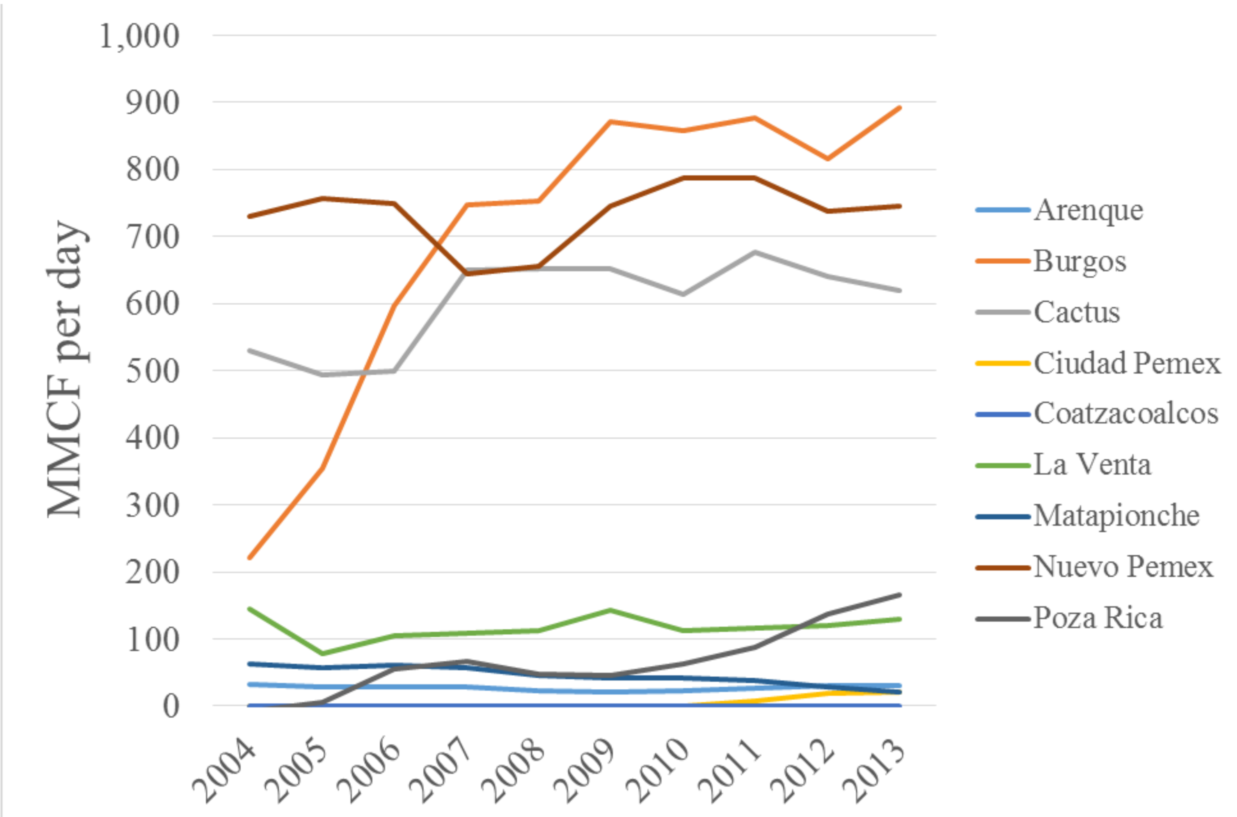
Figure 6. CO_2 Emissions and Natural Gas Production from PGBP



Source: SISPA, PGBP gas combustion and production data

Unsurprisingly, the pattern of natural gas production varies considerably across GPCs (Figure 7). Burgos began the period producing less than 300 million cubic feet (MMCF) per day as the fourth-largest gas producer. By 2007, however, it had risen to first place and continued increasing thereafter. Of the remaining two large GPCs, output for Nuevo Pemex fluctuated slightly from year to year, although 2013 production levels were not substantially different from those in 2004. At the same time, output in Cactus, which averaged 500 MMCF per day in 2004, exceeded 650 MMCF per day in 2007 and remained close to that level for the rest of the period. On close inspection, there are hints of interrelationships among certain GPCs, such as an apparent negative correlation between Cactus and Nuevo Pemex production levels.

Figure 7. Natural Gas Production by GPC



Source: SISPA, PGBP production data.

The other five GPCs have much less natural gas production than the top three. However, they exhibit some interesting changes. Poza Rica's production more than doubled over the 10-year period despite dropping to its lowest level in 2008. La Venta experienced a drop in production from 2004 to 2005 (46.4 percent) and then stable levels of production that rose only slightly out to 2013 (6.7 percent in total). Meanwhile, natural gas production in Matapionche decreased steadily during the entire period, from 61.1 to 21.5 MMCF per day. Finally, Matapionche consistently maintained the lowest levels of natural gas production.

Looking at LPG or heavy naphthas, the other major revenue-generating outputs, is not particularly informative either (Figure 8). From 2004 to 2014, the production of LPG and heavy naphthas dropped by 24.9 and 24.5 percent, respectively. Both curves show a similar shape, decreasing at 6.8 and 5.8 percent annually from 2004 to 2009 and then stabilizing thereafter. It may seem surprising that while natural gas production increased during this period, LPG and heavy naphtha production decreased. However, company officials indicate that this was primarily due to the changing quality of gas inputs.

Figure 8. LPG and Heavy Naphthas Production from PGBP

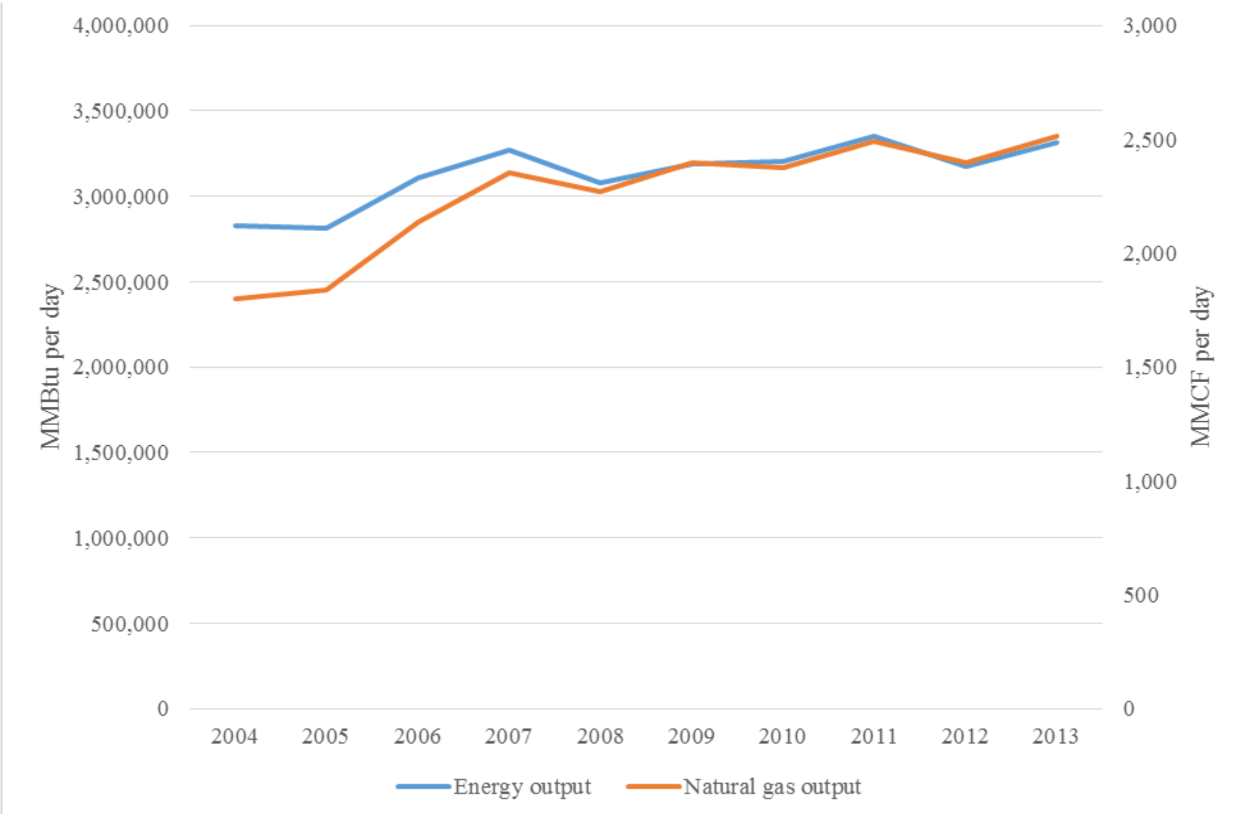
Source: SISPA, PGBP production data

3.4. Energy Output

Although natural gas is the most important product measured on the basis of energy content, the amount of energy that other outputs contribute is also important. To provide a comprehensive picture, it is necessary to include the energy content of these outputs as well.

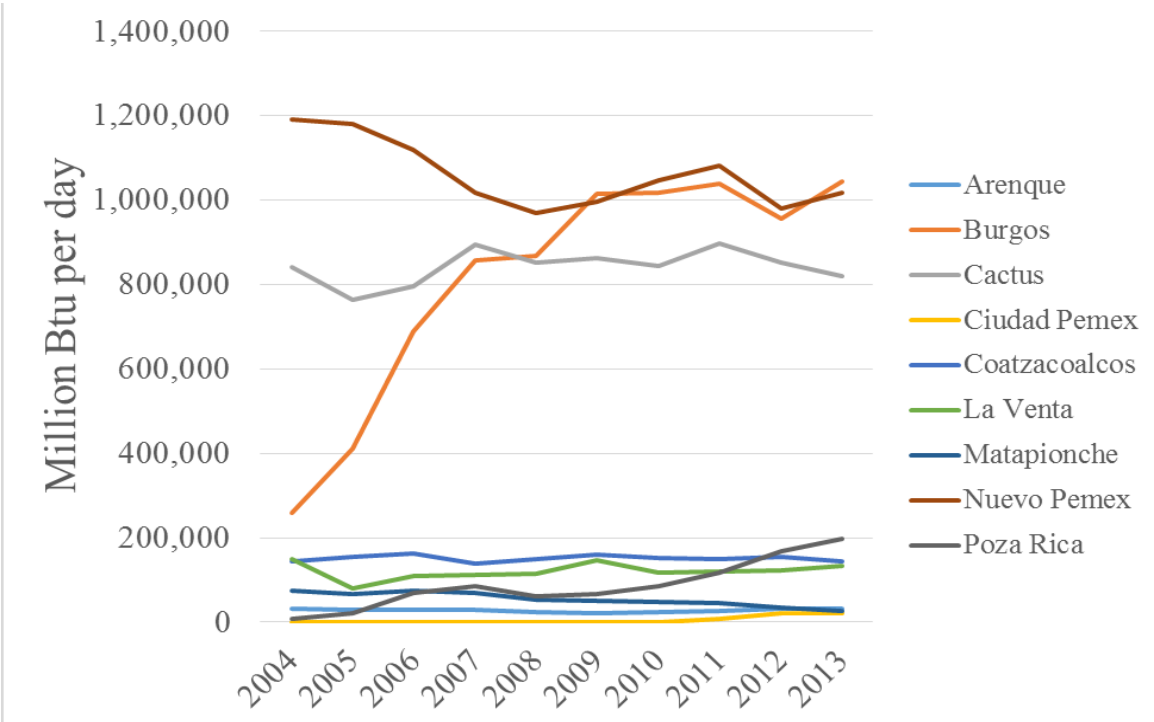
Similar to natural gas production, total energy output increased from 2004 to 2013, rising 1.4 percent annually over the period (Figure 9). Total energy output also experienced a slight dip in 2008, which is not reflected in the path of emissions for that year. Figure 10 displays total energy output by GPC. While relatively modest changes are seen in most GPCs over the study period, energy output increased quite dramatically at both Ciudad Pemex and Poza Rica.

Figure 9. Energy Output and Natural Gas Output from PGBP



Source: SISPA, PGBP production data.

Figure 10. Energy Output by GPC

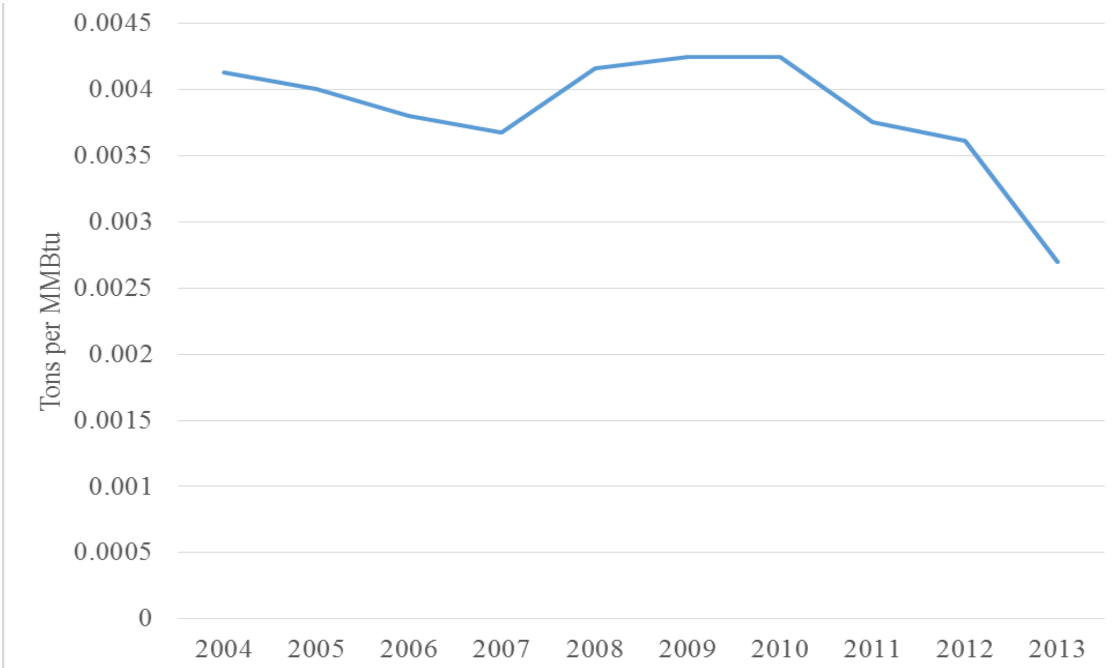


Source: SISPA, PGBP production data.

3.5. Emissions Intensity of Output

To evaluate how efficiently PGBP is operating, it is necessary to develop a measure of carbon efficiency that can be tracked over time. Emissions intensity (tons of CO_2 per MMBtu of product) is such a measure. Using the energy values of all six outputs as the measure of output, it is evident that emissions intensity followed a very similar path to that of total emissions (Figure 11). Emissions intensity dropped by 4.6 percent per year from 2004 to 2013, at a steeper rate than total emissions, but there was a spike in 2008, when emissions intensity increased by 13.1 percent. Evidently, something important happened in 2008 that caused substantial increases in emissions intensity and corresponding decreases in energy efficiency.

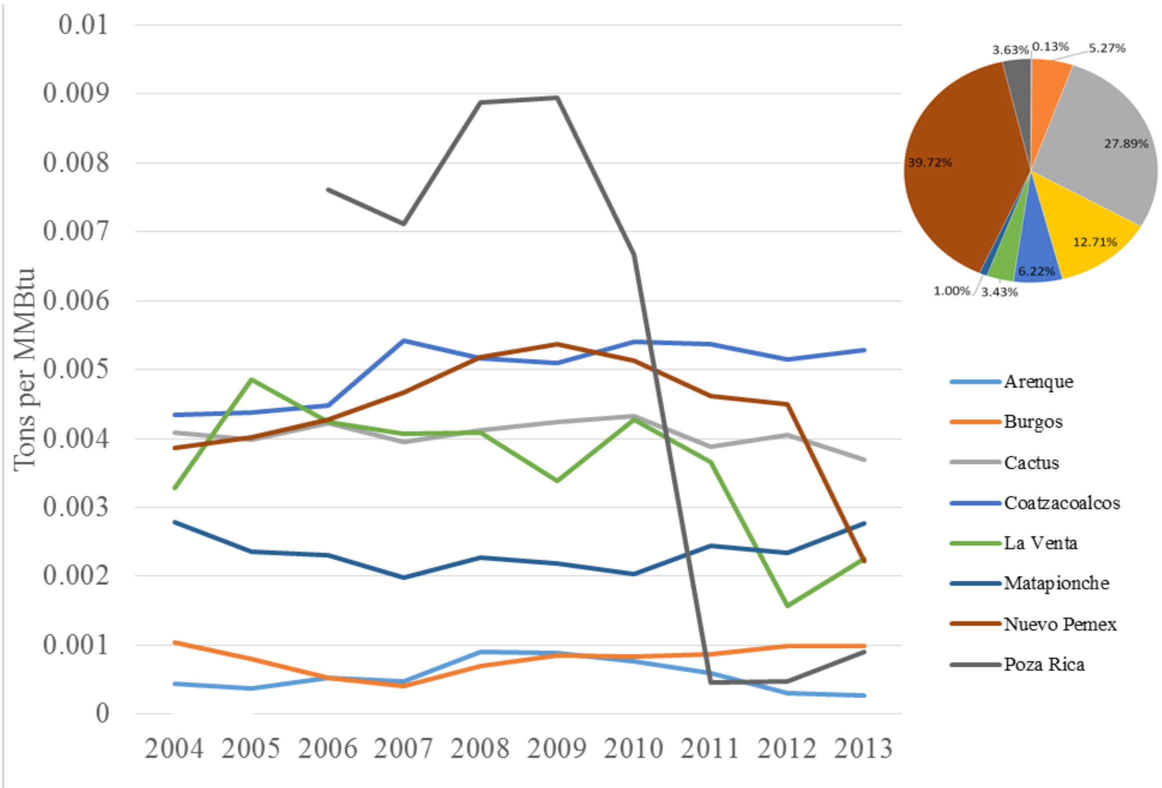
Figure 11. CO_2 Emissions Intensity for PGBP per MMBtu



Source: SISPA, PGBP gas combustion and production data.

Unsurprisingly, the emissions intensity patterns of several individual GPCs reflect those of the entire company (Figure 12). In 2004 and 2005, Poza Rica diverted its natural gas to the PEP fields and did not deliver it as an actual product. Poza Rica's emissions intensity increased by 24.6 percent from 2007 to 2008 and then decreased dramatically (more than 50 percent) from 2008 to 2012. However, Poza Rica is probably not a big driver of overall PGBP emissions, since it is such a small producer (as shown in the pie chart in Figure 12). Emissions intensity at Nuevo Pemex increased sharply (6.8 percent per year from 2004 to 2009) and then declined steadily by an average of 5.8 percent per year until 2012, with one final drop of 50.6 percent when the cogeneration project was introduced. Emissions intensity for La Venta, one of the less efficient plants, did not change dramatically over time except in 2012, when emissions intensity decreased by 56.9 percent. Burgos began the period as the second most efficient in 2005. Its emissions intensity dropped by 26.5 percent annually from 2004 to 2007 at a relatively steady pace, and by 2007 it was the most efficient GPC, before it became the third most efficient by increasing emissions intensity by 13.8 percent annually. Arenque had the lowest emissions intensity for most of the period, at about 0.0006 tons per MMBtu, but it was overtaken by Burgos in 2007 as the most efficient GPC, later tying for most efficient with Poza Rica. The emissions intensities of Cactus, Coatzacoalcos, and Matapionche remained close to the middle of the group and did not vary widely over the 2004 to 2013 period. Overall, emissions intensity shows a great deal of variation from 2004 to 2013 across the various GPCs.

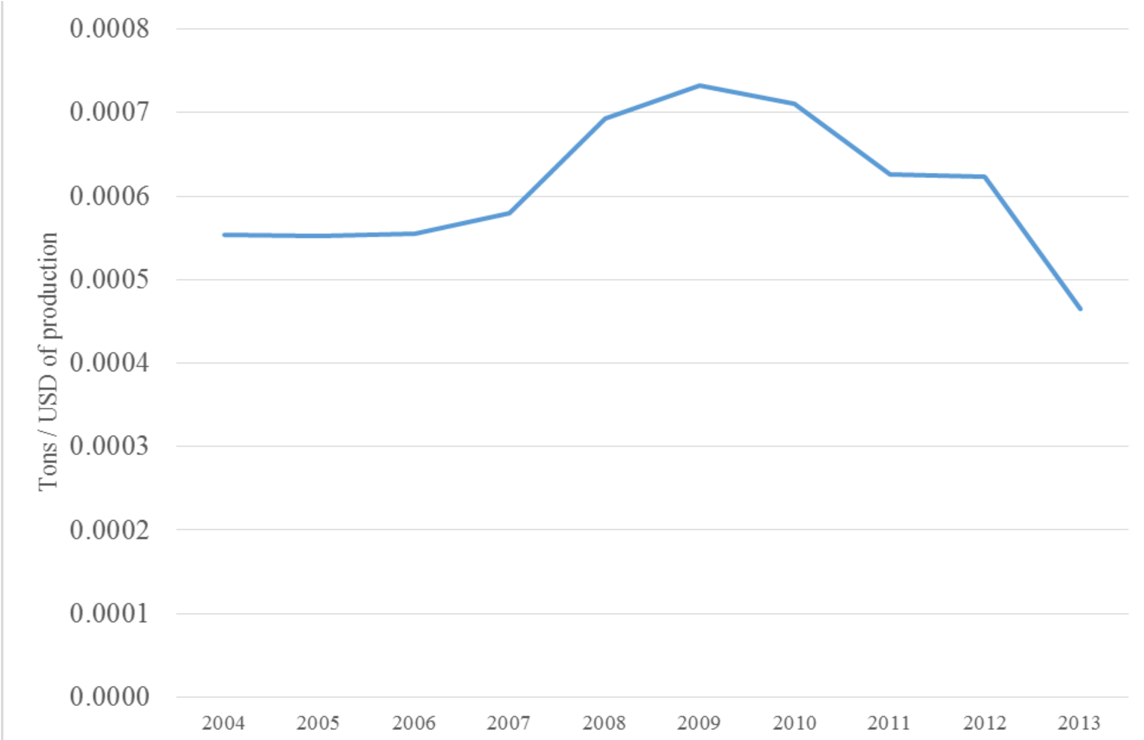
Figure 12. CO_2 Emissions Intensity by GPC per MMBtu



Note: Ciudad Pemex and Poza Rica (2004–05) are not included in this graph because they send natural gas to the petroleum exploration permit (PEP) fields and have artificially large emissions intensities. We do, however, include them in the aggregate calculation.
Source: SISPA, PGBP gas combustion and production data.

When we look at emissions intensity with regard to value of production, we see a generally similar picture at the PGBP level (Figure 13). However, we observe a small emissions intensity decrease of 1.9 percent per year, largely because Poza Rica shifted its natural gas output from the PEP fields to production.

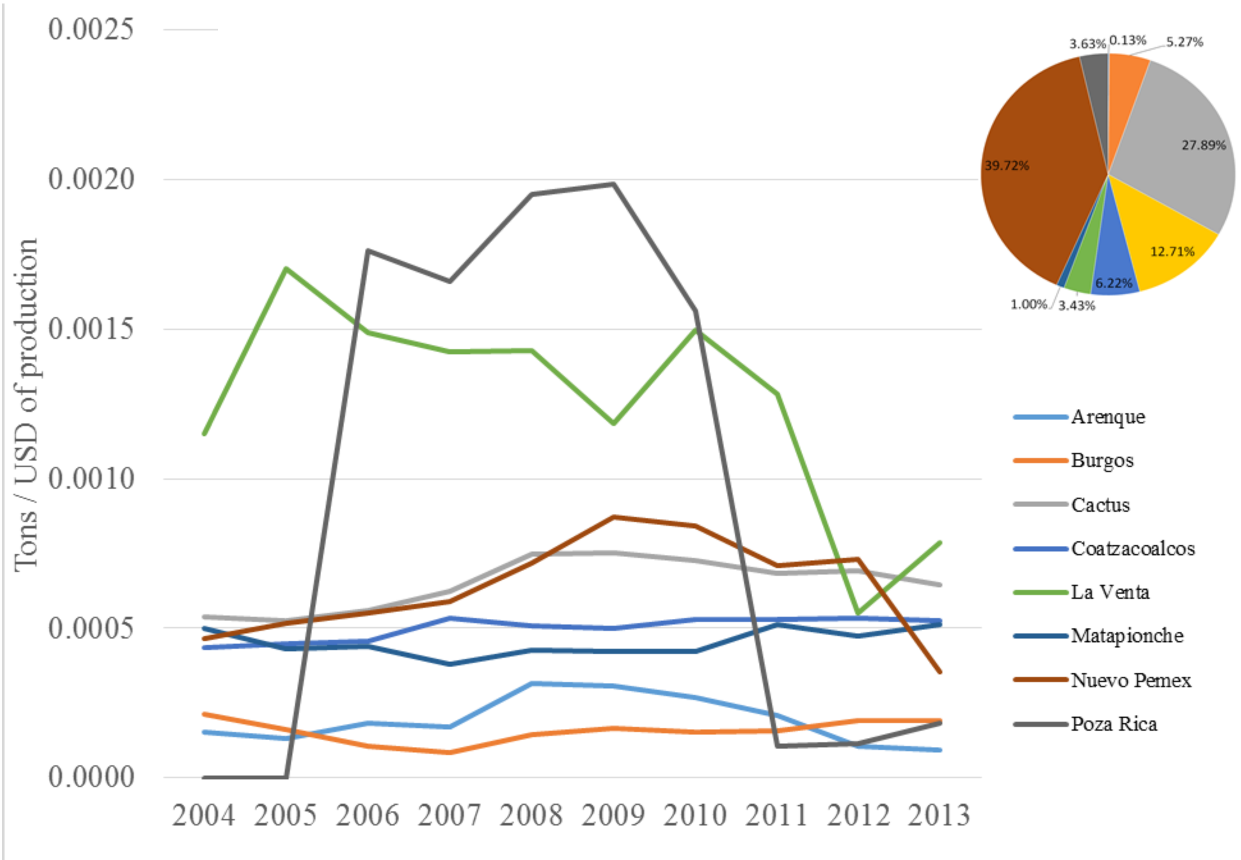
Figure 13. CO_2 Emissions Intensity for PGBP per US$



Source: SISPA, PGBP gas combustion, production, and price data

Looking at the changes in emissions intensity across GPCs yields a quite similar story when the metric used is the value of output in lieu of the energy content of output (Figure 14). The one outlier is La Venta, which is the most CO_2-intensive producer per US dollar (US$) for most of the period. This is because La Venta does not have any NGL products but is oriented exclusively to natural gas production, which accounts for most of the energy but only about a third of all revenue-generating production. We see a sharp decline in emissions intensity per US$ for both Poza Rica and La Venta in 2011. Again, these are relatively small plants that account for less than 4 percent of total CO_2 emissions from PGBP (as shown in the pie chart at upper right of Figure 14).

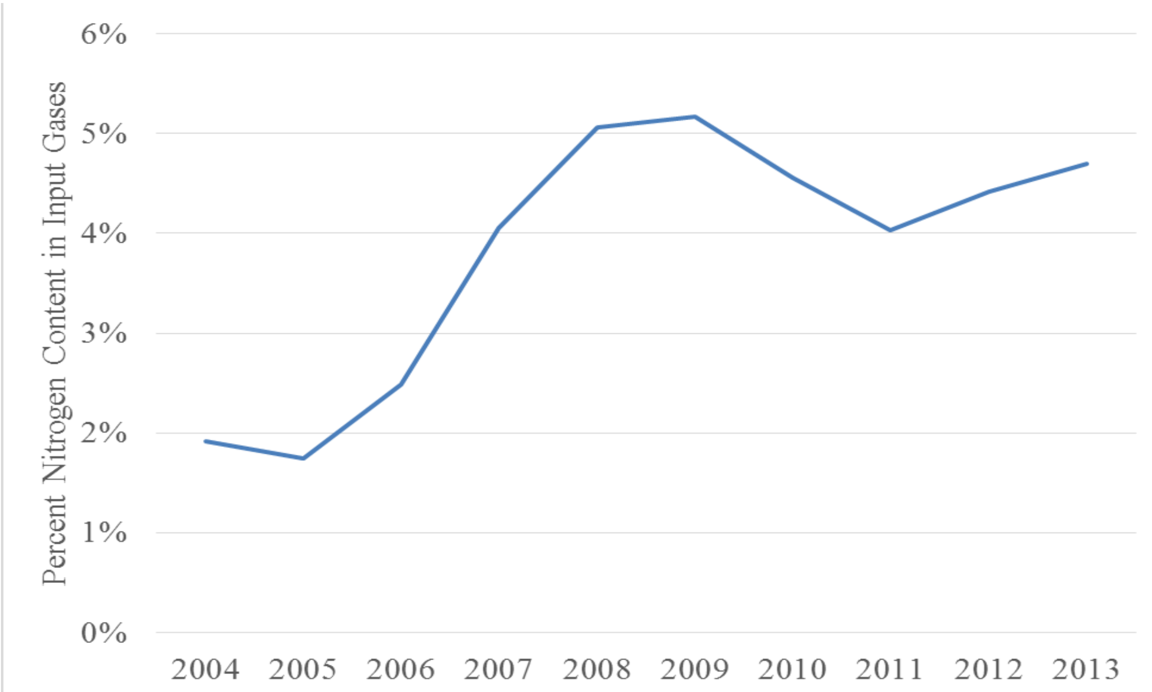
Figure 14. CO_2 Emissions Intensity by GPC per US$



Source: SISPA, PGBP gas combustion, production, and price data

One possible explanation for the observed trends in both total emissions and emissions intensity involves the quality of the gas inputs: a gas stream with more nitrogen requires more processing to produce a pipeline-quality product. As shown in Figure 15, the nitrogen content of the raw gas more than doubled over the period 2004–13, peaking in 2008–09. In the next section, we explicitly consider nitrogen content of the input gas as a factor in rising CO_2 emissions.

Figure 15. PGBP Gas Nitrogen Content



4. Statistical Modeling of Emissions

4.1. The Modeling Approach

In this section, we go beyond the descriptive analysis presented earlier and use relatively simple statistical methods to systematically analyze the changing PGBP input and product mix. We also present projections of future BAU emissions based on the modeling results and company projections of future natural gas production.

As described earlier, and characterized here in Table 1, natural gas processing is made up of six processes, each of which requires different energy inputs per unit of output.

Table 1. Natural Gas Processing

Process	*Description*	*Input or product*	*Unit*
1	Gas sweetening	Sour gas	MMCF per day
2	Sulfur recovery	Sour gas	MMCF per day
3	Condensed gas sweetening	Condensed gas	MMCF per day
4	Cryogenic expansion	Sweet gas	MMCF per day
5	NGL fractionation	NGLs	Barrels per day
6	Electricity generation	Electricity	Kwh per day

The quantity of outputs is a function of both the quantity and the quality of inputs that go into each production process. Output levels are a measure of how much of each process is undertaken. Based on these propositions, we develop a basic analytical framework and employ an ordinary least squares (OLS) regression model that assumes linear relationships among our outcome variable, arithmetic measures of CO_2 emissions, and explanatory variables.

The percentage of nitrogen in input gases is treated as a measure of input gas quality. A month-indexed trend variable serves as a measure of how much efficiency improves over time. Thus a finding of a statistically significant negative trend in CO_2 emissions after holding constant the quality of inputs and the production volumes would indicate that the PGBP processing system has improved its efficiency on a CO_2 basis over the data period. Conversely, failure to find such a trend would suggest that no significant efficiency gains could be demonstrated.

Our general approach is to model the relationship between production levels and CO_2 emissions, and then catch efficiency improvements as a residual. However, we have to choose which PGBP improvements should be treated as business as usual and which are onetime improvements that are truly out of the ordinary.

To distinguish between these two types of improvements, we reviewed a list of major technology improvements in PGBP from 2007 to 2013. As shown in Table 2, most of the listed projects are routine improvements to maintain aging equipment, each costing less than 100 million Mexican pesos (MXN) or US$10 million.

Table 2. PGBP Technology Improvements, 2003–07

Type of upgrade	*Equipment*	*In operation since*	*Approx. cost (MM$)*
Improved efficiency in boilers	CB-2524 de CPG Nuevo Pemex	May 2007	US$10
	BW-3 de CPG Poza Rica	July 2008	94.06 MXN
Boiler rehabilitation and efficiency program	CB-2522 CPG Nuevo Pemex	May 2007	US$10
	BW-4 CPG Poza Rica	August 2009	US$94.06
Boilers revamped	BW-1 del CPG Poza Rica	January 2011	94.06 MXN
Rehabilitation of turbo-compressors in Cryogenics 1 and 2 at CPG Nuevo Pemex	Compressor GB-2103 A	May 13, 2011	77.3 MXN
	Compressor GB-2103	October 30, 2011	77.3 MXN
	Compressor GB-3103 R	October 19, 2013	77.3 MXN
Rehabilitation of turbo-compressors in CPG Poza Rica that included change of wet seals to dry	Compressor GB-601 A	October 7, 2011	58 MXN
	Compressor GB-603 A	February 2012	50 MXN
Installation of plate heat exchangers as replacement of shell and tube heat exchangers in Poza Rica and Nuevo Pemex	CPG Nuevo Pemex: 4 exchangers, 2 in installation process	2010–13	6 MXN
	CPG Poza Rica: 7 exchangers, 4 installed	2010–13	6.2 MXN
CPG Nuevo Pemex Cogeneration 300 MW: cogeneration with gas turbines and heat recovery, which will use water from Mezcalapa River and natural gas to produce steam and electricity; project will provide 55–80% of steam needed and totality of electricity demand of complex, and will wheel electricity surplus (260 MW) to other Pemex workplaces, replacing equipment that is inefficient or at end of its life		April 2013	US$500

However, one project stands out as exceptionally large, costing an estimated US$500 million: the 300 MW cogeneration project at Nuevo Pemex. As described below in the statistical modeling, we treat this project as out of the ordinary, not part of the trend efficiency improvements routinely taking place at PGBP.[6]

Our approach minimizes the squared error of our estimates for the linear parameters. The estimators are unbiased and efficient under the assumption of an independent, identically distributed outcome variable, linear relationships between our outcome and explanatory variables, and an error term that is normally distributed and uncorrelated with the explanatory variables (homoscedasticity) and whose exception conditioned on explanatory variables is zero (exogeneity).

The general formulation for the regression is as follows:

$$\begin{aligned} Emissions = \; & \beta_1 \times Time + \beta_2 \times NG + \beta_3 \times Naptha + \beta_4 \times LPG \\ & + \beta_5 \times Sulfur + \beta_6 \times Ethane + \beta_7 \times Electricity \\ & + \beta_8 \times Gas\ Quality + \alpha_1 \times Nuevo\ Pemex\ Renovation + u \qquad (1) \end{aligned}$$

We also have a choice of how far to disaggregate our data. We can choose to estimate the model for total PGBP emissions or, alternatively, on the basis of GPC-level, process-level, or even equipment-level emissions. To estimate the model based on total GPC-level emissions, we would simply add up all inputs, outputs, and emissions within PGBP. The principal advantage of this approach is that it captures the exchange of raw and processed materials among the individual GPCs, along with other system complexities. The major drawback is the loss of statistical power, because we would aggregate about 1,000 observations to the level of 119 observations, one for each month in our sample.

An approach that provides greater statistical power would involve the creation of a panel dataset whose cross section consists of either the full group of GPCs or the production-level or equipment-level activities with the aim of capturing the differences among sweeteners, cryogenics units, fractionators, and so on. Although such disaggregation beyond the GPC level is feasible for some time periods, the size of our cross-section dataset would vary over time as a result of the rerouting of gases among GPCs. This leaves us with the aggregate approach and the

[6] An alternative way to distinguish among the various technology improvements would be on the basis of their relative profitability. However, information on profitability of the individual investments was not available.

GPC-level approach for consideration. Ultimately, we chose the aggregate approach because of the heterogeneity among the GPCs, which we discuss below.[7]

An inspection of the GPC-level data reveals clear differences in the way GPCs handle gas inputs and outputs. The individual GPCs have different types of equipment, including sweeteners, cryogenics units, fractionators, or other units. Consequently, the input gases into each GPC vary, as do the true relationships between explanatory variables and CO_2 emissions.

We estimate multiple regressions, one for each GPC, to demonstrate the extent of heterogeneity among GPCs. To perform these regressions as well as the subsequent whole PGBP regression, we include a monthly time trend; a cogeneration dummy to signify when the cogeneration program at Nuevo Pemex has started; natural gas production measured in MMCF per day; naphtha production measured in barrels per day; sulfur production measured in tons per day; LPG and ethane production, both measured in barrels per day; electricity sold measured in kWh per day; and the quantity of nitrogen in the input gases, represented as an interaction term between gas inputs measured in MMCF and molar concentration multiplied by 100. Two special cases are Ciudad Pemex, which sends its produced natural gas to the PEP fields for exploration, and Burgos, which has only a fractionator; thus we drop the variable labeled “nitrogen content at the gas input stage.”

4.2. GPC-Level Regression Results

As displayed in Table 3, all the regressions have a relatively high R-squared, ranging from 0.855 to 0.996, indicating that we explain a large proportion of the variation in CO_2 emissions for each GPC. Most but not all of the GPCs have significant time trends indicating systematic changes in efficiency, although the signs on the trend terms are both positive and negative.

[7] Still another approach to deal with the heterogeneity would be to use mixed modeling or hierarchical modeling to capture random slope differences in our explanatory variables among the GPCs. We chose not to use mixed models because the slopes vary not only among GPCs but also over time in a manner that seems to show a clear decisionmaking process about the structure of the PGBP system from one year to another. We wish to capture system-wide PGBP efficiency changes; this includes efficiency gains or losses in individual plants, as well as efficiency gains or losses due to structural changes in the whole PGBP system. More important, any assumptions we make about the structure of the PGBP system will not hold true as the PGBP system is improved over time, thereby reducing the credibility of the forecast.

Table 3. Individual GPC Regressions

	Time trend	*Co-generation*	*Natural gas*	*Naphtha*	*LPG*	*Sulfur*	*Ethane*	*Electricity*	*Gas quality*	*R-squared*
Arenque	0.05 *	–9.24 ***	0.48 ***	NA	NA	0.05	NA	NA	–0.07	0.855
Burgos	5.74 ***	–53.92	–0.60 *	0.01 **	0.03 **	NA	NA	0.0032	0.00	0.980
Cactus	5.47 ***	–517.30 ***	2.03 ***	0.01	0.01 *	1.62 ***	0.01	0.01***	–0.0251	0.998
Ciudad Pemex	–0.34	–434.10 ***	0.65	NA	NA	1.87 ***	NA	0.01***	0.06 ***	0.987
Coatzacoalcos	1.80 ***	–64.21 *	NA	0.02 *	0.01 *	60.75 *	0.01 ***	0.0032	NA	0.991
La Venta	–2.37 ***	79.16 **	2.97 ***	NA	NA	NA	NA	0.02 ***	0.09 **	0.979
Matapionche	0.12	–9.11	–0.58	0.17 ***	0.01	–0.35	NA	0.07 **	0.68 ***	0.992
Nuevo Pemex	–4.49 *	–1977.00 ***	3.26 ***	0.05 ***	–0.01 *	0.71	0.01	0.07 ***	0.11 ***	0.996
Poza Rica	5.25 ***	–204.40	–1.26	–0.41 **	0.13 *	39.93 ***	–0.01	0.00	–3.97 **	0.908

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Although these regressions model only one GPC at a time, in reality, neighboring GPCs surely affect our target GPC's efficiency. Thus it would be inaccurate to attribute the changes in efficiency solely to the individual GPCs. One could go through a great deal of modeling to isolate the efficiency change, but the many structural assumptions would undermine the usefulness of the model for forecasting.

We also see that the coefficients of our various outputs vary widely in estimating the relationships among output production quantities and CO_2 emissions. In cases where the coefficients are missing, it is because that GPC does not produce the output in question. We often find insignificant coefficients because the true slope appears to change from year to year as improvements are made to individual GPCs.

A good example of how efficiency changes can spill over is the cogeneration project at Nuevo Pemex. The excess electricity from Nuevo Pemex is used to power the rest of PGBP. Based on the time trends shown above in Figure 3, we see that several of the plants display a nontrivial drop in emissions once cogeneration is introduced to Nuevo Pemex. Further, these regressions do not account for important factors in determining CO_2 emissions at the GPC level and contain many implausible coefficients despite having decent explanatory power of the overall effects.

4.3. Aggregate-Level Regression Results

Our primary model results, presented in Tables 4 and 5, treat the sampled GPCs as a whole to capture the highly nonlinear effects of changing structures across the GPCs, the covariance of gas production among them, their relative sizes and production levels, and their general interdependence in manufacturing a product. We aggregate our monthly, 10-year GPC sample in the 2004–13 period to 119 observations.

As noted, the single efficiency improvement made by Pemex we explicitly control for is the new US$500 million cogeneration facility at Nuevo Pemex, a project that is far more expensive than the routine renovation or replacement needed for equivalent upkeep. Based on the coefficient on the variable labeled “Cogeneration” in Table 4, we estimate that the Nuevo Pemex cogeneration facility program has effectively reduced emissions by about 2,650 tons per day, 22 percent of the average emissions level in our sample.

Table 4. Statistical Model for PGBP CO_2 Emissions

	Estimate	*Standard error*	*t-value*	*p-value*
Time trend	–11.68*	4.65	–2.51	0.01
Cogeneration	–2650.00***	407.40	–6.50	0.00
Natural gas	1.22*	0.48	2.54	0.01
Naphtha	0.05**	0.02	2.91	0.00
LPG	–0.03**	0.01	–3.07	0.00
Sulfur	2.33***	0.40	5.82	0.00
Ethane	0.06***	0.01	4.94	0.00
Electricity	0.01*	0.01	2.25	0.03
Gas quality	0.12***	0.02	4.90	0.00
R-squared	0.9976			

* p < 0.05, ** p < 0.01, *** p < 0.001

Overall, our model explains 99.7 percent of the variation in CO_2 emissions, a relatively high R-squared even for a regression on a highly consistent physical process. We find that daily CO_2 emissions exogenously decrease by an average of 11.68 tons per day every month in our sample, or 1.17 percent yearly (95 percent confidence level). This exogenous effect includes both individual plant gains and improvements from structural changes in the PGBP system. It is not the case that all GPCs improved, as shown in the Table 3 regressions on individual GPCs, but overall PGBP efficiency in regard to CO_2 emissions has clearly improved over time.

We find a positive coefficient for natural gas production, not including gas sent to the exploration fields. Interestingly, if we do include natural gas sent to the exploration fields as equivalent to marketed gas (as shown in Table 5), we find generally similar results, albeit with somewhat larger coefficients on the time trend (–17.96) and natural gas (1.71) variables, changes expected at the higher production levels. Once again, we find highly significant results at the 99.9 percent confidence level.

At first glance, the negative coefficient on LPG in both Tables 4 and 5 seems like an anomaly, as it implies that emissions decline with greater LPG production. However, we believe that ethane, LPG, and heavy naphthas should be viewed in the context that all three are products of fractionation. Unsurprisingly, the quantities of the three products are also highly correlated with one another: LPG and naphtha production have a Pearson coefficient of 0.85. The products from fractionation have a positive and significant effect on CO_2 emissions at the 99.9 percent confidence level when jointly considered.

Our remaining outputs, sulfur and electricity, are also positive and significant at the 99.9 and 95 percent confidence levels, respectively. Our gas quality coefficient, which is measured as the quantity of nitrogen in the input gases, is positive and significant at the 99 percent confidence level. We do not include other interaction effects with production levels aside from the quantity of input gases. However, we examined several formulations for the gas quality variable and found none that changed our results by a noticeable degree. Similarly, we examined various aggregations of our output measures and observed no meaningful changes in the time trend.

Table 5. Statistical Model for PGBP CO_2 Emissions Based on Both Marketed and Production Gas

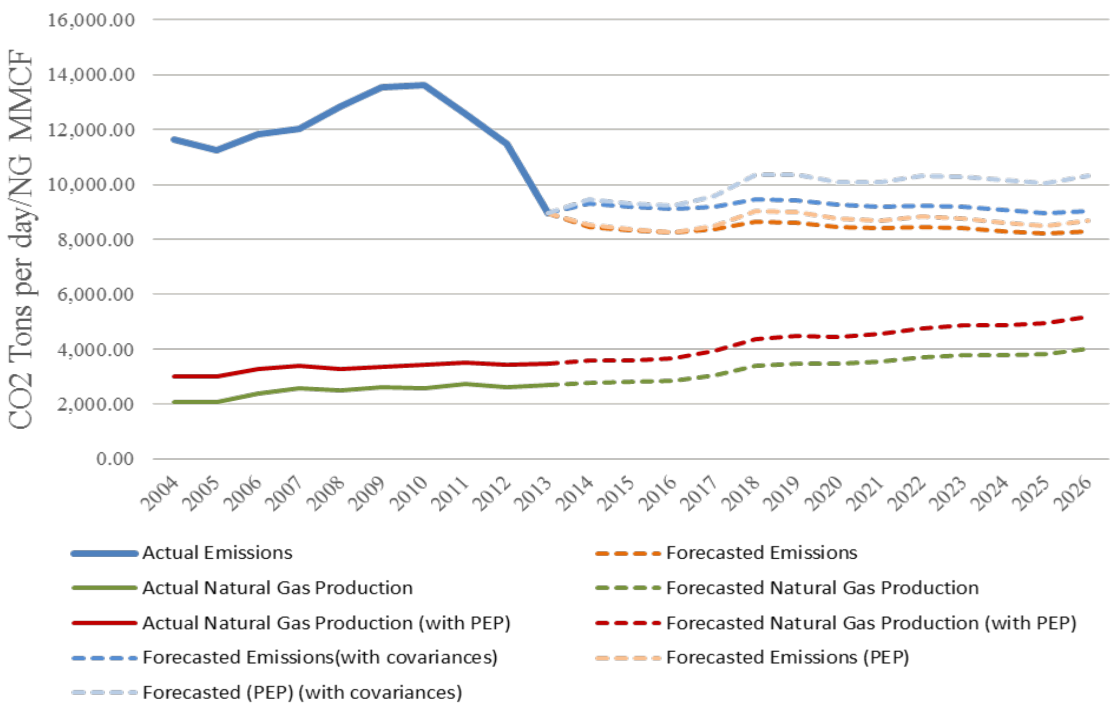
	Estimate	*Standard error*	*t-value*	*p-value*
Time trend	–17.96***	5.13	–3.50	0.00
Cogeneration	–2387.00***	408.30	–5.85	0.00
Natural gas	1.71***	0.47	3.67	0.00
Naphtha	0.04*	0.02	2.50	0.01
LPG	–0.04***	0.01	–3.87	0.00
Sulfur	1.90***	0.42	4.53	0.00
Ethane	0.07***	0.01	5.55	0.00
Electricity	0.01*	0.00	2.40	0.02
Gas quality	0.11***	0.02	4.83	0.00
R-squared	0.9976			

* p < 0.05, ** p < 0.01, *** p < 0.001

4.4. Projecting a BAU Path

We use our estimated model to project multiple CO_2 emissions paths under varying assumptions. Our natural gas production time series for 2014–26 is the natural gas production forecast used by Pemex. We combine this forecast and the model coefficients displayed in Tables 4 and 5 to produce a BAU path. In Figure 16, the solid blue part of the curve shows actual emissions measured from 2004 to 2013. The solid green curve shows actual natural gas production, not including gas sent the PEP fields. The dotted green curve shows the forecast of natural gas production, not including gas sent to the PEP fields. The red curves show a similar natural gas production series, including gas sent to the PEP fields.

Figure 16. Alternative Emissions Projections



In one approach, we do not account for covariance between natural gas production and other outputs. This is represented by the dotted orange curves. The dark orange curve does not include gas to PEP fields, but the light orange curve does. We hold all independent variables fixed at their December 2013 levels except for exogenous efficiency improvements and natural gas production. This includes fixed levels for ethane, LPG, naphtha, and sulfur production, as well as input gas quality, and a fixed effect from the cogeneration program started in Nuevo Pemex in April 2013. The 2014 CO_2 emissions level is 8,947 tons per day. The 2026 emissions level for the forecast without and with gas to PEP fields is 8,278 and 8,675 tons per day, respectively. This translates to an annual decrease of 0.60 and 0.24 percent in CO_2 emissions. However, Pemex projects natural gas production is also rising over the projection period, from 2,777 to 4,013 MMCF and from 3,580 to 5,172 MMCF, or 2.87 percent per year for both series. Taken together, the emissions intensities measured in terms of natural gas output are decreasing at annual average rates of 3.5 and 3.2 percent per year, respectively, over the period.

In what we consider a more realistic approach, we condition the growth of other outputs on the growth of natural gas. We assume a linear functional form for the relationship between the volumes of natural gas production and those of other outputs. For each output, we estimate an intercept and a natural gas coefficient. We leave the input gas quality at its 2013 level. This allows us to capture the growth or decline one would expect in other outputs in relation to natural gas production with no change in external factors.

The dark blue curve does not include gas to PEP fields, but the light blue curve does. The 2026 emissions level for the forecast without and with gas to PEP fields is 9,034 and 10,335 tons per day, respectively. This translates to an annual increase of 0.07 and 1.12 percent in CO_2 emissions. The emissions intensities measured in terms of natural gas output are decreasing at an average rate of 2.91 and 2.35 percent per year over the period.

5. Conclusions

As Pemex evaluates the prospects for developing a sectoral GHG offset program, with the expectation that some emissions reductions may be monetized via bilateral or international transactions, a critical first step is to establish a BAU emissions path. Focusing on Pemex Gas and Basic Petrochemicals (PGBP) as a pilot study, this paper has examined annual CO_2 emissions at the gas-processing center (GPC) level from 2004 to 2013, with the aim of developing both descriptive statistics and a series of simple models that may be used to project baseline emissions out to 2026 and beyond.

Visual inspection of the sample indicates reductions in CO_2 emissions per unit of output over the period studied. Specifically, total emissions decline by 2.9 percent per year, which corresponds to a 4.6 percent annual decline in emissions intensity. Statistical modeling can precisely account for changes in both inputs and outputs at the various GPCs, as well as changes in gas quality, to eliminate the possibility that the emissions reductions are due to changes in gas or other unusual circumstances. In fact, our modeling indicates statistically significant efficiency gains for the PGBP system as a whole over the period 2004–13, even when the changes in input quality and the quantities of key outputs are recognized. We estimate an emissions reduction of 1.17 percent per year, holding all other factors constant.

Beyond statistical methods, other modeling approaches could be used for developing baselines. For example, engineering models are now routinely used in the refining industry to estimate outputs, emissions, and other variables of interest. Not surprisingly, most of these approaches include details on capital, operation, and maintenance, and sometimes they include information on supply and demand elasticities for the key inputs and outputs. Optimization models, including linear programming models, are able to incorporate and systematically analyze a wide range of information on technologies, chemical transformations, and material inputs. All these approaches, however, have their own limitations and, importantly, require substantially more operational information than was available for the present analysis. The increased information requirement also makes it more difficult to gauge the accuracy of the models.

Still another approach to developing baselines would focus more heavily on internal company estimates. Such an effort would involve engaging Pemex experts in an assessment of future demand and supply for their products. Arguably, the company's experience and business insights would be valuable in crafting credible baseline projections. To ensure credibility in the international arena, it would be critical to subject such analysis to rigorous peer review by independent experts.

5.1. Credible BAU Paths at PGBP

Based on our analysis of historical data, and in the absence of additional information about Pemex's future plans, we project similar performance going forward, with efficiency gains of about 0.7 to 1.6 percent per year for the 2014–26 period. At the same time, we recognize that activity levels are likely to continue increasing over time. Thus we allow natural gas output to increase by 2.87 percent per year as projected by Pemex. Overall, our preferred estimate of 2026 CO_2 emissions for PGBP is 8,278 tons per day, equivalent to an average 0.6 percent decline per year.

To the extent that actual, realized emissions are below the baseline, offset credits may be created and sold in bilateral or international markets. As an example of potential revenues that may be generated in such a sale, we estimate that if Pemex were to reduce its PGBP emissions by 10 percent below our estimated BAU path and sell the resulting offsets at US$10/ton of CO_2—slightly less than the current allowance price in California—the resulting offsets would generate about US$40 million in revenues over the period 2013–26 (undiscounted). Larger emissions reductions or higher prices would generate correspondingly higher revenues. Of course, CO_2 emissions from PGBP constitute only a small fraction of Pemex's total GHG emissions. Thus the potential exists to reduce CO_2 emissions substantially and generate billions of dollars in revenue by monetizing emissions reductions throughout the company as part of a sectoral offset program.

5.2. Next Steps for Pemex

Looking ahead, the next step in this process is for Pemex to engage with potential international buyers of sectoral offsets.[8] In the course of that engagement, Pemex and the potential buyer would need to develop a "negotiated baseline," as outlined in Section 2 of this paper. In part, a negotiated baseline will depend on future (expected) output levels. Ultimately, the negotiated baseline should be based on what both Pemex experts and the international buyers believe is achievable under normal operating conditions. Of course, any international transaction would involve adherence to a stringent monitoring, reporting, and verification protocol.

Based on the initial response of the potential buyer(s), several outcomes are possible:

- The buyer might be willing to work with Pemex to negotiate a baseline for PGBP within the ranges calculated herein via statistical methods—that is, about 8,400 metric tons per day in 2026.
- Alternatively, the buyer might ask Pemex to supplement these estimates with additional information, such as the results of internal modeling of emissions trends based on engineering or other methods.
- Further, the buyer may seek additional information from Pemex on planned or potential maintenance or investment projects yielding cost-effective emissions reductions that could be carried out in accordance with improved industry practices and technologies.

Any potential buyer is also likely to seek a range of financial information from Pemex, including estimates of internal funds that could be used to support new efficiency-enhancing investments. Such estimates, in turn, could help inform the terms of an agreement on the nature and magnitude of compensation that might be negotiated to enhance the efficiency of Pemex operations in the coming years.

[8] Note that if a potential buyer of sectoral offsets wanted to broaden the boundaries to include other Pemex subsidiaries beyond PGBP, further data and modeling of baseline emissions would be needed, and the negotiations would become more complex.

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Appendix

Table A1. Energy content of Fuels

Fuel	*Energy content*	*Units*	*Source*
Natural gas	1,030	MBtu/MCF	Silverman (2014)
Ethane	1,783	MBtu/MCF	Engineering ToolBox (2014)
LPG	84,950	Btu/gallon	AFDC (2013)
C5+	4.2	MMBtu/barrel	Silverman (2014)
Naphtha	4.2	MMBtu/barrel	Silverman (2014)

Table A2. CO_2 Content of Natural Gas and Electricity

Fuel	*CO_2 content*	*Units*	*Source*
Natural gas	53.1	kg/MCF	EIA (2013)
Mexican electricity	0.5333	tons/MWh	Pemex (2013)

Table A3. Summary Data Used in the Statistical Analysis: Annual Averages, 2004–13

Year	*Natural gas (MMCF per day)*	*Natural gas to PEP (MMCF per day)*	*Sulfur (tons per day)*	*LPG (barrels per day)*	*Naphtha (barrels per day)*	*Electricity sold (kWh)*	*Nitrogen content (percentage of input gas)*	*Sweet gas input (MMCF per day)*	*CO_2 (tons per day)*
2004	2,064.10	813.90	2,086.05	159,445.28	73,595.46	22,050.62	1.92	3,791.09	11,659.31
2005	2,085.26	791.03	1,902.56	149,690.72	70,842.32	33,935.28	1.74	3,708.34	11,254.20
2006	2,376.50	781.58	1,954.40	146,699.01	72,217.06	42,094.13	2.48	3,985.80	11,824.80
2007	2,582.80	679.81	1,810.92	135,791.64	66,256.16	60,972.49	4.05	4,134.74	12,026.11
2008	2,485.78	663.60	1,813.77	118,577.28	55,727.12	64,436.14	5.06	4,084.49	12,826.98
2009	2,615.27	639.97	1,956.34	112,062.60	54,617.38	67,357.71	5.16	4,251.76	13,548.89
2010	2,593.24	710.35	1,842.43	117,700.72	58,701.22	81,958.38	4.56	4,304.23	13,607.47
2011	2,716.15	663.18	1,749.16	119,633.49	63,506.51	89,914.96	4.03	4,347.29	12,587.70
2012	2,600.70	731.00	1,626.69	110,845.88	54,673.56	68,468.51	4.42	4,206.75	11,474.73
2013	2,707.96	685.73	1,699.07	119,729.42	55,579.25	47,859.70	4.69	4,234.70	8,946.59

Source: Derived from SISPA