Final report

International Growth Centre

Building environmental regulation that enables growth

Michael Greenstone
Rohini Pande
Nicholas Ryan
Anant Sudarshan

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“Building Environmental Regulation That Enables Growth”

Michael Greenstone, Rohini Pande, Nicholas Ryan, and Anant Sudarshan

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Executive Summary

The purpose of this project is to improve the monitoring of industrial pollution by installing high-frequency particulate monitors, called Continuous Emissions Monitoring Systems (CEMS), to report pollution emissions in real time to the environmental regulator. We believe that this new monitoring technology may reduce industrial pollution, as plants being monitored more rigorously may choose to abate pollution, and the regulator itself may adapt its pattern of enforcement to make use of more accurate pollution data. The project intends to measure the effect of this improved monitoring via a randomized-controlled trial, where the treatment group of plants is connected to CEMS and the control group remains on manual monitoring of pollution as in the status quo.

Our sample contains 373 textile industries, located in the industrial city of Surat, that primarily use coal as a combustion emissions source. Detailed baseline surveys conducted in September 2014 demonstrate that all of these industries had at least one installed air pollution control device. Despite these devices, the mean measured PM stack concentration was 351 mg/Nm^3, and 71% of industries were in exceedance of regulatory standards, suggesting that most industries are likely not operating or maintaining their existing abatement equipment correctly. One reason that this status quo may persist is infrequent monitoring by the regulator.

A CEMS-based monitoring regime can offer several benefits. It provides real-time information on changing emissions levels, creates a more transparent regulatory process for industries and regulators, and provides the technical framework to implement an emissions trading market using load permits. Specific CEMS technologies are selected based on industry stack characteristics, but the physical components of CEMS monitoring invariably consist of a network of hardware devices and software programs that interlink industries to the regulator in a manner that allows emissions data to be securely transmitted at regular intervals. This technology contrasts to the current system of periodic manual stack sampling, in which a laboratory technician visits the plan, collects measurements and physical samples, and analyzes them in order to compute the pollutant concentration.

Since the beginning of implementation, we have been tracking the CEMS rollout in Gujarat, from the selection of a device, to installation, to online connectivity, to calibration and post-calibration testing. To date, over 95% of all planned installations have been completed in treatment industries, with negligible completed installations in other experimental groups. Installations have proceeded significantly more slowly than expected, mostly due to a lack of commitment among industries, a need for capacity-building at the industry and the regulatory level, and hardware and software vendor technical issues. We have attempted to address these issues through holding workshops with industry associations, hiring additional staff to assist in coordinating calibration tests, and providing frequent status updates to environmental regulators so that they can take action against lagging industries. Once industries are connected, we send weekly reports to regulators that summarize industry-level data availability and emissions levels. Some industries have been found to have extremely low

data availability, even after troubleshooting vendor software issues, and the Gujarat Pollution Control Board has recently begun to take regulatory action against them.

After monitoring the installation of CEMS and evaluating the short-term effects of CEMS usage, we have drawn certain key conclusions. First, there are significant challenges in ensuring that CEMS is installed in a timely fashion, calibrated correctly, and maintained by industry. Second, in the short run, we find no effect of CEMS on industry emissions. This result is not surprising, as the environmental regulators have not yet fully incorporated CEMS data into their monitoring regime, and industries may require additional capacity-building in order to understand how to apply insights from CEMS data into their plant operations. Lastly, because of incentive incompatibilities between regulators and industries, we have found potential evidence of CEMS under-reporting due to mis-calibration. This finding again speaks to the importance of a robust process flow for installing, calibrating, and maintaining CEMS in order to reap the benefits of these devices.

Good information is the foundation for effective regulation, and yet our work on this project illustrates some of the many challenges of installing, calibrating, and maintaining CEMS. These findings have become more policy relevant of late, as the Central Pollution Control Board has recently enacted sweeping legislation to mandate installation of PM continuous emissions monitoring equipment in over 3,000 industries across 17 categories (CPCB B-29016/04/06/PCI-I/5401). Throughout the evaluation, we have collaborated closely with environmental regulators at the national and state level though workshops, technical documentation, and other capacity-building activities. As CEMSs have become a clear policy priority in India, we expect our results to have wide relevance and applicability. We are also continuing to monitor the effects of CEMS in Surat over the longer term.

In addition, CEMSs form the technical backbone for the development of market-based regimes. Building on our past work, we are currently proposing the evaluation of a pilot emissions trading scheme in Gujarat. Our findings to date show that that CEMS monitoring of PM is viable and emissions trading can be a low-cost way to reduce particulate matter emissions.

This report is the final deliverable for a grant from IGC that funded the rollout of CEMS in treatment industries, and the data entry and analysis of endline data. To date, the CEMS rollout is complete, and we have collected data on the effects of CEMS through Ringelmann Tests. We present the results in the following report.

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I. Project Overview

Motivation

The full social costs of energy consumption include both the private costs of producing energy and, especially for fossil fuels, the external costs of shortened lifespans (Chen et al., 2013; Emerson et al., 2012; Lim et al., 2012, Muller et al. 2011) and a changing climate. The policy challenge is to enforce regulations to make energy bear its full social cost, a challenge especially salient in non-OECD countries, where energy use is expected to double in the next 30 years (Energy Information Administration, 2013). Environmental regulations are the main policy tool available to guide consumers and firms to internalize the full social costs of energy use. However, there is some skepticism that environmental regulations can be effective in developing countries (Greenstone and Hanna 2013), where the capacity for enforcement is weak.

Industrial regulation in India has a history of heavy-handedness, with industrial licensing and labor regulations impeding economic growth (Aghion et al., 2005; Aghion et al., 2008; Besley and Burgess, 2004; Ahluwalia, 2002; Bollard et al. 2013). Today, many of these constraints have been relaxed, but Indian growth has slowed, and skeptics—all the way up to the erstwhile Prime Minister—have fretted that environmental regulation may have taken their place (Times of India, 2011). In response, the current Prime Minister recently convened a high-powered committee to review the entire framework of India's environmental regulation. The final report contains many recommendations to increase the efficiency of environmental regulation, decreasing plant compliance costs while retaining or improving environmental outcomes. This report included the observation that *"This will imply a paradigm shift in the tenet of pollution control from present 'Command and Control' to Market Based Instruments like 'Cap & Trade'"* (Final Report of High Level Committee, MoEFCC, 2014).

Our own past research has illustrated the limitations of India's current command-and-control system for environmental regulation of industrial pollution. The regulator receives unreliable and infrequent emissions data (Duflo et al., 2013). Information flows to the regulator are weak but nonetheless backed by heavy penalties. The regulator requires plants to purchase costly abatement equipment but does not have the monitoring capacity to ensure that the equipment is used and emissions reduced. The result is that emissions are very high, but proxies like energy consumption or capital investment can be penalized with measures that are costly (e.g., plant closure) but unpredictable and thus ineffective (Duflo et al., 2014). However, a sign of hope: when the regulator gets better information on emissions, through more reliable environmental audits, plants do respond by reducing their pollution emissions.

Regulatory failure may be broken down into first, a lack of reliable information on emissions, and second, blunt but inconsistent incentives to actually reduce emissions. Technology is one part of the solution, and this project seeks to understand the effect of more reliable information through the installation of Continuous Emissions Monitoring Systems (CEMS) for industrial air pollution. Design research on CEMS have already led to the publication of the first specifications for such monitoring by India's Central Pollution Control Board, the funding of dedicated Data Acquisition and Handling Centers in Gujarat, and a corresponding regulatory mandate requiring plants to install CEMS monitoring equipment.

This project will contribute to the literature in two ways. First, we will use a political economy lens to attempt to measure whether greater transparency and use of technology can make regulation more effective when state capacity is low (Olken and Pande, 2012). Most Indians view environmental regulation as dismally corrupt. In the status quo, pollution regulation relies on manual monitoring by accredited laboratories, which certainly can be corrupted and in any case places high demands on the monitoring capacity of regulators (Duflo et al., 2013b). Field tests confirm the technical soundness of CEMS monitoring equipment, but beyond technical concerns, this present evaluation is vital to test whether information technology can surmount the institutional weaknesses that compromise manual monitoring of pollution by regulators.

Second, over the longer run, we will provide the first experimental analysis of the effect of a cap-and-trade emissions market on firm costs and compliance, relative to a command-and-control regime. All previous evaluations of cap-and-trade markets have been in developed economies and, because emissions markets encompass whole sectors, have lacked a clear counterfactual for plant emissions and costs. This project evaluates the functioning and success of CEMS alone. A robust CEMS system is essential for a successful ETS, since unreliable emissions readings would undermine the value of permits and hence the entire market.

RESEARCH DESIGN

Through a two-year collaboration with the Central Pollution Control Board (CPCB), State Pollution Control Boards (SPCBs) and technology vendors in India, we have jointly developed technical standards for low-cost and accurate pollution monitoring (CPCB, 2013). These standards have both dramatically cut the cost of CEMS for particulate matter and provided a scalable process for installing CEMS, controlling data quality, and delivering real-time emissions data to the regulator.

The research sample was selected from industries around the city of Surat, in Gujarat. Surat, with five million people, is the second-largest city in Gujarat and a center of textile manufacturing. All sample plants are located within a roughly 20km radius of the city center and hence their emissions affect ambient concentrations for a large population. Average fine particulate (PM_{10}) concentrations in Surat are about 50% above the ambient standard of 60 $\mu g/m^3$. Source apportionment studies for Surat and other similarly industrialized Indian cities find that industry accounts for 20-30% of ambient particulate matter, about coequal to or slightly smaller than the share of pollution from transportation (CPCB, 2011; Guttikunda and Jawahar, 2012).

The experimental sample of 373 industrial plants has been jointly selected with the Gujarat Pollution Control Board to cover the most polluting plants in the area. Plants within the Surat cluster were ranked by annual solid fuel consumption and the top 350 plants identified for the pilot evaluation. Table 1 lists key sample summary statistics, based on administrative data kept by the Gujarat Pollution Control Board. After this initial selection was made based on objective criteria, GPCB regional officers added an additional 23 industries to the sample. Nearly all of these plants are in the textile sector, and all burn solid fuel.

TABLE 1: SAMPLE SUMMARY STATISTICS

	Particulars	Mean	SD
Stack Characteristics	Stack Height (meters)	33.73	4.32
	Stack Diameter (meters)	0.93	0.19
Emission Source Potential	Fuel Consumption (metric tons/year)	4409.63	8358.80
	Concentration of PM (mg/nm3)	127.52	94.04
	Particulate Emissions (metric tons/year)	61.43	34.11
	Primarily Burns Solid Fuel (=1)	1.00	0.05
Fuels Used	Agricultural Waste (=1)	0.01	0.11
	Coal (=1)	0.59	0.49
	Coke (=1)	0.01	0.08
	LDO (=1)	0.00	0.05
	Lignite (=1)	0.39	0.49
	Observations (N)	*350*	

Source: Gujarat Pollution Control Board

The study uses a randomized phase-in design for the evaluation of the new CEMS monitoring regime in these sample industries. Before beginning the impact evaluation, the project started with a small group of pilot installations. To facilitate the impact evaluation, the remaining sample plants have been randomly assigned to one of three experimental Treatment CEMS groups, mandated to begin sending data from CEMS to the regulator in a staggered manner across three phases, numbered 1, 2 and 3. The idea is that plants randomly assigned to later phases without CEMS connections will serve as a control group for the plants in CEMS1 that get connections first. CEMS2 industries serve as a buffer between treatment and control installations. Table 2 lists the number of industries in each treatment assignment group.

TABLE 2: CEMS PHASED ROLLOUT TREATMENT ASSIGNMENT

Rollout Phase	Number of Industries	Treatment Assignment
Pilot	11	None
CEMS1	141	Treatment
CEMS2	82	None
CEMS3	139	Control

In order to measure the impact of CEMS devices on emissions and regulatory activity, we are collecting several types of data.

- **Baseline Survey:** In early 2015, we conducted a baseline survey of all sample industries in order to collect information on firm characteristics, installed equipment, and compliance costs. We also conducted manual stack sampling in order to establish baseline emissions levels. The survey included a general section, which asked questions about industry fuel consumption, production, and revenues; a technical section, which recorded information on all installed emission sources and abatement measures; stack attachment sheets, which collected data on every combustion source, pollution control device, pollution monitoring device, and fan connected to all industry parallel chains; and a sampling section.

- **Periodic Manual Stack Sampling:** Over the course of implementation, manual stack sampling has been conducted at participant plants. The industries are required to submit a yearly audit report to the regulator in which stack sampling is conducted. GPCB also conducts periodic manual stack sampling during audits and inspections. In addition, industries in the treatment group were required to conduct manual stack sampling in order to calibration their CEMS devices.

- **Ringelmann Tests:** These tests are visual measurements taken over a period of time at a distance from the stack to measure the apparent density of smoke. The measurements are graded on a scale from 0 to 5, with 0, 1, 2, 3, 4 and 5 equivalent to opacity of 0, 20, 40, 60, 80 and 100, respectively. These tests can be conducted without the knowledge of industries, and were conducted in three rounds over the course of the evaluation. The difference between the mean Ringelmann values of treatment and control industries was used to estimate the causal impact of CEMS on industry emissions. As CEMS were only installed in treatment industries, Ringelman Tests were the only cost-effective way to take several rounds of concurrent repeated measurements on emission concentrations from the full industry sample.

- **Regulator Communications to Industries:** As noted in previous progress reports, the pace of the CEMS rollout has been significantly slower than expected. J-PAL South Asia and Gujarat Pollution Control Board employees have both periodically interacted with industries in order to spur them to action, and employees from the Data Handling & Acquisition Center have been continuously on hand to offer troubleshooting and logistical support. As of June 2015, we began generating weekly reports on industries that did have connected, calibrated devices and sending them to GPCB. We maintain a record of communications between industries and the GPCB in order to ascertain if the introduction of CEMS changes regulatory behavior.

- **CEMS Implementation Data**: One significant contribution of this evaluation has been a systematic record of implementation challenges during the CEMS rollout. We have recorded the pace of each step of the installation process for all industries. We have logged all capacity-building events involving regulators, industries, and vendors. We have also recorded the incidence of hardware and software errors, and we have collected and analyzed all manual stack sampling data during CEMS calibrations.

II. Participant Industry Characteristics

We conducted detailed baseline surveys of participant industries from September 2014 to December 2014. The survey included a general section, which asked questions about industry fuel consumption, production, and revenues; a technical section, which recorded information on all installed emission sources and abatement measures; stack attachment sheets, which collected data on every combustion source, pollution control device, pollution monitoring device, and fan connected to all industry parallel chains; and a sampling section, in which GPCB-appointed laboratories conducted stack sampling at one industry stack. Surveys were completed in 339 industries, out of a planned sample of 373 industries. 34 industries had closed permanently, or were closed during the entire survey period.

Over 95% of industries in our sample were in the textile sector. The vast majority of these industries operated at least one boiler, and over half of these boilers had a capacity of between 3-6 tons per hour (THP). Our survey found that although all industries used highly-polluting coal to run their emissions sources, they all had at least one installed air pollution control device. This fact is unsurprising, as the GPCB mandates the installation of air pollution control devices, but does not verify that the devices are maintained in working order or run. In practice, these air pollution control devices become large capital expenditures with no economic or environmental benefits. And, as expected, despite the presence of these devices, measured PM emissions were high and often exceeding regulatory standards, suggesting that most industries are likely not operating or maintaining their existing abatement equipment correctly.

Emission Sources and Abatement Measures

Table 3 shows the most commonly-used fuels in our sample. Imported coal and lignite are used by almost all industries, and diesel is also used by many, indicating extremely high emission source pollution potential in our sample. Most industries burn more than one fuel, and also blend fuels. Coal and lignite are commonly blended, resulting in higher emissions than burning pure coal.

Table 3: Most Commonly Used Fuels

Fuel	# Industries
Imported Coal	321
Lignite	288
Diesel	249
Gaseous fuel	173
Pet Coke	24
Wood	15
Bagasse	9
Indian Coal	7
LDO	5
Other Liquid fuel	2
Furnace Oil	1

**Note: If an industry uses more than one type of fuel, they are represented more than once in the table*

Industries in our sample essentially use four types of air pollution control devices to reduce particulate matter emissions. These devices have varying methods of removing particulates, costs, and efficiencies. They are in Table 4.

TABLE 4: AIR POLLUTION CONTROL DEVICE DESCRIPTIONS

Device	Description
Bagfilter	A vibrating filter that physically traps particulates. The filter needs to be sized correctly, cleaned, and repaired in the case of tears.
Cyclone	Dust-laden gas is routed through a cylindrical or conical chamber, which encourages settling. Dust residue from cyclones need to be cleaned regularly in order for the cyclone operate at peak efficiency.
ESP	Electrostatic Precipitators are most effective method of pollution control, and are and extremely expensive. These devices are normally used only in power plants, and remove fine particles from flowing gas using the force of an induced electrostatic charge.
Scrubber	Uses liquid to wash particulates and other unwanted pollutants out of an exhaust gas stream. This liquid could be water, in the case of rinsing particulates, or other reagents in order to target other emissions. Scrubbers have the potential to remove both SOx and particulates.

Table 5 shows air pollution control device configurations by stack, and shows that all stacks in our sample have at least one APCD installed, and almost 90% of all stacks have more than one APCD installed.

TABLE 5: AIR POLLUTION CONTROL DEVICE CONFIGURATIONS, BY STACK

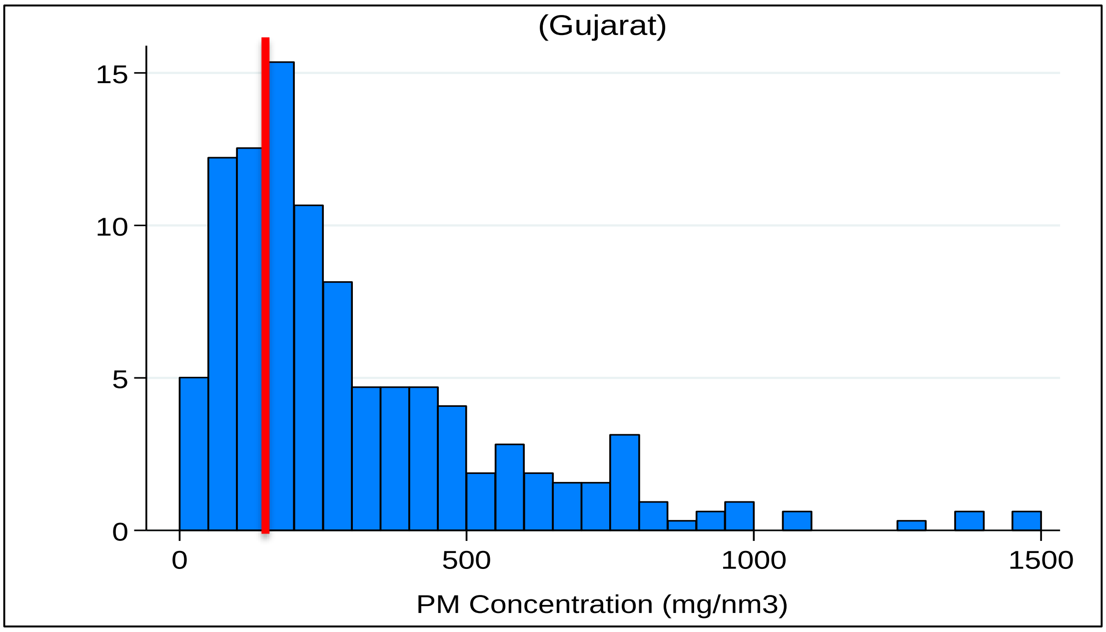
APCD Configuration	# Stacks	% of Stacks
Cyclone and Scrubber	121	32.8
Bagfilter, Cyclone and Scrubber	100	27.1
Bagfilter and Cyclone	97	26.3
Cyclone	26	7.0
Scrubber	7	1.9
ESP	6	1.6
Cyclone and ESP	5	1.4
Bagfilter	2	0.5
Bagfilter, Cyclone and ESP	2	0.5
Bagfilter and Scrubber	2	0.5
Bagfilter, Cyclone and GSC	1	0.3
Total	**369**	**100.0%**

**Note: Some industries in the sample have more than one stack*

EMISSIONS LEVELS

Despite the presence of significant capital equipment to control PM emissions, measured stack concentrations were high. The mean measured outlet PM stack concentration was 351 mg/Nm^3. This is equivalent to a median PM load of 24 metric tons/year per industry, or approximately 12,000 metric tons/year for all sample industries. 71% of industries were found to have PM stack concentrations greater than the regulatory standard. Figure 1 shows a histogram of outlet stack PM concentrations, with a red line marking the regulatory standard.

FIGURE 1: DISTRIBUTION OF STACK OUTLET PM CONCENTRATION



Note: Only one stack was sampled per industry. Concentrations over 1500 mg/Nm^3 were considered outliers.

III. Emissions Monitoring Technology

The Benefits of CEMS

Current environmental standards in India set limits on the maximum allowable concentration standards for pollution emissions in air and water at any given time. In the case of particulate matter, a byproduct of combustion emitted from industry smote stacks, regulators periodically conduct manual samplings at the industry stack in order to measure pollution concentrations. Unfortunately, these reports are usually spaced many months or perhaps a year apart, and provide no information on industry performance in the intervening periods, as particulate matter emissions can vary widely based on combustion conditions and abatement technology.

Continuous Emissions Monitoring Systems (CEMS) are instrumentation and software required to measure emissions from a stationary source on a practically continuous basis. Continuous measurement of PM emissions confers a number of benefits relative to manual stack sampling:

- **Real time information:** Emissions may vary quite widely in real time as a function of operating processes, the operational status of air pollution control devices (APCD), and fuel type and quality. Therefore, CEMS readings provide a more accurate record of emissions over time. This is beneficial for both regulators and industries, as plants could potentially use the data to make operational changes to improve process and combustion efficiency.

- **Transparency and Openness:** The use of PM CEMS technologies presents industries, regulators and potentially the public with high quality, on-going information on emissions from each source so equipped. In turn, this means that regulation based on this data is also transparent and clear, industries can predict and be aware of the costs of compliance and plan accordingly.

- **Load standards and Market Based Regulatory Mechanisms:** PM CEMS data enables the use of load standards instead of concentration standards as the basis for regulating stationary source emissions. This is advantageous because health and environmental concerns are normally influenced by the mass or volume (in the case of effluents) of pollutants emitted. Additionally, total mass load of emissions is the critical quantity involved in emissions trading schemes.

CEMS Technology and Protocols

The technology behind continuous emissions monitoring systems for particulate matter (PM CEMS) has been developed since the 1960s when PM CEMS were first used in Germany. In the 1970s, the use of PM CEMS became a federal requirement in Germany, and particulate matter concentrations began to be correlated to opacity meter readings in the United States. Since that time, various regulatory standards for PM CEMS have been developed in different countries, each of which has been designed for the specific needs and objectives of the regulator. Nevertheless all these standards share a common broad protocol designed to ensure that the underlying objective of reliable emissions monitoring is achieved.

Concurrent with their increasing use in various regulatory and industrial contexts, different technologies have been developed to make quantitative measurements of particulate matter concentrations or load in smoke stacks. Different physical principles are commonly used as the basis of measurement today and these include (i) light scattering, (ii) probe electrification, (iii) light extinction and (iv) optical scintillation. A less common technology that is sometimes used in special conditions is (v) beta attenuation.

Light scattering, extinction and scintillation based devices rely on changes in the optical properties of stack gas as the concentration of particles increases. Probe electrification relies on changes in generated charge in a probe due to moving particles in the gas stream.

A characteristic that is common to all of these technologies (with the exception of beta attenuation) is that they are based on indirect measurement principles and therefore require calibration to smoke stack conditions before use. Thus calibration of a particulate CEMS device is a central part of all performance specifications including this one. This calibration involves a comparison of the continuous emissions monitoring device to standard gravimetric sampling techniques that are in use all over the world today.

The technical framework of the PM-CEMS consists of a network of hardware devices and software programs that interlink regulated industries to the regulator in a manner that allows emissions data to be securely transmitted at regular intervals. The process begins with the collection of continuous PM mass flow data from an industry's stack, and moves through a secure and automated storage and transfer process to servers based at Data Acquisition and Handling Centres, where a number of functions ranging from analytics to data validation occur. The ultimate result is a set of reliable and accurate emissions data which serve as the foundation upon which the PM ETS rests.

The hardware components of CEMS in each industry consist of (i) a PM CEMS device for mass flow measurement (and a volumetric flow meter, if required), (ii) a Data logger unit for saving the CEMS data (if not inbuilt in PM CEMS Device), and (iii) a Data Acquisition System (DAS) with internet connectivity.

The software components of CEMS in each industry consist (i) the CEMS vendor software to transmit readings from the device to the Data Acquisition System, and (ii) DAS Bridge software to transmit readings from the vendor software to the DAHC server software at the environmental regulator.

Manual Stack Sampling

In India, as in many parts of the world, environmental regulators currently rely on periodic manual stack sampling in order to ascertain industry compliance. In the case of Gujarat, an accredited third-party laboratory, or the GPCB's in-house laboratory measures the amount of particulate matter emitted by withdrawing a sample from the emissions source iso-kinetically, using a glass filter. Other measurements are also taken at the time, including measuring the gas composition, velocity, and static pressure. The glass filter sample is then taken to a laboratory, the contents are desiccated to remove moisture, and the final weight of collected dust is taken. From this procedure, the gas flowrate, PM concentration, and dust loading are calculated.

Iso-kinetic sampling was conducted during the baseline surveys in September 2014 and during calibration sampling over the course of the implementation rollout. This sampling was conducted by GPCB-certified laboratories, and was supervised by J-PAL field staff. Over the course of the implementation period, industries submitted audit reports with manual sampling results to the regulator, and the regulator also conducted its own manual stack sampling. During calibration, treatment industries also hired and paid for sampling.

Ringelmann Tests

The Ringelmann Scale was developed in 1888 to measure the apparent density of smoke from a stack. It is graded on a scale of 0 to 5, with 0, 1, 2, 3, 4 and 5 equivalent to opacity of 0, 20, 40, 60, 80 and 100, respectively. Ringelmann surveys are conducted by standing at a distance from a smoke stack and holding a doughnut shaped chart with the scale and a peephole in the middle. The surveyor views the effluent gases emanating from the chimney through the chart peephole, with the sun behind him at specified angle. Although Ringelmann require stringent training of surveyors, as slight variations in color perceptions across time can result in large estimated emission shift, they can be a quick, effective, and inexpensive way to measure differences in relative emissions across industries. They have the added benefit of being conducted without the permission or prior knowledge of industries, so that they cannot modify operational processes to influence readings.

In our surveys, 30 Ringelmann observations were taken for all industries over 30 minutes. We constructed a Ringelmann measure for each industry based on the average of all 30 observations. Ringelmann surveys were conducted in September 2014 (at the time of baseline), October 2015, and March 2016.

IV. The CEMS Rollout in Gujarat

The Installation Process

Installing a CEMS device is a multi-step process, with industries, vendors, and the regulator each responsible for particular steps. After selecting a suitable device, industries contact vendors to purchase and install it. Regulators issue an industry User ID, so that the device can transmit readings to the server. After the device is installed and transmitting raw data, The PM CEMS device is ready for calibration. This is conducted by certified labs performing a parallel manual stack sampling, under guidelines developed by the CPCB.

The CEMS standards developed over the course of our previous research require that the device must undergo a Post-Calibration Performance Test to verify that the CEMS calibration meets the minimum performance requirements. Using Calibration PM Samples taken at different load conditions and emissions levels, the Post-Calibration Test ensures that device readings are valid under different operating conditions (for example, zero load, 25-75% of capacity, 75-100% of capacity), and that they meet minimum data availability standards. The Post-Calibration performance test is a measure of the average deviation (expressed as a Root Mean Square Percentage Error) between estimated mass flow rate or concentration based on the CEMS calibration equation and isokinetic values. The CEMS calibration equation is derived using the best linear fit between CEMS raw readings and isokinetic readings.

Over the course of implementation, we have tracked industry completion of each stage of the installation process, and we have provided periodic updates to GPCB. As industries have a varying level of commitment to completing these steps, the GPCB has also periodically taken regulatory action to speed the process.

Rollout Progress

Table 6 shows the status of the CEMS rollout in Gujarat to date. In treatment industries (CEMS1), 119 out of a planned 124 devices have been installed and have passed the Post-Calibration Test, over 95% of all planned installations. Only 4.6% of control (CEMS3) industries have calibrated devices, although 18.0% have installed the devices. Contamination is limited at this stage, but we are continuously monitoring all in-sample installations.

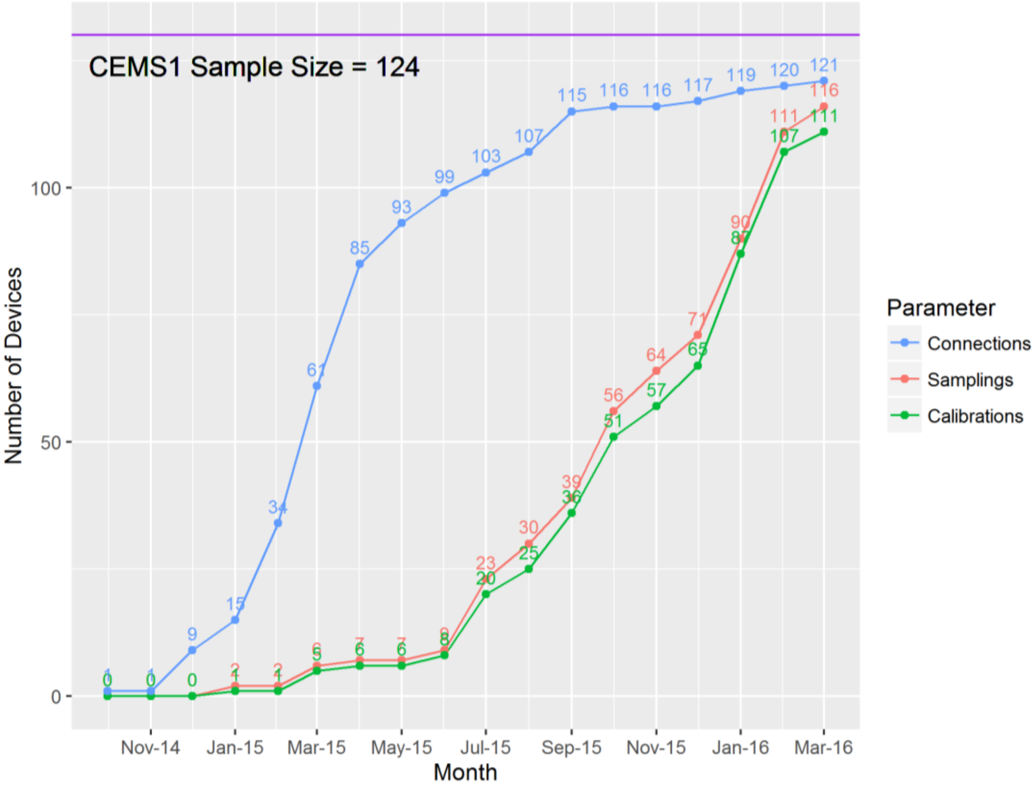
Table 6: CEMS Installation Status, by Phase

	Pilot	*CEMS1*	*CEMS2*	*CEMS3*
Number of Industries	11	141	82	139
Number of Operational Industries	11	124	73	128
PO Placed	11	124	25	35
PM CEMS Installed	11	121	14	23
Data Connectivity Established	11	121	13	21
Calibration Performed	10	119	1	6

** Status as of May 25, 2016*

Figure 2 shows the pace of CEMS1 installations and calibrations over the course of the project, using data from the CEMS server. The blue line shows devices that have been registered, the red line shows devices for which iso-kinetic sampling has been conducted, and the green line shows the number of devices that have been calibrated.

FIGURE 2: CEMS1 INSTALLATIONS AND CALIBRATIONS, OVER TIME



** Status as of March 31, 2016*

As we can see, there was a drive to install and register devices from January 2015 to September 2015. From June 2015, the numbers of device calibration samplings and completed calibration tests have sharply increased.

Installations proceeded significantly more slowly than planned. Many industries were not committed to complete the installation steps, and required continual follow-up from the J-PAL team, Data Acquisition and Handling Center Coordinators, and other environmental regulator staff. While some industries have appointed staff to continuously oversee their devices, others have left maintenance, cleaning, or connectivity problems unresolved for weeks.

There were also significant capacity gaps at both the industry and the regulator level that inhibited progress. Industries have relied on J-PAL and DAHC staff substantially for assistance troubleshooting problems. Staff within the GPCB also had to adjust to adjust to reading and taking action based on reports generated by the CEMS software. The ongoing success of the CEMS rollout will increasingly depend on industries developing greater capacity to maintain devices and to troubleshoot problems directly with the vendors rather than relying on J-PAL, and environmental regulators developing the capacity to interpret and use monitoring data in their day-to-day operations.

In addition, device and data-handling software vendors often failed to troubleshoot and respond to hardware and software issues in a timely manner. GPCB has sent out letters to CEMS device vendors directing them to expedite installations at industries where they have received purchase orders. Devices by some vendors failed calibration tests due to technical issues with connectivity to the server. The bridge software also experienced numerous technical glitches, which the Data Acquisition and Handling Center Coordinators has logged and reported.

Over the course of the CEMS installations, the J-PAL team has employed several key strategies:

- As individual industries had limited bargaining power while dealing with the CEMS vendors, industry associations took a lead in providing a platform for the vendors to market their products. J-PAL and the GPCB held numerous workshops at the industry association level to discuss the CEMS selection guidelines, to educate them on the CEMS installation process, and to provide a venue to meet vendors. The associations then negotiated prices with the vendors, and in some cases, sent out communications recommending vendors that their industry members could approach. In March 2015, the South Gujarat Textile Producers Association initiated plans to hire a full-time CEMS coordinator to serve its member industries. The industry association is also in the process of negotiating annual maintenance contracts with each CEMS vendor, in order to ensure that devices continue to function properly. In the longer run, an increased understanding of CEMS and maintenance requirements should lead to healthy market competition rather than a situation of asymmetric information and price competition with a significant quality trade-off

- There was often a significant lag between the installation of a CEMS device and its calibration. From April to July 2015, the J-PAL team held workshops with industries, and met with laboratories in order to discuss the calibration process. During the fall of 2015, J-PAL hired an additional Data Handling and Acquisition Center Coordinator to be located in the field, and to help industries coordinate and perform calibration tests. In addition, the GPCB held a workshop on the calibration process for laboratories in December 2015, to ensure they were following proper procedures. As a result of these measures, the pace of calibrations significantly increased from July 2015 to March 2016.

- Frequent status updates were important for identifying industries that were lagging in the installation process, so that GPCB could take action. J-PAL hired and trained a full-time Data Acquisition and Handling Center Coordinator to sit in the Surat Regional Pollution Control Board office. This staff member is responsible for issuing User IDs to industries, monitoring and logging their progress in the installation of devices, and troubleshooting problems related to data availability. During the fall of 2015, we hired a second staff member physically go to sample industries to troubleshoot problems and monitor installation and calibration processes. This up-to the-minute information on each industries' status allowed us to design periodic status reports for the GPCB that held lagging firms accountable. Based on this information, the GPCB would issue notices to industries.

A more detailed description of each meeting that J-PAL conducted with key stakeholders, including industries, vendors, software providers, and environmental regulators is included in Appendix 1 of this report.

Data Availability of Installed Devices

Although CEMS monitoring information for all connected devices is continuous available by logging into the ETS Bridger Software, we also issue weekly reports to regulators. In order to make these reports usable, we include a summary report of overall process in participant industries, as well as industry-level reports for CEMS data in the past week. We developed the report format jointly with GPCB regulators in order to ensure that it contains key indicators. The industry-level reports contain three key pieces of information:

- **Data availability:** The percentage of time that the CEMS device is reporting data in the over the past five weeks, as software, hardware, internet connectivity, and industry negligence may explain why a device is offline.

- **Emissions in terms of load:** The vast majority of CEMS devices in sample industries report emissions levels directly in terms of kilograms. Reporting in terms of mass is an important pre-requisite to emissions trading, as permits will be issued and traded on the basis of load. We currently report the variation of PM Mass over the week, by day, and the average PM mass per hour over the last five weeks.

- **Emissions in terms of concentration equivalent:** As current regulatory standards are issued in terms of PM concentration, we also report on the percentage of time for which estimated PM concentration was above the regulatory standard over the last five weeks. This percentage is calculated using the maximum flow rate measured during calibration.

Devices who passed the Post-Calibration Test were able to achieve 95% data availability. However, in practice, data availability fluctuates, and many industries initially displayed low availability. The necessary conditions for data availability include:

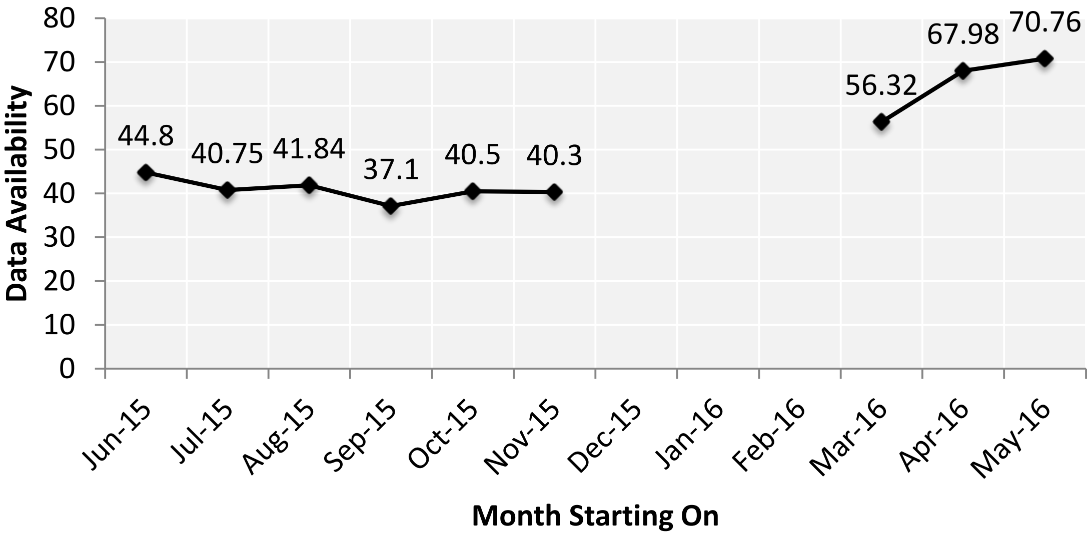
- **The CEMS device:** Industries are instructed to keep their devices turned on 24/7 while the plant is operational, although if the industry goes through longer shut-down periods, it is possible that they might shut down the device and data availability could be affected. The maintenance and power supply of the device is primarily the responsibility of the industries, although hardware problems that are reported by industries should be addressed in a timely manner by vendors.

- **The Data Acquisition System (Hardware):** In order to transmit data, industries require a personal computer with dedicated broadband internet. In addition, a data logger unit backs up data in case of internet connectivity issues. The responsibility of maintaining and switching on the computer and the data logger unit is with industry. Internet connectivity can occasionally prove difficult, as Surat is an industrial area that does not have high-speed connectivity. Industries are also responsible for resolving any broadband issues in a timely manner, and our team has found that, in most cases, they are not a barrier to achieving high data availability.

- **Software Components:** Industries need to run two applications on their computers in order to transmit CEMS data: the vendor application, and the ETS Bridge Software. Initially, there were several serious software issues that interfered with data availability on a large scale. Data Acquisition Handing Center Coordinators were able to help industries troubleshoot, remotely assess the computer in order to resolve minor issues, and consistently log major issues. The J-PAL team, GPCB, and the Industry Associations have repeatedly met with CEMS and ETS Bridge Software vendors to discuss ongoing unresolved problems, and the vast majority have been fixed since December 2015.

Figure 3 shows the overall data availability of online devices from June 2015 to May 2016. There is gap in data from November 2015 to February 2016 while the server and bridge software was updated, and data was not logged correctly. This figure underscores the need to ensure the full process flow is managed before results can be obtained. Thus far we have focused on getting the technical side correct and intend to follow by helping the regulator integrate this information into their own process workflow.

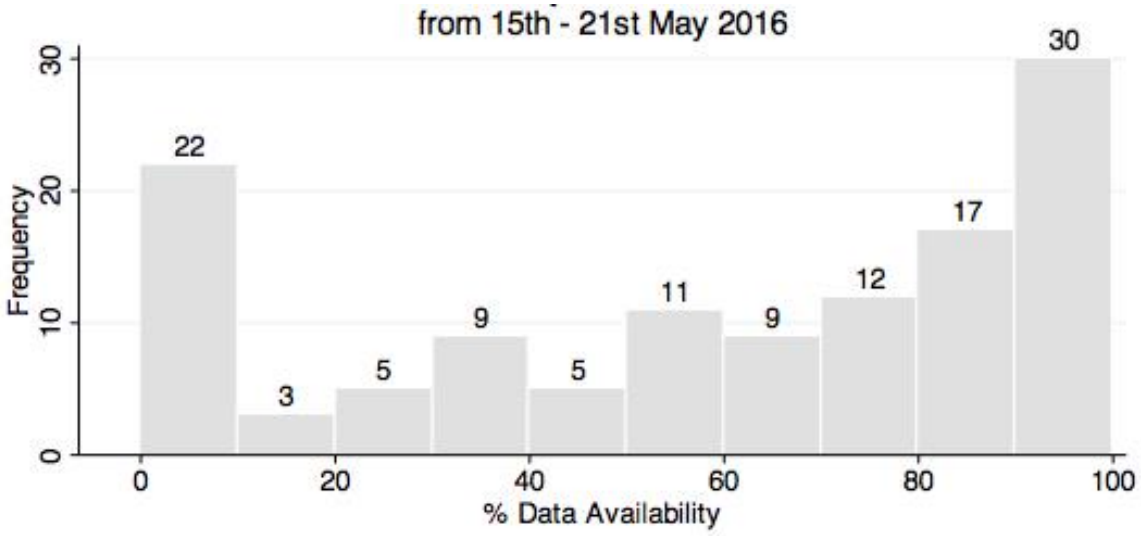
FIGURE 3: OVERALL DATA AVAILABILITY PERCENTAGE, OVER TIME



Most major software issues have been resolved by vendors as of December 2015. Remaining gaps in data availability are likely due to industry negligence. Specific industry barriers to improving data availability include the fact that most upper-level industry management does not understand how CEMS functions. The industries also often lack competent staff to oversee CEMS operations, report errors, and troubleshoot with DAHC staff.

Figure 4, which shows the distribution of data availability for industries in Surat, tends to support this hypothesis. The majority of industries either have data availability less than 20% or greater than 80%, showing that very high availability is achievable for many industries, presumably through good practices of running all components of the system and taking action to resolve all hardware, software, and connectivity issues in a timely manner. Likewise, there are a significant percentage of industries that have low or no data availability. Few industries seem to have intermittent problems.

FIGURE 4: DATA AVAILABILITY DISTRIBUTION FOR ONLINE INDUSTRIES



In order to ensure continued high data availability, we highlight industry-wise data availability percentages in our weekly reports. On May 18, 2016, the GPCB issued a show-cause notice to industries with low data availability.

V. The Impact of CEMS

Regulatory Action

One of our key research questions is whether access to high-quality, high-frequency PM emissions monitoring data will shift the behavior of regulators in the Gujarat Pollution Control Board. We measure this effect through monitoring regulatory actions directed towards participant industries over the course of the evaluation. To date, the GPCB has initiated regulatory actions against industries for failing to install, calibrate, or operate their CEMS devices, but Surat Regional Officers are not utilizing industry-level status reports to inform regulatory action for non-compliance with PM concentration standards.

From August 2014 through July 2015, the main focus of the project has been on installing CEMS devices in participant industries. Many staff members within the GPCB have been continuously involved in the process. At several points, the GPCB has also issued regulatory show cause notices to industries that were not complying with the order to install CEMS in a timely manner.

From July 2015, the focus of the intervention become ensuring that the installed devices were transmitting high-quality, high-frequency data to regulators. GPCB labs are currently auditing the 11 industries with suspiciously low calibration test values. In May 2016, regulators also issued a show cause notice to industries with low data availability.

As the installation and calibration process is nearly complete, and overall data availability is improving, we will continue to monitor regulatory actions on the basis of CEMS-reported emissions levels. A detailed table of interactions between key stakeholders can be seen in Appendix 1. An example of an industry-level status report can be seen in Appendix 2.

Emissions Levels

We also hypothesized that industries would shift their own operational behavior in response to the installation of CEMS devices. In the short-term, we have found no effect of CEMS on emissions levels in participant industries, although this is unsurprising considering that the rollout itself has taken significantly longer than expected, and the GPCB has not yet incorporated CEMS measurements into their regulatory process flow. We plan to continue measuring the longer-term effects of CEMS during our continued collaboration with GPCB.

We have measured the effect of the CEMS on emission levels over three rounds of Ringelmann Testing in treatment and control industries. Baseline measurements were taken in September 2014, Round 1 was conducted in October 2015, and Round 2 was conducted in March 2016. Table 7 shows summary statistics for all three rounds of data collection. Ringelmann measures reading increased from baseline to Rounds 1 and 2, but did not significantly change between Rounds 1 and 2. In all Ringelmann rounds, the mean and median measure was between 1 and 2.

TABLE 7: RINGELMANN SUMMARY STATISTICS, (N=282)

Survey Round	Mean Value	Standard Deviation	Minimum	Median	Maximum
Baseline (full sample)	1.1	0.6	0	1.1	3.2
CEMS1	1.01	0.67	0	0.95	2.53
CEMS3	1.12	0.64	0	1.13	2.63
Round 1 (full sample)	1.9	0.9	0.4	1.7	4.9
CEMS1	1.97	0.85	0.67	1.8	4.40
CEMS3	1.92	0.64	0.43	1.7	4.87
Round 2 (full sample)	1.8	0.7	0.7	1.7	4.6
CEMS1	1.88	0.73	1	1.72	4.37
CEMS3	1.83	0.7	0.73	1.8	4.5

Table 8 shows the pairwise differences between Ringelmann rounds as well as between treatment groups. We see that there is a statistically significant increase in Ringelmann readings from baseline to the next round of readings.

We believe that the significant increase from baseline to Round 1 in both treatment and control industries could be partially explained by more rigorous training on how to conduct the measurements. Although Ringelmann data does have limitations in estimating PM concentrations based on subjective judgements of color by surveyors, previous analysis has found that baseline Ringelmann measures were correlated with iso-kinetic sampling results. We believe they are a useful proxy for measuring relative emission intensity across a panel of industries. As can be seen in Table 8, there are no statistically significant differences between treatment and control industries during any Ringelmann rounds.

TABLE 8: PAIRED SAMPLES TEST, RINGELMANN SURVEYS

Pair	Mean Value	95% Confidence Interval	T
Full Samples, over rounds			
Baseline – Round 1	-0.823	[-0.94, -0.7]	-13.314
Round 1 – Round 2	0.082	[-0.04, 0.2]	1.338
Treatment Assignment, within rounds			
Baseline CEMS3 – CEMS1	0.116	[-0.06, 0.30]	1.296
Round 1 CEMS3 – CEMS1	-0.055	[-0.29, 0.18]	-0.416
Round 2 CEMS3 – CEMS1	-0.050	[-0.24, 0.14]	-0.514

Again, we have reason to believe that the long-term effect of CEMS will be greater than zero, when devices are installed, properly calibrated, and sending data that is periodically viewed by the regulator. These results emphasize the importance of incorporating a CEMS process flow into regulatory procedures and industry operations. Our research has documented some of the consistent challenges to doing this, and has suggested some best practices as CEMS rollouts continue at scale.

Conclusions and Next Steps

Policy Relevance

Good information is the foundation for effective regulation, and Indian regulators have made significant progress in harnessing technology to improve information quality. In 2013, we worked with the Central Pollution Control Board to publish technical standards for PM continuous emissions monitoring. In 2014, the CPCB mandated the installation of PM continuous emissions monitoring equipment in over 3,000 industries across 17 categories (CPCB B-29016/04/06/PCI-I/5401).

Our work on this project illustrates some of the many challenges of installing, calibrating, and maintaining CEMS devices. Although the GPCB has been an enthusiastic partner, there have been significant implementation bottlenecks, including a lack of industry commitment, lack of regulator and industry capacity, and lack of vendor responsiveness. We have held workshops to educate industry associations, trained staff at the GPCB on CEMS data handling protocols, and logged and resolved hardware and software errors. This research and capacity-building work can be invaluable for other state Pollution Control Boards that want to institute a CEMS monitoring regime. Concretely, we are currently providing technical support to the Maharashtra Pollution Control Board as they rollout CEMS in the industrial cluster of Chandrapur. We have also analyzed CEMS data from industries in Tamil Nadu to identify possible cases of under-reporting during calibration. As improving emissions monitoring technology through CEMS has become a clear policy priority in India, we expect our results to have wide relevance and applicability. We are also continuing to monitor the effects of CEMS in Surat over the longer term.

Towards an Emissions Trading Scheme

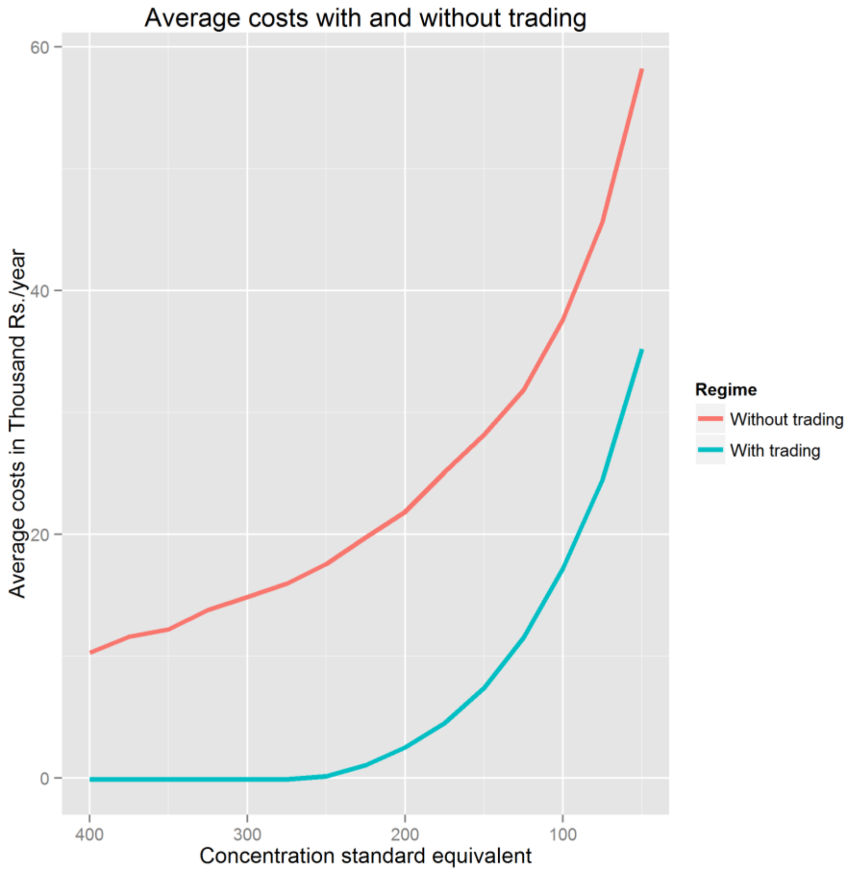
CEMS technology itself has significant consequences for environmental regulation, but it is also the technical backbone for the development of market-based regimes. Building on six years of close collaboration with environmental regulators at the national and state level, our research team is currently proposing the evaluation of a pilot emissions trading scheme in Gujarat. Our findings to date show that that CEMS monitoring of PM is viable and emissions trading can be a low-cost way to reduce particulate matter emissions. Key findings include:

- **Accurate and Low-cost CEMS Monitoring for PM is Feasible.** A transparent and reliable monitoring system for particulate matter emissions is a critical pre-requisite for a successful trading program. This allows regulators to view real-time data on industry emissions, and to estimate the total emissions load. The publication of Specifications and Guidelines for Continuous Emissions Monitoring Systems (CEMS) for PM Measurement, with Special Reference to Emissions Trading Programs in November 2013 was a landmark outcome. Our work in this current project demonstrates that a stable system of installing devices and monitoring emissions levels and data quality is possible. Over the course of the evaluation, Gujarat is has developed the manpower, technical, and data-handling resources to administer a CEMS regulatory regime.

- **Existing PM Emission Concentrations are High**. Our comprehensive baseline survey of approximately participant industries in Gujarat gathered information on firm characteristics, combustion sources and installed pollution control devices, and measured emissions. We found large differences in average measured PM concentrations within industrial sectors, and even amongst industries with similar emission source-APCB chain combinations.
- **Industries Under-Utilise Existing Air Pollution Control Equipment.** Most industries had already installed some pollution control device, based on GPCB directives. Yet they continually emit large amounts of particulate pollution, and without CEMS, they are rarely reprimanded, and therefore have little incentive to operate or maintain this equipment consistently. This suggests significant potential for a pilot emissions trading scheme, as heterogeneous industries (with respect to plant emissions and air pollution control equipment) have the option to trade permits in order to comply with regulatory standards.
- **Emissions Trading Would Reduce Emissions at Low Cost to Industry.** Using data collected from the baseline survey, and additional inputs from the Federation of Indian Chambers of Commerce and Industry (FICCI) on pollution control device costs and efficiencies, we have constructed a model to estimate annual compliance costs for firms in Surat under various regulatory regimes and standards. Figure X, on the next page, shows these aggregated estimated costs for participant industries, with regulatory pollution standards getting more stringent along the x-axis. As we can see, costs increase for industries as they have to undertake more abatement activities, but, comparing cap-and-trade costs and command-and-control costs, we found that compliance costs significantly less under a market-based regime. At the load-based equivalent of the current regulatory standard, 150 mg/Nm^3, emissions trading would reduce compliance costs to industries by an estimated 73%.

In the next phase of our collaboration with environmental regulators, we hope to confirm the economic and environmental benefits of a pilot emissions trading market in India. CEMS data will be integral to the process of permit allocation and end-of-period reconciliation. Real-time data will also allow industries to make informed permit purchase and abatement decisions.

FIGURE 5: AVERAGE ANNUAL COMPLIANCE COSTS FOR INDUSTRIES IN SURAT



APPENDIX 1: LIST OF CEMS STAKEHOLDER MEETINGS

Date	Purpose
22nd July, 2014	Workshop for awareness of CEMS
28th July, 2014	Meeting with vendors on calibration
10th September, 2014	Meeting with industries from Pandesara, Surat City and Udhana clusters who had not placed purchase orders and/or not submitted User ID forms
17th September, 2014	Meeting with Kadodara cluster industries who have not placed purchase orders and/or not submitted User ID forms
18th September, 2014	Meeting with Jolva Cluster industries who have not placed purchase orders and/or not submitted User IDs forms
19th December, 2014	Meeting with industries who have not placed purchase orders
28th January, 2015	Review meeting at Surat RO office
7th February, 2015	Calibration workshop for 127 industries and informed verbally the final date of installation should be no later than 15th February 15
26th February, 2015	Review meeting with industries to track the timeline at SGTPA Hall, Pandesara, headed by GPCB's Regional Officer and Vigilance Officer
7th March, 2015	One on one meeting by GPCB's Regional Officer and Vigilance Officer at Surat with the industries which have not completed CEMS calibration
1st April, 2015	Meeting with Industries of CEMS1 Roll-out and Vendors regarding committing to a timeline for installation and calibration
1st April, 2015	Meeting with Industries of CEMS1 Roll-out and Laboratories to confirm timeline and capacity for isokinetic sampling
8th April, 2015	Team's visit to GPCB office to understand the XGN process
9th April, 2015	Meeting with Mr. Bhimani (GPCB) to discuss the Monthly report formats
23rd April, 2015	Meeting with GPCB officials to discuss the calibration results, issues and challenges
7th May, 2015	Meeting with Vendor and Industries to resolve the industry wise issues and to give overview about ETS to new staff of the Vendor\
13th May, 2015	Visit of Labs to discuss the CEMS Calibration and Iso-kinetic sampling
14th May, 2015	Visit of Labs to discuss the CEMS Calibration and Iso-kinetic sampling
15th May, 2015	Meeting with Mr. Bhimani (GPCB) to discuss the calibration progress, action plans and GPCB server data transfer
26th May, 2015	Meeting with Mr. Bhimani and Mr. Thaker (GPCB) to discuss calibration issues
27th May, 2015	DAHC Team - Calibration issues and resolutions training
10th June 2015	Meeting to update regarding ETS and CEMS roll-out progress
11th June 2015	Training to DAHC Team to resolve software issues and meeting with RO
12th June 2015	Meeting with vendors to resolve errors in data reporting and CEMS software
2nd July, 2015	Meeting regarding Pilot ETS and CEMS rollout with Mr. Hardik Shah, Member Secretary, GPCB
3rd July, 2015	Meeting with a vendor at GPCB RO, Surat
3rd July, 2015	Visit to two industries in Surat to understand the ground realities of the whole lifecycle as data travels from being collected at the sensors in the CEMS device to being sent from the PC in the industries.
10th July, 2015	Meeting with Mr. K C Mistry, Unit head Surat To discuss the industry wise status update and follow up actions
11th July, 2015	Meeting with Mr. Bhimani to discuss Market Design plan
13th July, 2015	Meeting regarding Pilot ETS and WQT project in Gujarat with Mr. Hardik Shah, Member Secretary, GPCB
11th August, 2015	Meeting with Mr. Patel concerning completion of inspections; Meeting with Mr. Bhimani (GPCB) to discuss market design and abatement estimates from baseline survey

12th August, 2015	Meeting with Mr. Kalyani (VO, GPCB) about pending installations and vendor issues with Chemtrols devices
22nd August, 2015	Meeting with Mr. Bhimani (GPCB) to discuss the CEMS rollout, data validation, and the market design document.
9th September, 2015	Meeting with SPTPA to resolve CEMS implementation issues, attended by 70 industries, 3 vendor representatives, and several GPCB issues; Meeting with Mr. Kalyani (VO, GPCB) to discuss delays in the CEMS rollout and vendor issues.
October 3, 2015	Meeting between Mr. Bhimani (GPCB) and three CEMS vendor representatives in Delhi to resolve ongoing hardware and software issues and repeated installation delays
18th November, 2015	Meeting in Delhi to discuss strategy for back-checking calibration results with Mr. Hardik Shah, Member Secretary, GPCB
15th December, 2015	Meeting to discuss a workshop for calibration laboratories with Mr. Hardik Shah, Member Secretary, GPCB
30th December 2015	Meeting with lab representative to discuss best practices on CESM Calibration
11th February, 2016	Meeting requesting GPCB CEMS audits of 11 industries with abnormally low calibration values with Mr. Hardik Shah, Member Secretary, GPCB
16th March, 2016	Meeting to discuss CEMS audits for remaining industries with abnormally low calibration values with Mr. Hardik Shah, Member Secretary, GPCB
19th April, 2016	Meeting concerning updates on market trading and GPCB CEMS audits with Mr. Hardik Shah, Member Secretary, GPCB
12th May 2016	Meeting with GPCB Surat RO to discuss data availability of industries and suggest sending regulatory notifications to industries with low data availability.

APPENDIX 2: SAMPLE INDUSTRY-LEVEL REPORT

GJSRT299290111-2016-05-22

Gujarat Pollution Control Board
ISO-14001 Certified Organization

Continuous Emissions Monitoring System

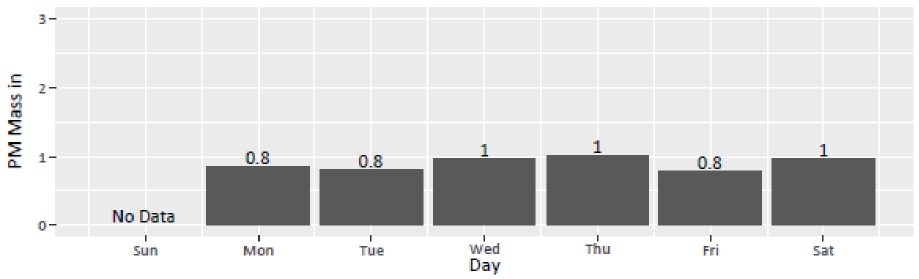
Weekly Report

Industry Name: Anandi Silk Mills Pvt. Ltd.

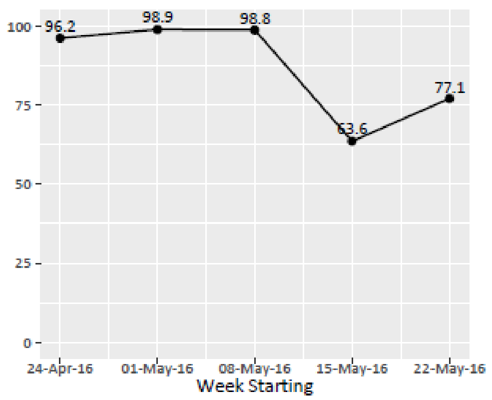
Week	Industry Name	Stack Name	Data Availability	Average PM Mass (kg/hour)	% of Time for which estimated concentration >150 mg/Nm3*
24-Apr-16 to 30-Apr-16	Anandi Silk Mills Pvt. Ltd.	MAIN	96.2%	1.1	0%
01-May-16 to 07-May-16	Anandi Silk Mills Pvt. Ltd.	MAIN	98.9%	0.9	0%
08-May-16 to 14-May-16	Anandi Silk Mills Pvt. Ltd.	MAIN	98.8%	1.4	0%
15-May-16 to 21-May-16	Anandi Silk Mills Pvt. Ltd.	MAIN	63.6%	0.7	0%
22-May-16 to 28-May-16	Anandi Silk Mills Pvt. Ltd.	MAIN	77.1%	0.9	0.3%

Legend:
High Data Availability | Medium Data Availability | Low Data Availability

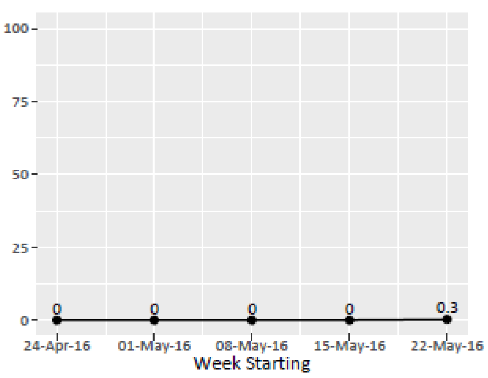
Variation of PM Mass Over Last Week



Data Availability (in %)



% of time for which estd. concentration >150 mg/Nm3



Note: All PM Concentration values for type-1 devices have been obtained using the formula:
PM Concentration = PM Mass / (maximum velocity during calibration * stack cross-sectional area)

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