Impacts of CDM projects on sustainable development: Improving living standards across Brazilian municipalities?

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Abstract

The goal of the Clean Development Mechanism (CDM) is both emission reduction and sustainable development, but while emission reductions generate revenues for the project developer, no such benefit results from the achievement of sustainable development. The objective of this research is therefore to analyze to which extent CDM investments have led to sustainable development benefits, and whether there is a difference in these effects between renewable energy and waste handling and disposal projects. Complementary to existing studies, which are based on potential effects reported ex-ante by project developers, this paper aims at quantifying impacts of CDM projects on sustainable development based on empirical data. Using data for years 2000 (pre-CDM) and 2010 (post-CDM) for Brazilian municipalities, this paper combines difference-in-differences assessment with matching techniques to identify the effect of CDM investments on development and poverty indicators by distinguishing for four project’s types: hydro, biomass energy, landfill gas and methane avoidance. Results show that CDM project types have stimulated local income and labor opportunities but only hydro projects have contributed to reduce poverty at the municipal level for the period analyzed.

Keywords: Clean development mechanism, Sustainable development, Renewable energy and waste handling and disposal projects, Brazil, Development and poverty indicators, Difference-in-differences and matching techniques

1. Introduction

According to the twofold objective of the CDM instrument, this mechanism was designed not only “to help developed countries fulfill their commitments to reduce emissions”, but also “to assist developing countries in achieving sustainable development”. What sustainable development means or how this concept is or should be understood under this framework is (still) arguable or not clear (Banuri and Gupta, 2000; Schneider, 2007). Under the Marrakesh Accords (2001), each host country must decide what aspects of sustainable development should be accomplished when implementing CDM projects in its territory.

Concerns regarding the effective achievement of this objective have emerged and been discussed even before the official launch and implementation of the CDM instrument in host countries (See: Banuri and Gupta, 2000; Kolshus, Vevatne, Torvanger, & Aunan, 2001). Moreover, potential conflicts and trade-offs between the two CDM objectives may arise when trying to fulfill both targets through the implementation of CDM projects (Kolshus et al., 2001; Sutter, 2003). Since the CO2 emission reductions is the only objective that is rewarded by the market through the generation of Certified Emission Reduction (CER) credits, the CDM instrument does not create by itself adequate incentives to fulfill the sustainable development objective (Ellis, Winkler, Corfee-Morlot, & Gagnon-Lebrun, 2007; Paulsson, 2009).

Moreover, the Designated National Authorities (DNAs), the entities in charge of approval of CDM projects in the host country, might have incentive to relax the stringency of the sustainable development requirements in order to attract more CDM investors (May, Boyd, Veiga, & Chang, 2004; Olsen, 2007; Muller, 2007), thus reinforcing the trade-off between the two objectives. Although very few developing countries have developed their own requirements for hosting CDM projects, these scarce efforts lose strength due to the lack of monitoring and verification of compliance of the sustainable development criteria (Wang, Zhang, Cai, & Xie, 2013; Crowe, 2013). In addition, the absence of international standards for sustainable development assessment of CDM projects as well as the missing obligation for the host countries to verify project’s achievements in this aspect (in contrast to the existing strict monitoring of CO2 emission reductions) might exacerbate the trade-off (Olsen and Fenhann, 2008).
Although several definitions of sustainable development have been discussed in the literature, this concept can be generally understood as the intersection of three dimensions or pillars (WCED, 1987): social equity, economic growth and environmental protection. Under the framework of CDM projects, the sustainable development criteria should be based on country-specific development priorities with focus on these three dimensions (Olhoff, Markandya, Halsnaes, & Taylor, 2012).

Although several earlier studies have attempted to highlight the potential of CDM projects in contributing to sustainable development in host countries (Richards, 2003a; Troni et al., 2002; Smith and Scherr, 2002), other studies have also argued that this target was in reality more a hypothesis than a real causality effect (Markandya and Halsnaes, 2002; Kolshus et al., 2001). Since the CDM is a market instrument that targets least-cost mitigation projects rather than poorest communities, the sustainable development objective was expected to be overtaken by the reduction emission goal. Moreover, the assessment of any sustainable development impact due to CDM activities were left to host countries, so that very little in the Accord ensured that these benefits were effectively attained (Begg et al., 2003).

Those studies, that discussed the theoretical ability of CDM projects in generating synergies between environment and local livelihood improvements, have identified high potential in renewable energy projects and used the framework that links the provision of clean energy to local sustainable development to explain causal effects (Troni et al., 2002). Under this framework, the access to energy is a key vehicle that drives sustainable development through the provision of basic needs (e.g.: cooked food, piped water), realization of productive activities (e.g.: manufacturing, commerce) and protection of local environment; thus generating improvements in livelihood conditions (UNDP, 2000, 2005).

In the context of CDM, the effects of small-scale rural renewable energy projects in local sustainable development have been translated into the opportunities generated by improved access to clean energy services by poor households through income diversification due to enterprise development and employment generation, improved health due to access to cleaner water as well as reduced fuel wood consumption, education due to lighting appliances as well as time available for studying at night, gender benefits due to less time collecting firewood and water by women, among other benefits (Troni et al., 2002, Brunt and Knechtel, 2005). In a similar way, effects in sustainable development have been analyzed in other sectors such as forestry (Smith and Scherr, 2002). Therefore, distinguishing impacts by project type is relevant to understand the nature and causality of effects at the local level.

In the particular case of Brazil, the third largest host country worldwide in terms of the number of CDM projects, its Designated National Authority (DNA) has explicit criteria to determine the contribution of CDM projects to sustainable development in the project area (ICGCC, 2003) as well as it has conducted very stringent evaluation processes (Hultman, Pulver, Guimarães, Deshmukh, & Kane, 2012); however, there are no indicators or specific measurement tools for monitoring and verifying compliance of the sustainable development goal established officially by the corresponding DNA (Americano, 2008).

The objective of this research is to determine to what extent CDM investments have provided Brazilian municipalities with sustainable development benefits by measuring the impact on development and poverty indicators. This research contributes to this strand of the literature in four ways: first, most assessments have applied qualitative methods and data based on expected effects; in contrast, we aim at quantifying the aggregated impact of CDM projects by combining difference-in-differences assessment with matching techniques using empirical data for the years 2000 (pre-CDM) and 2010 (post-CDM). Second, available studies on the impacts of CDM on poverty alleviation are still very limited (Crowe, 2013; Dirix, Peters, & Sterckx, 2016), so this research also aims at contributing to fill this gap in this specific niche. In addition, we also explore impacts on inequality and unemployment, variables barely analyzed in the empirical literature. Third, this study estimates impacts across Brazilian municipalities, or within-country analysis; since each country must define its own sustainable development criteria according to its national priorities, an analysis at the sub-national scale (in this case, at the municipal level) is more relevant and appropriate than cross-country comparisons. Finally, this paper investigates whether renewable energy projects (i.e.: hydro and biomass energy) have positive effects on sustainable development, by contrasting the effects triggered by this project type with waste handling and disposal projects (i.e.: landfill gas and methane avoidance).

This paper is organized as follows: Sections 2 presents a review of the literature on the impacts of CDM investments on sustainable development in host countries, Section 3 describes the situation of CDM projects in Brazil, while Section 4 describes the data and the methodological approach. Results of the regression analysis are presented in Section 5, while policy implications and conclusions are inferred in Section 6.

2. Empirical literature review

The empirical literature on the impacts of CDM projects can be divided into two main groups: the first group encompasses those studies that evaluate the effectiveness of CDM projects in reducing CO\textsubscript{2} emissions\footnote{Findings from this first group of studies are not conclusive; while some studies do not support any contribution of CDM to reducing CO\textsubscript{2} (Schneider, 2007; Zhang and Wang, 2011), others have confirmed a significant decline associated with CDM projects (Huang and Barker, 2012).}, while the second group assesses the impacts on sustainable development in host countries. In this section, the literature review focuses on this last group by presenting an overview of aspects/dimensions, proxy variables, main findings, methodologies and data used to determine the CDM achievements in sustainable development. As this study analyses the impacts on development and poverty indicators, we review empirical studies on poverty alleviation and discuss their main findings.

Research on the impacts of CDM has assessed effects using several group indicators that encompass the most relevant areas of any sustainable development strategy: social, economic and environmental. Some common indicators used to evaluate the economic aspects of sustainable development achievements of CDM projects are households’ and/or per capita income (Subbarao and Lloyd, 2011; Bayer, Urpelainen, & Wallace, 2013) as well as generation of local employment (Sutter and Parreño, 2007; Olsen and Fenmann, 2008; Alexeev et al., 2010; Subbarao and Lloyd, 2011; Wang et al., 2013) and technology transfer (Schneider, Holzer, & Hoffmann, 2008; Dechezlepretre, Glachant, & Meniere, 2009; Seres, Haites, & Murphy, 2009, 2010; Alexeev et al., 2010; Costa-Junior, Pasini, & Andrade, 2013; Lema and Lema, 2013).

With respect to the social aspect of sustainable development, some studies have focused on analyzing impacts of CDM projects on health, education (Subbarao and Lloyd, 2011) and poverty alleviation (Sirohi, 2007; Subbarao and Lloyd, 2011; Crowe, 2013). Regarding this last group, studies available on this topic are still very limited (Crowe, 2013; Dirix et al., 2016). Although poverty alleviation is not explicitly part of the CDM mission, this aspect is integral of any sustainable development strategy; therefore,
CDM projects should deliver a minimum of pro-poor co-benefits (Sirohi, 2007; Dirix et al., 2016).

Finally, in the environmental sphere, research focuses on the impacts on environmental amenities such as air, water or soil (Sutter and Parreño, 2007; Olsen and Fenfanh, 2008; Alexeew et al., 2010; Subbarao and Lloyd, 2011). Additionally, some studies have applied scores based on set of indicators (Nussbaumer, 2009; Alexeew et al., 2010; Subbarao and Lloyd, 2011; Drupp, 2011) and indexes² (He, Huang, & Tarp, 2014) that represent the multidimensionality of the sustainable development concept.

With respect to findings, these are not conclusive (Shishlov and Bellassen, 2012; Wang et al., 2013; Michaelowa, Jember, & Diagne, 2014). Some studies have reported positive contributions to local sustainable development in terms of increasing income (Bayer et al., 2013) and employment generation (Olsen and Fenfann, 2008; UNFCCC, 2011; Wang et al., 2013), improved air quality (Olsen and Fenfann, 2008), and successful technological transfer (Schneider et al., 2008; Seres et al., 2009, 2010). On the other hand, there is a strand of the empirical literature that found no impacts at the local level associated with the implementation of CDM projects (Sutter and Parreño, 2007; Headon, 2009; Alexeew et al., 2010; Drupp, 2011; Subbarao and Lloyd, 2011; Costa-Junior et al., 2013; Lema and Lema, 2013). In the particular case of poverty alleviation, some authors argued that CDM projects may have the potential to deliver benefits to poor income groups (Sirohi, 2007; Capeor and Ambrosi, 2008; Wood, 2011); however, findings do not support this strongly (Sirohi, 2007; Subbarao and Lloyd, 2011; Crowe, 2013). According to these studies, CDM projects had very limited or no impact in reducing local poverty.

One explanation for the absence of impacts is that there is an inherent conflicting relationship between the two CDM objectives (Olsen, 2007). This hypothesis of the trade-off between the CDM objectives has been empirically tested by few studies that also have analyzed impacts of CDM on sustainable development; all of them have identified a trade-off in favor of the cost-efficient emission reduction target (Schneider, 2007; Sutter and Parreño, 2007; Pearson, 2007; Alexeew et al., 2010). A second explanation states that there is a “race to bottom” in which host countries have lowered their sustainable development requirements to attract more CDM project developers (Drupp, 2011; Alexeew et al., 2010). In addition, as sustainable development priorities and assessment criteria vary across host countries as well as there is no universal way to assess impacts, it is expected to observe variation in targets (Subbarao and Lloyd, 2011).

Regarding the methodologies applied to assess CDM impacts on sustainable development, most studies have adopted qualitative rather than quantitative approaches (Wang et al., 2013). Some examples of qualitative approaches are checklists (Olsen and Fenfenn, 2008), scoring pattern methods (Subbarao and Lloyd, 2011), content analysis (Costa-Junior et al., 2013) and the Multi Criteria Assessment (MCA) method and its further adaptations (e.g.: the Multi-Attribute Assessment of CDM or MATA-CDM-Sutter, 2003). These studies have relied, in almost all cases, on information provided by the Project Design Document (PDD) of each CDM project (Lema and Lema, 2013; He et al., 2014).

The guideline for the design of PDD files requires a section that describes the potential impacts of the project on sustainable development. In this section, project developers must highlight the positive effects on one or more dimensions; most common benefits describe are environmental and health (e.g. reduction of air pollutants and GHG emissions), technology transfer or local job opportunities (e.g. during construction and operation phases)³. In general, this description of the sustainable development benefits tends to be vague without clarifying causality effects at the local level as a result of project’s activities. Although some expected impacts can be understood directly (e.g. human health improvements as a consequence of reduction in air pollution), other effects might be complex due to their interaction with myriad of variables and sectors (e.g. indirect job generation or income diversification as a result of access to cleaner energy sources). Another important drawback of using data from the PDD is that it only reflects potential or expected results and thus, it does not capture real impacts that took place after implementing the CDM project as it is only an ex-ante analysis (Nussbaumer, 2009).

Very few studies have attempted to quantify impacts of CDM projects using empirical data from statistical sources. For instance, Input-Output models have been used to estimate employment flow across sectors at the sub-national level in China (Wang et al., 2013) and a few panel models have tried to estimate the determinants of CDM project’s distribution within-country (Bayer et al., 2013) or to assess the fulfillment of the sustainable development goal through cross-country comparisons (He et al., 2014)⁴. For Brazil, there has been no quantitative assessment conducted yet, but qualitative techniques using data from the PDD as well as stakeholders’ interviews have been applied to determine impacts. For instance, Fernández, Mileni, Lumbraeras, and Celio (2014) analyzed the impacts on local employment, health, education and empowerment of vulnerable people; while Costa-Junior et al. (2013) focused on successful transfer and promotion of cleaner technologies using data from the PDDs as well as case studies. According to these studies, CDM projects have succeed in delivering economic results in the short-term (i.e.: employment during construction and maintenance phase, increasing local income), but failed to promote long-term benefits in some Brazilian states.

3. The CDM in Brazil

Brazil is the third largest country worldwide regarding the number of registered CDM projects. The first project was registered in 2004, a landfill gas project located in the municipality of Nova Iguaçu in Rio de Janeiro federate state, and until 2015 around 338 projects have been registered in the pipeline (UNEP 2016). CDM projects in Brazil can be divided into two main categories according to their sectoral: renewable energy projects (61%) and waste handling and disposal projects (34%). The rest (5%) went to projects in the chemical and manufacturing industries. Within the renewable energy sector, hydro (45%), wind (27%) and biomass energy (22%) are the main project’s types. Most predominant sub-types in this sector are: run-of-river hydroelectric power (hydro projects), wind (wind projects) and bagasse power (biomass energy projects). In the waste handling and disposal sector, main types are methane avoidance (56%) and landfill gas (44%). Regarding subtypes in this sector, most important categories are landfill

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² He et al. (2014) used the Sustainability-adjusted Human Development Index (Pineda 2012), which is an extension of the Human Development Index (HDI).

³ In very few cases, it is mentioned that part of project’s income will be allocated to the municipal government, which in theory would designate it to local education and health.

⁴ Bayer et al. (2013) identified three main determinants of CDM investments across provinces in China for period 2004–2009: high electricity consumption, low per capita income and absence of FDI inflows. He et al. (2014) used the Sustainability-adjusted Human Development Index (SHDI) to determine contributions of CDM to this aspect using a sample of 58 host CDM countries for period 2005–2010.
flaring, landfill power (landfill gas projects), and manure (methane avoidance).

With regard to the size, almost 70% of the projects are large scale\(^5\), while the remaining 30% are small scale projects. In the renewable energy sector, in a similar way, 70% are large; in particular, 100% of the wind projects are of large scale. In the waste handling and disposal sector, 61% are large projects; where all landfill gas type projects are large, while the methane avoidance at almost 80%. In terms of geographical distribution of CDM projects in Brazil: macro regions where CDM projects were implemented are the South-east with 39.3% of the total; the North-east with 21.6%, the South with 19.2% and the Central-west with 14.5%. Few projects (5.3%) were implemented in the North (Amazonian), a region characterized by high forest density. Regarding renewable energy projects, more than 50% are located in the South-east and South region (30.4% and 22%, respectively), and 28% in the North-east.

One interesting finding is that almost 80% of the CDM projects in the North-east are investments in the renewable energy sector; this reflects the high potential of this region to host energy projects such as hydro and wind. Regarding waste management and disposal projects, 51% of total are located in the South-east, 18% in Central-west and 17% in the South. The distribution of CDM projects reflects a general division of the country, where the South and South-east are much more developed and industrialized than the north (Fernández, Mileni, Lumbreras, & Cello, 2012).

At the municipal level, the distribution of CDM projects by macro region is displayed in Table 1. At the national level, 7.6% (or 425 municipalities) has at least one CDM project that was implemented during period 2004–2015. This number exceeds the total number of registered CDM projects (338) because, in some cases, some project’s activities included more than one municipality, therefore the geographical scope could go beyond that area. The macro region with the lowest percentage of municipalities with CDM projects with respect to its total is the North-east (2.8% or 51 municipalities), while the region with the highest percentage is the Central-west (15% or 72 municipalities), followed by the South-east (10.1% or 168 municipalities).

Characterizing those municipalities with CDM investments, Table 2 displays descriptive statistics that compare means of the CDM sample with means at the macro region level. In general, CDM municipalities’ depicts lower rates of rural population, higher GDP share in the industry sector and higher percentage of households with access to water and electricity.

With respect to sustainable development, the Brazilian DNA has explicit criteria to determine the contribution of CDM projects to sustainable development. These criteria include six main indicators: contributions to local environmental sustainability, the improvement of working conditions, net employment creation, fair income distribution, technology development, and regional integration and linkages with other sectors (ICGCC, 2003). Although Brazil had one of the most stringent DNA processes (Hultman et al., 2012), the DNA has not established any indicator or measurement tools for monitoring and evaluating the contribution of CDM projects in the territory to local sustainable development (Americano, 2008).

4. Methodological approach

4.1. Data

In the context of CDM projects, the sustainable development criteria reflect country-specific development priorities. Due to limited scope of this study and challenges in data constraints, we try to assess impacts of CDM projects on two dimensions: the economic and social, through the outcome indicators listed in Table 3:

We have included in the analysis two development indexes: the overall Municipal Human Development Index (MHDI) and the overall Firjan Municipal Development Index (FMDI), as well as their respective income and labour/income sub-indexes. Although both indexes (MHDI and FMDI) might present some similarities (both are the average of three sub-indexes in the areas of income, education and health), there are some important differences in terms of methodology of calculation and data sources. For instance, in the case of the income sub-indexes, the income MHDI is basically the residents’ income in a certain location, while the labour and income FMDI is an average of five indicators\(^6\) that monitors and characterizes the formal job market at the local level. In a similar way, both education\(^7\) and health sub-indexes are calculated using different methodologies. Regarding data sources, the MHDI is calculated using data from the Demographic Censuses of 2000 and 2010, by the United Nations Development Programme Brazil (UNDP Brazil) in cooperation with the Brazilian Institute of Geography and Statistics (IBGE), while the FMDI uses data from official sources such as the Ministry of Labour and Employment, Ministry of Education and Ministry of Health and it is calculated by the Industry Federation of the State of Rio de Janeiro (Firjan).

Other outcome indicators such as per capita income, poverty indicators (i.e. percentage of poor households), Thel index and unemployment rates were also obtained from the 2000 and 2010 census data (UNDP Brazil) in cooperation with the IBGE. Regarding data on CDM investments, this information comes from the CDM Pipeline Analysis and Database of the United Nations Environment Programme (UNEP). With respect to the unit of analysis, we look at the municipality level, which is the smallest unit of disaggregation available in data for Brazil. The analysis includes only CDM projects that are large scale, assuming that this size may have an influence area whose effects could reach the municipality level. Data is available for two periods: 2000 (baseline or pre-CDM) and 2010 (follow-up or post-CDM).

4.2. Methodology

In order to estimate impacts of CDM on selected outcome indicators, a difference-in-differences (DiD) approach combined with matching techniques was applied. The DiD is a technique commonly applied in policy impact analysis and experimental analysis since its straightforward implementation (Khandker, Koolwal, &

\(^{5}\) Large and small scale projects follow different rules, but in general, requirements are less strict in the last case. To fall under the category of small project, for instance, a project in renewable energy must be 15MW or less of output per year; in the case of energy efficiency projects, these must reduce energy consumption by 60 Gigawatt hours per year or less. For other categories, these must reduce up to 60,000 tons of CO\(_2\) annually (Carbon Market Watch, 2000).

\(^{6}\) These five indicators are intended to reflect formal employment creation, labor market absorption, formal income creation, average formal wages and income inequality at the municipal level (Firjan, 2015).

\(^{7}\) The MHDI education sub-index is composed of two indicators: educational level of the adult population and educational flow of young people, while the FMDI education sub-index is the average of seven sub-indexes: kindergarten enrollment rates, elementary school drop-out rates, elementary education age-grade

\(^{8}\) The MHDI longevity sub-index is a measure of life expectancy at birth, while the FMDI health sub-index is focused on primary health care and mortality. This last sub-index is the average of four indicators with equal weight: average pre-natal visits, undefined cause deaths, infant mortality by avoided causes and hospital admission linked to lack of preventive care (Firjan, 2015).
It aims at comparing changes over time of an intervention in a group that are affected or treated to a group that is not (or control group). Additionally, the DiD is an attractive option when using research design based on controlling for confounding; it has the advantage of eliminating unobserved differences between treated and non-treated individuals that are time invariant and which cross-section matching estimators fail to eliminate (Smith and Todd, 2005; Lechner, 2010). Moreover, the matching procedure ensures that similar regions are compared as treatment and control group.

Under this before-after framework, there is a pre-treatment era and a post-treatment era; and between these two periods the policy intervention took place. A key assumption is the parallel trends between the treatment and control group: an average change in the comparison (or control) group represents the counterfactual change in the treatment group if there were no treatment. Although this assumption presents some difficulties to be tested, there are some alternatives. For instance, if it is possible to have data for more than one pre-treatment period, one can estimate average treatment effects for those periods. If they are statistically significant, then there is evidence against the pre-trend common assumption, in other words, in the pre-treatment era the effect was already present (Beatty and Shimshack, 2011; Lima and Silveiro-Neto, 2017).

The propensity score matching is a non-experimental sampling method that produces a control group whose distribution of covariates is similar to that of the treated group (Khander et al., 2010). The idea is to find a similar control unit to compare with a treated unit, thus to reduce selection bias and improve the balance between treated and control group.

Here, we will perform the kernel matching, in which all treated units are matched with a weighted average of all controls and weights are inversely proportional to the distance between the propensity score of the treated and control groups. There are two main advantages of using this estimator (Baser, 2006): first, since all controls are used in weighting, lower variance is achieved; second, it works better with large and asymmetrically distributed control data as it is in this case.

In this case, data is available at the municipal level for two periods: 2000 (baseline or pre-CDM) and 2010 (follow-up or post-CDM). As the follow up period is 2010, we considered only those municipalities with CDM projects implemented before 2010 as treatment group. In addition, we have differentiated the projects according four types: hydro, biomass energy, landfill gas and methane avoidance. Wind projects were not included because most CDM investments in projects under this category took place after 2010. Municipalities with CDM projects by project type before 2010 are displayed in Table 4.

After finding good matches for the treatment group, average treatment effects are estimated. The Average Treatment Effect on

| Table 1 | CDM in Brazil: project type and distribution across municipalities by macro region (period: 2004–2015). |
|---------|---------------------------------------------------------------|
| Region  | Number of CDM projects | % CDM project type | Total municipalities | Municipalities with CDM |
|---------|-------------------------|-------------------|----------------------|-------------------------|
| North   | 18                      | 5.3               | 3                     | 25                      |
| North-east | 73                  | 21.6              | 6                     | 51                      |
| Central-west | 49                | 14.5              | 2                     | 70                      |
| South-east | 133               | 39.1              | 39.1                 | 168                     |
| South   | 65                      | 19.2              | 7                     | 110                     |
| Total   | 338                     | 100               | 56                    | 425                     |

| Table 2 | Characterization of municipalities with CDM projects by macro region (Year: 2000). |
|---------|------------------------------------------------------------------------------------------------|
| Region  | Rural population (%) | Share of industry (%) | Households with access to water (%) | Households with access to electricity (%) |
|---------|----------------------|-----------------------|------------------------------------|----------------------------------------|
| North   | 41.1%                | 12.0%                 | 45.9%                              | 70.1%                                  |
| North east | 45.6%             | 19.0%                 | 42.3%                              | 82.2%                                  |
| Central-west | 28.6%            | 14.0%                 | 79.8%                              | 91.4%                                  |
| South-east | 22.8%             | 23.4%                 | 90.9%                              | 97.1%                                  |
| South   | 39.7%                | 20.8%                 | 89.3%                              | 95.3%                                  |
| Total   | 48.7%                | 8.4%                  | 33.9%                              | 65.2%                                  |

| Table 3 | List of outcome indicators. |
|---------|-------------------------------|
| Variable | Unit | Source |
| Municipal Human Development Index: Overall MHDI | (0-1) | UNDP Brazil |
| Municipal Human Development Index: Income MHDI | (0-1) | UNDP Brazil |
| Firjan Municipal Development Index: Overall FMIDI | (0-1) | Firjan |
| Firjan Municipal Development Index: Labour and income FMIDI | (0-1) | Firjan |
| Per capita income | Reals | IBGE |
| Percentage of poor households | % | IBGE |
| Percentage of population vulnerable to poverty | % | IBGE |
| Theil index | (0-1) | IBGE |
| Unemployment rate | % | IBGE |

(Other common matching estimators are the nearest-neighbor and 2 to 1 matching, the radius matching, the stratified matching and the Mahalonobis matching.

Samad, 2010); it aims at comparing changes over time of an intervention in a group that are affected or treated to a group that is not (or control group).

Additionally, the DiD is an attractive option when using research design based on controlling for confounding; it has the advantage of eliminating unobserved differences between treated and non-treated individuals that are time invariant and which cross-section matching estimators fail to eliminate (Smith and Todd, 2005; Lechner, 2010). Moreover, the matching procedure ensures that similar regions are compared as treatment and control group.

Under this before-after framework, there is a pre-treatment era and a post-treatment era; and between these two periods the policy intervention took place. A key assumption is the parallel trends between the treatment and control group: an average change in the comparison (or control) group represents the counterfactual change in the treatment group if there were no treatment. Although this assumption presents some difficulties to be tested, there are some alternatives. For instance, if it is possible to have
the Treated (or ATET) is the difference between the outcomes of the treated and the outcomes of the treated if they had not been treated. Regarding treatment groups, the treated group is represented by those municipalities where CDM projects were implemented, while the control group is represented by non-CDM municipalities.

With respect to the covariates, a list is displayed in Table 5. The variables selected as covariates are used for matching. In the selection of these covariates, we consider aspects such as geography and weather (e.g., longitude, latitude, altitude), municipality size (area, population), economic conditions (employment in the industry sector, extreme poverty), infrastructure and accessibility (distance to capital of the federate state). The rationale behind matching is to identify (based on the available covariates) a control municipality with similar characteristics of a treated municipality for comparisons.

The main data sources of the covariates are the Brazilian Institute of Geography and Statistics (IBGE), the Institute for Applied Economic Research (IPEA). Stata 14 was used for data analysis. Diagnostic tests for balancing of covariates for each project type are shown in the Appendix.

5. Results

Impacts were estimated for projects in the renewable energy (hydro and biomass energy projects), and waste handling and disposal (landfill gas and methane avoidance projects) sectors. Impacts of wind energy projects were not estimated due to sample size as most projects under this category were implemented after 2010. Results for the renewable energy projects sample are displayed in Tables 6 and 7 (hydro and biomass energy, respectively).

Results of the hydro project sample show that the overall FMDI in the treatment (or CDM) after intervention, had a very slight and significant increase of 0.011 points. Similarly, the overall MHDI also shows an increase of 0.01 after intervention in those municipalities with CDM projects. There are no significant impacts on labor/income indexes probably due to labor demand characteristics: hydro projects are capital intensive and might generate only few job opportunities, mostly for skilled workers during construction and operation phases (Helston and Farris, 2016); therefore, a significant local employment generation is not expected.

Regarding poverty indicators, although the percentage of poor households is higher in the treatment than in the control group in the baseline, this difference decreases after the intervention by 1.6 percentage points in municipalities with CDM. Moreover, the Theil index also reported slightly but significant differences: inequality dropped by 0.02 percentage points in CDM municipalities. Hydro projects in other countries have been successful in reducing poverty through improvements in energy security at the local level (IHA, 2002, 2017). Enhanced energy security has the potential to improve time allocation and economic productivity at the household level that could lead to increased income opportunities with positive effects in poverty reduction (Bonan, Pareglio, & Tavoni, 2016). Despite this impact on local poverty reduction, no significant impacts have been found on other variables.

In the case of biomass energy projects (Table 7), there is a positive and significant difference on the overall FMDI of 0.02 point, indicating an improvement in this general development index in municipalities with CDM projects. However, this is not the case for the overall MHDI. Moreover, there is a positive and highly significant increase on the labor and income FMDI of 0.07 point, indicating that CDM has positively contributed to activate the local economy.

Biomass energy projects can generate both unskilled and skilled job positions during a project’s life (IIEA, 2010; ERIA, 2008); indeed they may have the potential to perpetuate employment at the local/regional level (BERC, 2006). Moreover, biomass production...
is a labor intensive process that could represent an important source of primary jobs in rural areas (ERIA, 2008). In addition, provision of quality power (cleaner and more reliable energy supply) might help in increasing enterprise development, contributing to increase and diversify income sources at the local level (IIED, 2010). Regarding poverty vulnerability and inequality, although these variables show a significant and negative effect, this is very small. No significant impacts has been identified on unemployment rates.

Tables 8 and 9 display the results for waste management projects (landfill gas and methane avoidance projects, respectively). In the case of landfill gas projects, there is a positive and highly significant increase on the overall FMDI of 0.02 points in CDM municipalities (Table 8). In addition to that, the labor and income FMDI shows an increase of 0.04 points in the treatment group after intervention. No impacts on poverty indicators were found. Impact on inequality is significant and negative, while there is a significant reduction on unemployment.

In the case of methane avoidance projects, there is a positive and significant increase on the overall FMDI of 0.02 points in CDM municipalities (Table 9). Additionally, the labor and income FMDI also shows an increase of 0.06 points in the treatment group after intervention. Results on poverty does show a negative effect but significant at 10%, meaning that CDM projects have not contributed to reduce poverty at the municipal level. Regarding unemployment rates, the impact is significant and indicates a reduction of unemployment in treated municipalities.

6. Discussion and conclusions

In contrast to most previous studies in this field which are ex-ante analysis based on data provided by project developers, this research has attempted to estimate ex-post impacts of CDM projects on sustainable development using empirical data from official statistical sources. Here, we focus on identifying impacts on development and poverty indicators. Results show that there are positive and significant differences for the income and labor FMDI; small and significant effect shows that CDM projects have the potential to stimulate the local economy through employment and income benefits. This result was found for all project types, except for hydro. This might be explained through the differences in factor’s demand requirements by project’s category: hydro projects tend to be more capital intensive.

Table 6
Estimations for CDM renewable energy projects: Hydro.

|                     | Baseline | Follow-up | DiD |
|---------------------|----------|-----------|-----|
|                     | Control  | Treated   | Diff | s.e. | Control | Treated | Diff | s.e. | Diff | s.e. |
| Overall MHDI        | 0.592    | 0.582     | -0.01 | 0.002 | 0.705   | 0.706   | 0.001 | 0.002 | 0.011 | -0.001 |
| MHDI income         | 0.639    | 0.646     | 0.008 | 0.002 | 0.696   | 0.703   | 0.007 | 0.002 | -0.001 | -0.001 |
| Overall FMDI        | 0.598    | 0.590     | -0.008 | 0.003 | 0.703   | 0.705   | 0.002 | 0.012 | 0.010 | -0.009 |
| FMDI Labour and income | 0.418 | 0.446     | 0.028 | 0.006 | 0.460   | 0.479   | 0.019 | 0.006 | -0.009 | -0.009 |
| Per capita income   | 459.62   | 482.63    | 23.0  | 7.79  | 647.4   | 663.7   | 16.3  | 7.79  | -6.7  | -6.7  |
| % of poor households | 25.06  | 26.79     | 1.73  | 0.53  | 11.49   | 11.62   | 0.13  | 0.53  | -1.60 | -1.60 |
| % of people vulnerable to poverty | 49.4 | 50.1      | 0.6   | 0.66  | 26.5    | 29.3    | 0.8   | 0.66  | 0.22  | 0.22  |
| Theil index         | 0.50     | 0.56      | 0.06  | 0.006 | 0.41    | 0.45    | 0.04  | 0.006 | -0.02 | -0.02 |
| Unemployment rate   | 8.91     | 8.68      | -0.23 | 0.16  | 4.92    | 5.15    | 0.23  | 0.16  | 0.45  | 0.45  |

* Significant at 10%.
** Significant at 5%.
*** Significant at 1%.

Table 7
Estimations for CDM renewable energy projects: Biomass energy.

|                     | Baseline | Follow-up | DiD |
|---------------------|----------|-----------|-----|
|                     | Control  | Treated   | Diff | s.e. | Control | Treated | Diff | s.e. | Diff | s.e. |
| Overall MHDI        | 0.64     | 0.64      | 0.00  | 0.003 | 0.73    | 0.73    | 0.00  | 0.003 | 0.00  | 0.00  |
| MHDI income         | 0.67     | 0.67      | 0.00  | 0.002 | 0.72    | 0.72    | 0.00  | 0.002 | 0.00  | 0.00  |
| Overall FMDI        | 0.66     | 0.66      | 0.00  | 0.004 | 0.76    | 0.77    | 0.02  | 0.004 | 0.02  | 0.02  |
| FMDI Labour and income | 0.47 | 0.46      | -0.02 | 0.008 | 0.54    | 0.59    | 0.05  | 0.008 | 0.07  | 0.07  |
| Per capita income   | 559.3    | 547.2     | -3.1  | 9.51  | 744.3   | 733.7   | -10.6 | 9.51  | -7.5  | -7.5  |
| % of poor households | 16.1    | 15.6      | -0.4  | 0.4   | 15.6    | 15.7    | 0.1   | 0.4   | 0.5   | 0.5   |
| % of people vulnerable to poverty | 40.1 | 39.0      | -1.0  | 0.65  | 19.6    | 20.8    | 1.2   | 0.65  | 2.2   | 2.2   |
| Theil index         | 0.48     | 0.46      | -0.02 | 0.006 | 0.37    | 0.39    | 0.02  | 0.006 | 0.04  | 0.04  |
| Unemployment rate   | 11.2     | 12.3      | 1.1   | 0.19  | 5.6     | 6.8     | 1.2   | 0.19  | 0.4   | 0.4   |

* Significant at 10%.
** Significant at 5%.
*** Significant at 1%.

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12 For instance, during design, construction, operation and maintenance of equipment at the landfill and power generation units.
while the other project categories (e.g. biomass energy) are more labor intensive.

Positive and significant differences have also been identified for the overall FMDI in those municipalities with CDM projects. For interpretation, it is important to take into account that this indicator is a compound index that weights three different dimensions: employment/income, health and education. Although impacts on health are expected (e.g.: due to the reduction of air pollution by landfill gas and methane avoidance projects), the estimation of this component does not include direct measurements on improvements, for example, in the case of respiratory diseases. Moreover, the educational dimension CDM investments are not expected to have a significant effect on the educational aspect; therefore, this finding might be interpreted carefully.13

Other aspects or dimensions such as environmental quality, which are also relevant when analyzing local sustainable development, were not assessed in this paper due to data constrains. Projects such as landfill gas and methane avoidance are expected to achieve considerable reductions in several air pollutants and volatile organic compounds (VOCs) emissions, thus leading to significant improvements in health conditions at the local level (EPA, 2012).

No long-term positive and significant impacts on poverty and inequality indicators have been identified, except for hydro projects. These findings are in line with ex-ante studies based on the PDDs that question the contribution of CDM projects to poverty alleviation (Sirohi, 2007; Subbarao and Lloyd, 2011; Crowe, 2013). Presumably, some short-term effects could have taken place during the first two or three years after project’s registration (e.g.: during construction and/or operation phases), resulting in positive changes but these could have vanished after few years. The decade that separates the pre-treatment and the post-treatment period (2000 and 2010, respectively) prevents us to validate this hypothesis of short-term effects of CDM investments on poverty at the municipal level. However, for policy purposes, it is also relevant to know the long term or more permanent response of the CDM implementation. Indeed, more longitudinal research is needed that looks into the development of effects over time, covering both temporary and permanent effects.

Regarding the ability of the selected indicators to capture the CDM effects, it can be argued that some indicators represent more accurately the reality of the Brazilian municipalities than others; therefore, they could capture the CDM impacts more precisely. This is the case when comparing the income and labour FMDI with the income MHDI. As described in the data subsection, while the income MHDI represents per capita income, the income and labour FMDI is an average of several indicators that represent aspects such as labour market, income creation and income inequality indicators have been identified, except for hydro projects. For interpretation, it is important to take into account that this indicator is a compound index that weights three different dimensions: employment/income, health and education. Although impacts on health are expected (e.g.: due to the reduction of air pollution by landfill gas and methane avoidance projects), the estimation of this component does not include direct measurements on improvements, for example, in the case of respiratory diseases. Moreover, the educational dimension CDM investments are not expected to have a significant effect on the educational aspect; therefore, this finding might be interpreted carefully.13

Table 8
Estimations for CDM Waste management and disposal projects: Landfill gas.

| Outcome variables                          | Baseline          | Follow-up         | DiD            |
|-------------------------------------------|-------------------|-------------------|----------------|
|                                           | Control | Treated | Diff | s.e. | Control | Treated | Diff | s.e. | Control | Treated | Diff | s.e. |
| Overall MHDI                              | 0.66    | 0.67    | 0.010 | 0.004 | 0.75    | 0.762   | 0.011 | 0.004 | 0.001   | 0.001   |      |      |
| MHD1 Income                               | 0.70    | 0.71    | 0.009 | 0.004 | 0.75    | 0.76    | 0.014 | 0.004 | 0.005   | 0.005   |      |      |
| FMDI                                      | 0.67    | 0.70    | 0.03  | 0.006 | 0.78    | 0.82    | 0.04  | 0.006 | 0.02    | 0.02    |      |      |
| FMDI Labour and income                    | 0.53    | 0.62    | 0.09  | 0.01  | 0.65    | 0.77    | 0.12  | 0.01  | 0.04    | 0.04    |      |      |
| Per capita income                         | 665.6   | 712.5   | 46.9  | 19.7  | 862.7   | 930.7   | 68.0  | 19.7  | 21.10   | 21.10   |      |      |
| % of poor households                      | 14.0    | 13.4    | −0.6  | 0.49  | 5.9     | 5.7     | −0.3  | 0.49  | 0.30    | 0.30    |      |      |
| % of people vulnerable to poverty          | 34.8    | 32.2    | −2.6  | 0.84  | 19.2    | 18.4    | −0.8  | 0.84  | 1.82    | 1.82    |      |      |
| Theil index                               | 0.51    | 0.50    | 0.01  | 0.009 | 0.43    | 0.471   | 0.04  | 0.009 | 0.05    | 0.05    |      |      |
| Unemployment rate                         | 12.9    | 15.8    | 2.88  | 0.27  | 6.6     | 7.1     | 0.5   | 0.27  | −2.39   | −2.39   |      |      |

* Significant at 10%.
** Significant at 5%.
*** Significant at 1%.

Table 9
Estimations for CDM Waste management and disposal projects: Methane avoidance.

| Outcome variables                          | Baseline          | Follow-up         | DiD            |
|-------------------------------------------|-------------------|-------------------|----------------|
|                                           | Control | Treated | Diff | s.e. | Control | Treated | Diff | s.e. | Control | Treated | Diff | s.e. |
| Overall MHDI                              | 0.605   | 0.624   | 0.019 | 0.002 | 0.715   | 0.729   | 0.014 | 0.002 | −0.005  | −0.005  |      |      |
| MHD1 Income                               | 0.65    | 0.67    | 0.02  | 0.002 | 0.70    | 0.72    | 0.02  | 0.002 | 0.00    | 0.00    |      |      |
| FMDI                                      | 0.61    | 0.63    | 0.02  | 0.003 | 0.71    | 0.75    | 0.04  | 0.003 | 0.02    | 0.02    |      |      |
| FMDI Labour and income                    | 0.43    | 0.45    | 0.02  | 0.006 | 0.488   | 0.57    | 0.08  | 0.006 | 0.06    | 0.06    |      |      |
| Per capita income                         | 500.1   | 554.1   | 54.0  | 7.7   | 685.2   | 753.1   | 67.9  | 8.65  | 13.9    | 13.9    |      |      |
| % of poor households                      | 22.7    | 19.5    | −3.2  | 0.41  | 9.7     | 7.6     | −2.1  | 0.41  | −1.1    | −1.1    |      |      |
| % of people vulnerable to poverty          | 47.0    | 43.8    | −3.2  | 0.55  | 26.4    | 23.1    | −3.3  | 0.55  | −0.14   | −0.14   |      |      |
| Theil index                               | 0.52    | 0.55    | 0.03  | 0.005 | 0.41    | 0.43    | 0.02  | 0.005 | −0.01   | −0.01   |      |      |
| Unemployment rate                         | 9.4     | 9.6     | 0.2   | 0.14  | 5.1     | 4.9     | −0.2  | 0.14  | −0.4    | −0.4    |      |      |

* Significant at 10%.
** Significant at 5%.
*** Significant at 1%.

13 Despite the similarities between the MHDI and the FMDI, only the last index has shown significant differences in the analysis. This can be attributed to the differences in data sources, dimensions included and methodologies for calculating each of them. have a significant impact on local health and environment (EPA, 2012).
inequality. Thus, this last indicator may reflect better the economic performance at the municipal level. Another important difference is data sources, which may play a role in the accuracy of these indicators: while all MHDI indicators are built on census data, the FMDI indicators use official statistics from the Ministry of Labour.

With respect to the ability of other selected indicators such as poverty variables and the Theil index, it can be argued that effects on poverty alleviation and inequality could be even more long-term as it may take a while until employment generation could lead to better living standards at the local level. For this reason, the time frame of this analysis may not fit to identify effects in these indicators. Regarding unemployment rates, as this variable captures only the formal labor market, it may not be a suitable indicator if the CDM attracts workers from the informal labor market. As quantification is relevant for assessment, further research may focus on the development of indicators able to capture the CDM impacts more accurately.

It is important to highlight that the implementation of any renewable energy project will not lead automatically to sustainable development benefits\(^\text{14}\). Although enhanced energy access has demonstrated to provide communities with several benefits, e.g. time allocation improvements and more dynamic labor markets (Bonan et al., 2016), findings are still inconclusive due to methodological challenges to elucidate causal-link effects (Alloissio et al., 2017). The causality chain may involve high levels of complexity due to the diverse interactions among socioeconomic variables and sectors; moreover, potential negative effects might threaten to offset positive gains on welfare (ERIA, 2018).

Some alternatives have been discussed in order to enhance the performance of CDM projects in delivering sustainable development benefits such as the adoption of premium add-on standards (Wood, 2011; Crowe, 2013), the adoption of discount rates to CERs (Alexeew et al., 2010) or the implementation of a two-track CDM (Tovanger, Shrivastava, Pandey, & Tornbald, 2013). The implementation of these proposals, however, is not exempt of political and market challenges. Other important challenges still remain such as the adequate quantification tools of project’s performance with respect to sustainable development achievements, and monitoring and reporting of the impacts (Olsen, Arens, & Mersmann, 2017). Lessons from the CDM experience could contribute in the formulation of new instruments in the context of the Paris Agreement. This experience is valuable for the future design, formulation and implementation of the Sustainable Development Mechanism (SDM) established under the Accord, which keeps the twofold objective of the CDM.

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Appendix

Diagnostic tests

After performing the matching and estimating the treatment effects, it is required to conduct a diagnostic analysis to assess the extent of corresponding balancing achieved on the two matched samples (treated and control) before and after matching. This procedure is also used to choose the set of matching parameters (covariates) that achieves the best balancing. There are several options to test for it; here, we use some numeral and graphical diagnostics: the standardized percentage bias, ratios of variance and some graphical representation using the estimated propensity scores. If several tests indicate balance, there is a greater likelihood that covariates are balanced across treatment and control groups in the matched sample.

The first indicator or the standardized percentage bias is the percentage difference of the sample means in the treated and control sub-samples as a percentage of the square root of the average of the sample variances in the treated and control group (Rosenbaum and Rubin, 1985). The percentage bias should be under 10 to be considered acceptable. The second measure, the variance ratio, is the ratio between the variance of the treated over the variance of the control group. If the Rubin’s variance ratio is applied, it is the ratio of the variance of the residuals orthogonal to the linear index of the propensity score in the treated group over the control group (Rubin, 2001). This indicator, again, is estimated for each covariate used; values between 0.8 and 1.25 represent a “good” balance.

The last measure is a graphical representation or a density plot of the covariates in treated against density plot of covariates in control before and after the matching. Graphical diagnostics can be helpful for a quick assessment of the extent of covariate imbalance. Both indicators for each covariate (standardized percentage bias and variance ratio) are displayed together with overall measures of covariate imbalance for the four project’s types.

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\(^{14}\) Although most literature are focused on detangling the causality effects of renewable energy projects on sustainable development, this can be extended to other categories such as waste management projects.
Table 1.1
Standardized percentage bias and ratio of variance before and after matching (Type: Hydro).

| Covariate                  | Unmatched | Mean | % | % | V(T)/V(C) |
|----------------------------|-----------|------|---|---|-----------|
|                            | Matched   |      |   |   |           |
|                            | Treated   | Control | Bias | reduct bias |           |
| Longitude                  | U         | 50.25 | 46.07 | 73.2 | 0.60      |
|                           | M         | 50.46 | 49.47 | 76.2 | 1.18      |
| Latitude                   | U         | −20.59 | −16.32 | −59.2 | 0.51      |
|                           | M         | −20.59 | −20.34 | −3.4  | 0.76      |
| Altitude                   | U         | 470.52 | 385.76 | 32.7 | 0.72      |
|                           | M         | 464.85 | 452.28 | 4.8  | 0.80      |
| Population                 | U         | 72392 | 31301 | 18.2 | 1.80      |
|                           | M         | 35544 | 41889 | −2.8 | 84.6      |
| Ratio of rural population  | U         | 0.24  | 0.39 | −67.7 | 0.85      |
|                           | M         | 0.23  | 0.26 | −13.4 | 0.92      |
| Area                       | U         | 1919.7 | 1530.3 | 8.6  | 0.25      |
|                           | M         | 1995.4 | 1893.6 | 2.2  | 0.26      |
| Distance to capital        | U         | 947.2  | 1077.8 | −31.0 | 0.80      |
| of the federate state      | M         | 945.8  | 943.5  | −0.6  | 0.78      |
| Access to waste collection| U         | 95.87  | 87.43  | 58.5  | 0.12      |
| at home                    | M         | 95.94  | 94.96  | 6.8   | 0.54      |
| Access to running water    | U         | 89.45  | 75.96  | 66.2  | 0.33      |
| at home                    | M         | 89.46  | 88.59  | 4.2   | 0.84      |
| Illiteracy rate            | U         | 10.14  | 19.09  | −99.9 | 0.20      |
|                           | M         | 10.26  | 11.13  | −9.7  | 0.62      |
| Infant mortality rate      | U         | 18.32  | 26.38  | −79.3 | 0.19      |
|                           | M         | 18.26  | 18.94  | −6.7  | 0.68      |
| GDP share in the industry  | U         | 0.23   | 0.15   | 60.6  | 1.27      |
| sector                     | M         | 0.23   | 0.20   | 18.2  | 0.71      |
| Region                     | U         | 3.93   | 3.23   | 64.4  | 0.36      |
|                           | M         | 3.92   | 3.87   | 5.1   | 0.62      |

Table 1.2
Overall measures of covariate imbalance (Type: Hydro).

| Sample        | Ps | R²  | LR chi2 | p > chi2 | Mean Bias | Med Bias | Rubin B | Rubin R |
|---------------|----|-----|---------|----------|-----------|----------|---------|---------|
| Unmatched     | 0.131 | 230.20 | 0.00 | 56.1 | 62.5 | 128.8 | 0.26 |
| Matched       | 0.030 | 14.14 | 0.44 | 7.8  | 5.9  | 29.8  | 0.57 |

Graph 1.1. Standardized percentage bias before and after matching (Type: Hydro).

Graph 1.2. Density plots of the propensity score (Type: Hydro).

Note: Unmatched (bias before matching); matched (bias after matching).
Table 2.1
Standardized percentage bias and ratio of variance before and after matching (Type: Biomass energy).

| Covariate                        | Unmatched | Matched | Mean | % | % | V(T)/V(C) |
|----------------------------------|-----------|---------|------|--|---|-----------|
|                                  | Treated   | Control | Bias | reduct bias | V(C) |
| Longitude                        | U         | 48.77   | 46.12| 47.7 | 94.9 | 0.51 |
|                                  | M         | 49.17   | 49.04| 2.5  | 88.7 | 1.45 |
| Latitude                         | U         | −20.81  | −16.36| −64.2 | 96.1 | 0.39 |
|                                  | M         | −21.68  | −21.85| 2.5  | 96.1 | 0.80 |
| Altitude                         | U         | 458.34  | 386.64| 26.9 | 88.7 | 0.82 |
|                                  | M         | 493.07  | 501.2 | 3.0  | 88.7 | 0.56 |
| Population                       | U         | 1.1e+05 | 31448| 25.5 | 95.5 | 0.05 |
|                                  | M         | 52746   | 56088| −1.2 | 95.5 | 0.05 |
| Ratio of rural population        | U         | 0.14    | 0.39 | −130.0 | 95.5 | 0.05 |
|                                  | M         | 0.08    | 0.11 | −16.1 | 87.6 | 1.06 |
| Area                             | U         | 1154.6  | 1539.4| −9.1 | 82.9 | 0.08 |
|                                  | M         | 1011.8  | 1077.8| −1.6 | 99.9 | 0.05 |
| Distance to capital of the federate state | U      | 839.8   | 1077.3| 72.5 | 99.9 | 0.05 |
|                                  | M         | 752.6   | 768.0 | 0.0  | 99.9 | 0.08 |
| Access to waste collection at home | U       | 97.54   | 87.49 | 26.9 | 88.7 | 0.08 |
|                                  | M         | 98.55   | 98.54 | 0.0  | 99.9 | 0.08 |
| Access to running water at home  | U         | 93.28   | 76.05 | 26.9 | 97.1 | 0.98 |
|                                  | M         | 96.11   | 95.60 | 2.6  | 97.1 | 0.98 |
| Illiteracy rate                  | U         | 9.99    | 76.05 | 26.9 | 97.1 | 0.98 |
|                                  | M         | 8.94    | 95.6  | 2.6  | 97.1 | 0.98 |
| Infant mortality rate            | U         | 19.09   | 26.30 | −66.7 | 99.8 | 0.36 |
|                                  | M         | 17.32   | 17.34 | −0.1 | 99.8 | 0.83 |
| GDP share in the industry sector | U         | 0.29    | 0.15  | 211.8 | 86.3 | 0.86 |
|                                  | M         | 0.31    | 0.29  | 16.7 | 86.3 | 0.42 |
| Region                           | U         | 3.97    | 3.23  | 26.9 | 97.1 | 0.98 |
|                                  | M         | 4.06    | 4.09  | −2.6 | 96.2 | 0.64 |

Table 2.2
Overall measures of covariate imbalance (Type: Biomass energy).

| Sample          | Ps R² | LR chi² | p>chi² | Mean Bias | Med Bias | Rubin B | Rubin R |
|-----------------|-------|---------|--------|-----------|----------|---------|---------|
| Unmatched       | 0.188 | 169.28  | 0.00   | 67.5      | 66.6     | 160.6   | 0.29    |
| Matched         | 0.031 | 5.12    | 0.98   | 4.8       | 2.5      | 40.6    | 0.61    |

Graph 2.1. Standardized percentage bias before and after matching (Type: Biomass energy).

Graph 2.2. Density plots of the propensity score (Type: Biomass energy).
Table 3.1
Standardized percentage bias and ratio of variance before and after matching (Type: Landfill gas).

| Covariate                        | Unmatched Mean | Matched Mean | % Bias | % Reduct bias | V(T)/V(C) |
|----------------------------------|----------------|--------------|--------|---------------|-----------|
|                                  | Treated        | Control      |        |               |           |
| Longitude                        | U              | 45.77        | 46.15  | −6.9          | 0.49      |
|                                  | M              | −21.11       | −16.37 | −64.0         | 0.60      |
| Latitude                         | U              | −23.59       | −22.40 | −16.1         | 0.96      |
|                                  | M              | 426.62       | 533.71 | −11.4         | 0.70      |
| Altitude                         | U              | 383.46       | 387.17 | 1.2           | 0.90      |
| Population                       | U              | 8.8e+05      | 28276  | 55.4          | 340.9     |
|                                  | M              | 2.6e+05      | 2.3e+05| 1.5           | 0.84      |
| Ratio of rural population        | U              | 0.05         | 0.39   | −203.0        | 0.07      |
|                                  | M              | 0.07         | 0.08   | −7.6          | 0.51      |
| Distance to capital of the federate state | U              | 1021.6       | 1075.9 | −14.5         | 0.42      |
| Access to electricity at home    | U              | 99.64        | 91.86  | 79.4          | 0.00*     |
|                                  | M              | 99.51        | 99.55  | −0.4          | 99.5      |
| Access to running water at home  | U              | 95.92        | 76.09  | 110.4         | 0.04*     |
|                                  | M              | 95.65        | 95.6   | 0.3           | 99.7      |
| Illiteracy rate                  | U              | 6.39         | 19.0   | −149.9        | 0.06      |
|                                  | M              | 6.47         | 6.93   | −5.5          | 0.78      |
| Infant mortality rate            | U              | 17.80        | 26.29  | −81.7         | 0.24      |
| GDP share in the industry sector | U              | 0.25         | 0.15   | 92.2          | 0.54      |
|                                  | M              | 0.26         | 0.28   | −10.2         | 0.41      |
| Region                           | U              | 3.7          | 3.2    | 40.0          | 0.56      |
|                                  | M              | 4            | 3.8    | 9.5           | 0.87      |

Table 3.2
Overall measures of covariate imbalance (Type: Landfill gas).

| Sample       | Ps R² | LR chi2 | p>chi2 | Mean Bias | Med Bias | Rubin B | Rubin R |
|--------------|-------|---------|--------|-----------|----------|---------|---------|
| Unmatched    | 0.43  | 225.92  | 0.00   | 73.1      | 64.0     | 130.0   | 2.14    |
| Matched      | 0.01  | 10.14   | 0.81   | 9.1       | 7.6      | 27.7    | 0.8     |

Graph 3.1. Standardized percentage bias before and after matching (Type: Landfill gas).

Graph 3.2. Density plots of the propensity score. (Type: Landfill gas).
Table 4.1
Standardized percentage bias and ratio of variance before and after matching (Type: Methane avoidance).

| Covariate                        | Unmatched | Matched | Mean | Treated | Control | Bias | % | %  | V(T)/V(C) |
|----------------------------------|-----------|---------|------|---------|---------|------|----|----|-----------|
| Longitude                        | U         |         | 49.23| 46.09   | 58.4    | 5.8  |    | 82.4| 1.12      |
|                                  | M         |         | 49.60| 49.04   | 10.3    | 2.2  |    | 97.2| 0.80      |
| Latitude                         | U         |         | –21.55| –16.29 | –78.2   | 2.2  |    | 62.5| 0.77      |
|                                  | M         |         | –21.56| –21.70 | 2.2     | 2.2  |    | 62.5| 0.77      |
| Altitude                         | U         |         | 548.37| 384.19 | 62.5    | 6.9  |    | 89.0| 0.80      |
|                                  | M         |         | 551.77| 533.71 | 6.9     | 6.9  |    | 89.0| 0.80      |
| Population                       | U         |         | 22392 | 28301   | 27.8    | 2.2  |    | 92.2| 1.09      |
|                                  | M         |         | 1544  | 17889   | 2.2     | 2.2  |    | 92.2| 1.09      |
| Ratio of rural population        | U         |         | 0.19  | 0.39    | –102.9  | 5.1  |    | 1.13| 0.55      |
|                                  | M         |         | 0.19  | 0.23    | –21.3   | 79.3 |    | 79.3| 0.61      |
| Area                             | U         |         | 1757  | 1532.7  | 5.1     |    |    | 5.1 | 0.18      |
|                                  | M         |         | 1858.5| 1661    | 4.5     |    |    | 12.0| 0.13      |
| Distance to capital of the federate state | U     |         | 877.88| 1079.3  | –50.0   |    |    | 50.0| 0.57      |
|                                  | M         |         | 877.35| 884.9   | –1.9    |    |    | 96.2| 0.80      |
| Access to electricity at home    | U         |         | 98.36 | 91.78   | 64.3    |    |    | 96.2| 0.80      |
|                                  | M         |         | 98.27 | 91.63   | 6.3     |    |    | 90.2| 0.44      |
| Access to running water at home  | U         |         | 93.66 | 91.86   | 9.8     |    |    | 90.0| 0.08      |
|                                  | M         |         | 93.66 | 91.86   | 9.8     |    |    | 90.0| 0.08      |
| Illiteracy rate                  | U         |         | 8.38  | 9.09    | –123.9  |    |    | 60.1| 0.13      |
|                                  | M         |         | 8.44  | 9.50    | –12.3   |    |    | 90.1| 0.69      |
| Infant mortality rate            | U         |         | 17.80 | 26.38   | –85.4   |    |    | 92.3| 0.80      |
|                                  | M         |         | 17.62 | 18.23   | –6.6    |    |    | 92.3| 0.80      |
| GDP share in the industry sector | U         |         | 0.20  | 0.15    | 47.6    |    |    | 83.1| 0.66      |
|                                  | M         |         | 0.20  | 0.19    | 8.2     |    |    | 83.1| 0.66      |
| Region                           | U         |         | 3.93  | 3.23    | 61.6    |    |    | 39.5| 0.33      |
|                                  | M         |         | 3.92  | 3.95    | –3.7    |    |    | 93.9| 0.82      |

Table 4.2
Overall measures of covariate imbalance (Type: Methane avoidance).

| Sample   | Ps R² | LR chi2 | p > chi2 | Mean | Med | Rubin B | Rubin R |
|----------|-------|---------|----------|------|-----|---------|---------|
| Unmatched | 0.211 | 399.22  | 0.00     | 69.0 | 62.5| 104.8   | 2.14    |
| Matched   | 0.025 | 12.47   | 0.64     | 7.9  | 6.9 | 27.3    | 0.72    |

Note: Unmatched (bias before matching); matched (bias after matching).

Graph 4.1. Standardized percentage bias before and after matching (Type: Methane avoidance).

Graph 4.2. Density plots of the propensity score (Type: Methane avoidance).
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