Do sustainable energy policies matter for reducing greenhouse gas emissions?

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August 12, 2019

Abstract

Yes, they *matter*. To reply to this question, we assess the impact of energy efficiency and renewable energy policies on six different air pollutants: carbon dioxide (CO_2), methane (CH_4), nitrous oxides (N_2O), non-methane volatile organic compounds (NMVOCs), nitrogen oxides (NO_x) and sulphur dioxide (SO_2) in the case of the Italian provinces in the decade 2005-2015. The empirical analysis is performed in a panel data context by means of propensity score matching with multiple treatment, since our framework is characterized by the presence of two treatments, corresponding to the two different energy policies analyzed, i.e. energy efficiency policy and renewable policy. These two policies can be applied by each province as mutually exclusive strategies or as joint strategies. Our results show that renewable policies are the most efficient in terms of climate goals especially when planned on a local scale, while energy efficiency policies alone are ineffective. Moreover, the success of these policies depends on the type of pollutant to be reduced. Finally, we note that the effect of these two policies was reinforced by the counter-cyclical fiscal policies implemented to contrast the Global Financial Crisis in 2008.

Keywords: Energy efficiency policies; Renewable energy policies; Global air pollutants; Local air pollutants; Propensity score matching with multiple treatment; Italian provinces.

JEL classification: Q50; Q40; Q53; Q58; Q48; Q20.

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1 Introduction

Nowadays, sustainable energy is at the heart of economic growth and the climate change agenda. Attention to the environment and the awareness of the need to mitigate climate changes has led the policymaker to discourage the use of fossil energy sources, such as oil, natural gas and coal, and to encourage an efficient use of the existing energy sources in almost all countries in the world during the last few decades.

According to RISE (2018), sustainable energy policies *matter* for the successful realization of this transition. In fact, they are a driver for renewable energy innovations, which are in turn determinant for the adoption of energy efficiency measures and the diffusion of renewable energies. Moreover, they are often a prerequisite for mobilizing finance, which is crucial to meet climate goals. Strengthening policy and regulatory environments should thus have positive repercussions on sustainable energy outcomes in the long run.

Italy is the third top performer among OECD high income countries both in terms of renewable energy and energy efficiency measures, and is an interesting case of study for many reasons. It has experienced an extraordinary growth in the renewable energy sector since 2009, with the share of renewables in total final consumption that rose from 10 to 13.5 per cent from 2010 to 2013. This trend suggests that Italy is on track to exceed its 2020 target of 17 per cent (IEA, 2016), taking a leading role in implementing the EU Roadmap 2050.[1] Italy is also the eighth-largest emitter of greenhouse emissions (GHG) in the OECD and the fourth-largest in the European Union. The energy sector is the largest contributor to national total GHG emissions with a share equal to 82.4 per cent in 2012.

Many efforts have been made to reduce air pollution: a national GHG emissions reduction plan was adopted in 2002, and updated in 2012.[2] Furthermore, the National Energy Strategy was established in 2013 with the aim of reducing energy costs, meeting environmental targets, strengthening security of energy supply and fostering sustainable economic growth.[3] Given that Italy is a net importer of energy, the National Energy Strategy has a specific focus on the promotion of renewable energy and energy efficiency measures.[4]

With regard to energy and climate policies, the principle of subsidiarity ensures the

[1] The Roadmap 2050 project is an initiative of the European Climate Foundation (ECF) which aims to provide a practical, independent and objective analysis of pathways to achieve a low-carbon economy in Europe, in line with the energy security, environmental and economic goals of the European Union.

[2] The aim of this plan is to establish a set of potential mitigation measures in order to reach Italy's Kyoto target.

[3] The National Energy Strategy is the outcome of a comprehensive consultation process with the energy sector and all interested stakeholders (IEA, 2016).

[4] During recent decades, many other measures have been implemented in order to promote energy efficiency, like tax incentives and tradable energy efficiency certificates, and to obtain cost-effective energy savings (IEA, 2016). The positive impact of all these actions on GHG reduction has been favored by the global economic recession, which has led to a notable reduction of total emissions since 2008.

transposition of the European directives by each Member states. In Italy, the responsibility for this kind of intervention is principally given to Regions, Provinces, and Municipalities, which legislate in compliance with state guidelines. This legislative process was helped by the reform of the Constitution in 2001, which gave greater policy autonomy to Regions and local authorities.[5]

There are many papers in the literature studying the consequences of the adoption of energy efficiency and renewable energy measures (Lehemann, 2012; Sánchez-Braza and Pablo-Romero, 2014; Lehr et al., 2016), but only few analyze the direct impact of this kind of intervention on environmental degradation (see, for example, Blesl et al., 2007; McCollum et al., 2012, Comodi et al., 2012; Bellocchi et al. 2018). These works usually use various simulation models, and alternative energy scenarios are built. They also consider the impact of energy strategies on CO_2 emission reduction, which is generally the only air pollutant analyzed. When the analysis is performed for Italy, great attention is given on the role played by local governments in terms of energy policy planning and the achievement of climate goals (Comodi et al., 2012; Bellocchi et al. 2018; Sarrica et al., 2018).

The aim of this paper is to assess the impact of sustainable energy policies on air emissions in Italy. The empirical analysis is performed by combining two novel datasets. Data on air pollutants are provided by '*Invetaria*', a database retrieved by the Italian Institute for Environmental Protection and Research (ISPRA) and only partially investigated by Germani et al. (2014). Six different air pollutants, whose emissions are measured in 2015, are analyzed: carbon dioxide (CO_2), methane (CH_4), nitrous oxides (N_2O), Non-methane Volatile Organic Compounds (NMVOCs), nitrogen oxides (NO_x) and sulphur dioxide (SO_2). Policy variables are built on the basis of the information obtained from another database provided by ISPRA named '*Air quality improvement measures*'. We focus our attention only on energy efficiency and renewable resource measures planned in the years 2005-2010 on a local, or regional or local and regional scale, and investigate their potential different effects on air pollution. To the best of our knowledge, these data have not yet been studied in the literature.

Furthermore, unlike the existing literature, our empirical framework is based on propensity score matching with multiple treatments,[6] since two treatments are considered in our setting, corresponding to the two different energy policies analyzed, i.e. energy efficiency policy and renewable policy. These two policies can be applied by each province as mutually exclusive strategies, or together as a joint strategies, to fight environmental degradation.

[5]In Italy, a province is an administrative sub-division of a region, which is an administrative sub-division of the State. Italy today has 110 provinces.

[6]A similar approach is followed by Sánchez-Braza and Pablo-Romero (2014), when evaluating the effects of a property tax bonus to promote the installation of solar-thermal energy systems in buildings in Andalusia. However, in this case, the treatment is a binary variable indicating those municipalities which established property tax bonuses in 2010 compared to those which did not.

Several considerations can be drawn from our main results. In fact, we find that *i)* sustainable energy policies have considerable repercussions on air pollutants, probably due to the fact that their effects have been reinforced by the counter-cyclical fiscal policies implemented to contrast the Global Financial Crisis in 2008, together with the emission reductions due to the collapse of the economic activity in the same time period; *ii)* renewable policies are the most efficient in terms of climate goals and their impact on air emissions is stronger when these interventions are planned on a local scale; *iii)* energy efficiency policies alone are ineffective, since they contribute to reducing air pollution only when they are planned together with renewable policies; *iv)* the effectiveness of these policies depends on the type of pollutant to be reduced.

The rest of the paper proceeds as follows. Section 2 provides an overview of environmental quality conditions and the energy scenario in Italy. Section 3 presents the empirical framework adopted in order to disentangle the effects of the two types of sustainable energy policies on greenhouse gases. Section 4 describes the data used in the subsequent analysis. Section 5 shows the main empirical results when energy policies are planned only at local level, only at regional level, and both at local and regional level. Section 6 discusses the main implications of our findings. Finally, Section 7 briefly concludes.

2 A general overview: environmental quality and the energy scenario in Italy

2.1 Environmental quality in Italy

Carbon dioxide (CO_2), together with methane (CH_4) and nitrous oxides (N_2O), are the main greenhouse gases responsible for global warming (UNEP, 1999; IAE, 2016). They are classified as global pollutants, since the marginal damage produced by one unit of pollution does not depend on the location of emission and reception. Three other important gases are non-methane volatile organic compounds (NMVOCs), nitrogen oxides (NO_x) and sulphur dioxide (SO_2), which are classified as local pollutants. In these cases, the marginal damage produced by one unit of pollution varies considerably between locations, depending on ecological, technical and socioeconomic conditions at the point of the location and reception of emission.

Although some of these pollutants are also produced in nature, the main environmental problems result from human activities. In general, the emissions of these pollutants have declined during the last decade, in line with falling energy supply due to the economic downturn, the contraction of the manufacturing sector, and the increased share of renewable sources in the energy mix (IAE, 2016).

More specifically, carbon dioxide emissions account for around 80 per cent of the total greenhouse gas emissions in Europe. For this reason, this pollutant is one of the key indicators considered for monitoring the evolution of climate change in the European

Union. Due to data availability, it is also the most widely investigated pollutant in the empirical literature (Declercq et al., 2011; Hermannsson and McIntyre, 2014; Alberini et al., 2018; Lægreid and Povitkina, 2018). Recently, the European Commission has stressed new policies aiming to reduce the level of methane and nitrous oxide, emissions which are generally attributed to the agricultural sector.

Moreover, tropospheric ozone is principally due to NMVOCs and NO_x gases, which contribute to the formation of photo-oxidants and photochemical smog. SO_2 emissions come from the combustion of sulfur-containing fuels, such as coal and oil, and the extraction of gasoline from oil. Volcanic eruptions are another important source of SO_2 emissions. Together with nitrogen oxides, SO_2 emissions are responsible for the acidification of soil and water.

Air pollution emissions are measured in mega-grams,[7] and have varied considerably across the 20 Italian regions during the last decade, as reported in Figures 1 and 2.

Figures 1 and 2 about here

Figures 1 and 2 show the considerable reduction registered for all the pollutants in the years 2005, 2010 and 2015. In general, Lombardy, Emilia Romagna, Veneto and Lazio exhibit the highest concentration of the emissions of global pollutants, which, in most of cases, are double than the national average. For example, CO_2 emissions in these regions are equal to 35,504, 27,373, 32,160 and 35,324 and the national average is 14,826 in 2015. Similar trends are observed for all the other gases.

SO_2, NO_x and CO_2 present a yearly average contraction equal to 7.79, 4.60 and 4.07 per cent, respectively, in the years 2005-2015, while the remaining gases record a decrease on average of about 2 per cent in the same time period.[8] In particular, SO_2 emissions are very high in Emilia Romagna especially in 2005 and 2010, while very low levels are recorded in 2015 in all the regions. NMVOCs, instead, are the only gases in the sample which exhibit higher levels in Southern than Northern regions.

Lastly, Figures 3 and 4 illustrate air emission levels for the selected gases for the top ten most polluted provinces. High emissions are recorded in Rome and Milan, independently of the pollutants considered. For global gases, Brescia, Padova, Turin, Verona and Bologna also appear in all the rankings proposed by Figure 3.

Figures 3 and 4 about here

2.2 Sustainable energy policies in Italy

The legislative framework for energy policies has considerably changed during recent decades. It is constituted by the intersection of four distinct levels. The highest level

[7]In the Appendix, Table A1 provides pollutant description.

[8]More specifically, the reduction is equal to -1.99, -1.85 and -1.75 for N_2O, NMVOCs and CH_4, respectively.

is the European Union directives, which are then transposed and implemented at national level. The Energy Efficiency Directive establishes a set of binding measures in order to reach the European energy efficiency target, equal to 20 per cent by 2020 (see 2012/27/EU), and all European countries are encouraged to use energy more efficiently at all stages of the energy chain, from production to final consumption.

At national level, in the light of the principle of subsidiarity, the responsibility of the implementation of energy policies is attributed to Regions, Provinces, and Municipalities, with State determining the fundamental principles. Regions and Autonomous Provinces legislate in compliance with state guidelines. (For a detail description of energy governance in Italy, see Sarrica et al., 2018).[9] The rapid devolution of legislative and regulatory powers to the Regions has been favored after the 2001 reform of the Italian Constitution, which provided a new framework for sharing regulatory competences between the State and the Regions, including energy (IEA, 2016).

In particular, Regional Policy is fundamental to meeting the goals of the Europe 2020 Strategy for smart, sustainable and inclusive growth in the European Union.[10] Regional Policy also gained importance after the Global Financial Crisis in 2008, in the light of its crucial role for mitigating the impact of this dramatic breakdown of economic activity involving most of the Member states, and also for reaching many European policy objectives in terms of the environment, climate change and energy issues. For example, the European Regional Energy Balance and Innovation Landscape (EREBILAND) project is one of the most recent ambitious attempts in this sense, since it emphasizes the importance of integrating regional interventions with actions planned on a local scale, given the key role of local institutions for the development of initiatives aimed of reducing greenhouse gas emissions and the production of cleaner energy.[11] Furthermore, the importance of the local authorities is also due to the fact that they are close to citizens, and consequently they are fundamental for the organization of information campaigns designed to increase public awareness of energy and climate issues (Commodi et al., 2012).

This trend justifies our decision to conduct our empirical analysis using data disaggregated at *province* level, since provinces represent the smallest level of governance for which exhaustive and complete data are available. In addition, the time period taken into consideration (2005-2015) is interesting since it reflects significant changes related to the

[9]National energy targets and strategic choices are set by the National Action Plan and the National Energy Strategy, while the Energy and Environmental Regional Plan and the Municipal Energy Plan are set by regions and municipalities, respectively.

[10]Regional Policy is delivered through two main funds: the European Regional Development Fund (ERDF) and the Cohesion Fund (CF). Together with the European Social Fund (ESF), the European Agricultural Fund for Rural Development (EAFRD) and the European Maritime and Fisheries Fund (EMFF), they make up the European Structural and Investment (ESI) Funds. More details are available at *https://ec.europa.eu/regional_policy/en/policy/what/investment-policy/*.

[11]This project is based on a multi-disciplinary approach, and the issues of energy scarcity and efficient use of available resources are analyzed by considering the integration of spatial scales, from EU-wide to regional or local, and cross-sectoral characteristics.

energy sector in Italy.

With regard to energy efficiency policies, we consider those interventions, planned on a local or regional level in the years 2005-2010, whose aim is to promote district heating, wood biomass district heating and energy savings. As noted above, energy efficiency measures are the priority according to the EU Directive. In particular, in this paper, we focus on interventions adopted in order to incentive the development of district heating, mainly concentrated in the North of Italy since the 1970s. Nowadays, 85 per cent of the district heating volume is in Lombardy (45 per cent), Piedmont (27 per cent) and Emilia Romagna (14 per cent).

Similarly, with regard to renewable resource policies, we consider those interventions, planned at local or regional level in the years 2005-2010, which provide incentives for the installation of photovoltaic and solar systems, and the promotion of the production of renewable energy (for wind, solar energy and so on) in the industrial and public sectors. During those years, renewable energy gained a larger share of the total energy mix in all the sectors (heating and cooling, electricity and transport). The total share of renewable energy in fact more than doubled from 7.9 to 18.2 per cent in total primary energy supply in 2005 and 2015 (IEA, 2016).[12]

In Italy, sustainable energy policies were implemented by many regions and/or provinces in the years 2005-2010. Table 1 reports the cases of energy efficiency and renewable energy policies adopted either at regional or local level.

Tables 1 about here

It is worth noticing that, in general, Lombardy, Liguria, Emilia Romagna, Trento, Valle d'Aosta and Veneto, which are in the North of Italy, are the regions applying energy policies on an ongoing basis. No policies have been implemented by the Southern regions, while Marche and Umbria are the most significant cases for the Centre of Italy.

In the following empirical analysis, these two policies are analyzed alternatively and jointly, in order to shed light on the debate on the usefulness of combining different policies for reaching environmental goals (OECD, 2007; Costantini et al., 2017). On this issue, Lehmann (2012) notes that a policy mix is necessary in case of local pollutants, when there are technological spillovers and in case of high transaction costs and asymmetric information. However, a single policy would be sufficient in case of negative externalities due to the emissions of global pollutants.

Furthermore, we consider sustainable energy policies planned in three different circumstances: at local level, at regional level, and both at local and regional level. Tables 2, 3 and 4 report when and where these interventions were planned on a local scale, on a regional scale and both.

[12]More specifically, this positive trend is due to the significant developments in solar power, which increased on average by 63.7 per cent per year from 2005 to 2015, while wind power grew by 21.6 per cent in the same period. Bio-fuels and waste exhibit a yearly increase of 11.1 per cent.

Tables 2, 3 and 4 about here

It is worth noting that, as shown by Tables 3 and 4, energy efficiency policies are planned by the same regions that also adopt renewable energy policies. This is the case of Lombardy, Marche, Valle d'Aosta and Veneto in Table 3, and of Emilia Romagna and Liguria in Table 4.

3 Evaluation by using propensity score matching with multiple treatments: model approach

The development of public policy evaluation has benefited from the use of causal inference, which compares participants and non-participants in public policies. In this framework, a methodology popular in the empirical literature is propensity score matching, which takes into consideration endogeneity problems arising from selection bias (Fredriksson and Wollscheid, 2014; Sánchez-Braza and Pablo-Romero, 2014; Wang et al., 2019).

This model requires the definition of a treatment indicator, which is traditionally a binary variable. However, our context is characterized by the presence of two treatments, corresponding to the two different energy policies analyzed, i.e. energy efficiency policy and renewable policy. These two policies can be applied by each province as mutually exclusive strategies or joint strategies to reach this goal.

Therefore, following Lechner (2001, 2002), we employ a generalized propensity score matching approach with multiple treatments, which indeed makes it possible to isolate the effects of different public interventions on the variable of interest by maintaining control over other factors that affect it.[13]

We indicate energy efficiency policy and renewable energy policy with the acronyms E and R respectively. Four mutually exclusive groups of strategy (S) are thus defined: the case of no treatment is indicated with S_0 describing the situation where no policies are planned by the policymaker in the years 2005-2010, while the circumstances S_E and S_R represent provinces only adopting energy efficiency policy and renewable energy policy in the period 2005-2010, respectively. The case $S_{E,R}$ represents provinces where both these interventions are promoted in the time span 2005-2010.

The main goal of our empirical analysis is to compare the effects on air pollution of these four mutually exclusive strategies S_0, S_E, S_R and $S_{E,R}$. In order to do that, the treatment indicator T_i is equal to 0, 1, 2 and 3 if S_0, S_E, $S_{E,R}$ and S_R respectively hold (for details, see the following Subsection 4.2).

The response variable Y_i is air pollution, measured in 2015, in each province i. In particular, for any province i, the variable Y_i is the value of the response variable associated

[13]It is worth noticing that this methodology has been used in different fields of the empirical literature. For example, Dai et al. (2018) apply it to estimating the causal effect of export and innovation on firm performance.

with the value of the treatment indicator T_i as follows:

$$Y_i = \begin{cases} Y_{0i} & \text{if } T_i = 0 \\ Y_{1i} & \text{if } T_i = 1 \\ Y_{2i} & \text{if } T_i = 2 \\ Y_{3i} & \text{if } T_i = 3 \end{cases}$$

So, Y_{0i} indicates the value of the response variable if the province i does not adopt any energy policy, Y_{1i} indicates the value of the response variable if the province i plans energy efficiency policy, Y_{2i} indicates the value of the response variable if the province i jointly adopts energy efficiency and renewable policies, and Y_{3i} indicates the value of the response variable if the province i applies renewable energy policy.

Then, average treatment effects on the population ($ATTs$) are estimated in the following six pairwise comparisons:

1. S_E/S_0, energy efficiency policy versus no treatment;
2. S_R/S_0, renewable policy versus no treatment;
3. $S_{E,R}/S_0$, energy efficiency and renewable policies versus no treatment;
4. $S_{E,R}/S_E$, energy efficiency and renewable policies versus energy efficiency policy;
5. $S_{E,R}/S_R$, energy efficiency and renewable policies versus renewable policy;
6. S_E/S_R, energy efficiency policy versus renewable policy;

Thus, the pairwise comparison of the effects of treatment m and l can be defined as:

$$ATT_{m,l} = E(Y^m - Y^l|S = m) = E(Y^m|S = m) - E(Y^l|S = m) \tag{1}$$

where $ATT_{m,l}$ denotes the expected average effect of treatment m relative to treatment l for the ith province randomly selected from the population receiving treatment m, and S represents the four mutually exclusive strategies described above.

However, the term $E(Y^m|S = m)$ is not observable. In order to overcome this identification problem, under the conditional independent assumption, the variable Y_i is assumed to be independent of the treatment T_i, conditional on a set of observable covariates (X_i), introducing the main macroeconomic characteristics of each province that can influence the outcomes and the selection of treatments. As a consequence, Equation (1) is rewritten as follows:

$$ATT_{m,l} = E(Y^m|S = m) - E_X \left\{E(Y^l|X, S = l)|S = m\right\} \tag{2}$$

Equation (2) indicates that the outcome of provinces receiving treatment m can be proxied by the outcome of provinces that actually undergo treatment l, given that they have similar macroeconomic characteristics. In particular, the matching procedure makes it possible to form pairs of provinces with similar macroeconomic characteristics, with the only difference being their adoption (or not) of certain types of energy policies.

However, exact matching is difficult, and it is common practice in the literature to obtain it by means of the probability of selecting each province into each specific treatment m conditional on the set of selected covariates (X_i) as follows:

$$p^m(X) = P(S = m|X) \tag{3}$$

More specifically, in our framework, Equation (3) introduces the probability of a province adopting certain energy policies conditioned on the values taken by a vector of covariates. Starting from Rosenbaum and Rubin (1983), this probability is commonly defined as propensity score and is estimated using a multinomial probit model. Matching conditions are identified by using as proximity criterion the nearest neighbor matching method in our empirical analysis.[14] Therefore, by jointly considering Equations (2) and (3), we obtain Equation (4), which is the heart of our estimation strategy:

$$ATT_{m,l} = E(Y^m|S = m)E_{p^m(X),p^l(X)}E(Y^l|p^m(X), p^l(X), S = l)|S = m \tag{4}$$

Finally, we evaluate the quality of matching between our treated and untreated provinces in each of the considered six pairwise comparisons by testing the so-called balancing hypothesis, in order to assess whether the observations with the same propensity score have the same distribution of observable characteristics, independent of the treatment.

4 Data

4.1 Air pollutants

Following UNEP (1999), we consider the following air pollutants: carbon dioxide (CO_2), methane (CH_4) and nitrous oxides (N_2O), which are the three greenhouse gases mainly responsible for the global warming, and three indirect local pollutants: non-methane volatile organic compounds (NMVOCs), nitrogen oxides (NO_x), and sulphur dioxide (SO_2), of which high levels of emission have negative impact on human health.

Data on air pollution are provided by *Invetaria*,[15] a database retrieved by the Italian Institute for Environmental Protection and Research (ISPRA).[16] They are disaggregated

[14] In some sporadic cases, the quality of the matching is higher with the application of the kernel method, which is therefore preferred to the nearest neighbor algorithm.

[15] They can be downloaded from the following link: $http://www.sinanet.isprambiente.it/it/sia-ispra/inventaria$.

[16] ISPRA was established by Decree no. 112 of 25 June 2008, converted into Law no. 133 (with amendments) on 21 August 2008, and performs the duties of three former institutions: APAT (Agency for Environmental Protection and Technical Services), ICRAM (Central Institute for Applied Marine Research), and INFS (National Institute for Wildlife). It acts under the vigilance and policy guidance of the Italian Ministry for the Environment and the Protection of Land and Sea.

by activity according to the SNAP (Selected Nomenclature for Air Pollution) classification. The SNAP classification consists of 11 macro-sectors, which include all human activities relevant for atmospheric emissions, including agriculture, the industrial sector, and road, air, and sea transportation.[17] A complete list of the selected items belonging to each macrosector emitting air pollution is provided in Appendix A (Table A2).

Emission series, disaggregated according to the SNAP classification, are available for all the 110 Italian provinces and the final selected observations refer to the year 2015.[18] They are all measured in myriagram (Mg). These data are thus organized to form six distinct panel datasets, one for each air pollutant. The total number of cross-sections corresponds to the 110 Italian provinces, while the industry-dimension of each panel datasets corresponds to the SNAP items, which vary for each pollutant depending on data availability (these are 82 for CO_2, 81 for CH_4, 63 for N_2O, 69 for NO_x, 98 for NMVOCs and 41 for SO_2). For more detail, see again Table A2 in Appendix A.

To the best of our knowledge, these data have been only partially investigated by Germani et al. (2014), who study the relationship between income, demographic characteristics and concentrations of air industrial pollutants in Italian provinces. However, they limit their analysis to emissions from the industrial sector, by considering only the following macro-sectors: combustion in energy and transformation industry (macro-sector 1), combustion in manufacturing industry (macro-sector 3) and production processes (macro-sector 4).

4.2 Policy variables

Policy variables are elaborated starting from the indications retrieved from the ISPRA database 'Air quality improvement measures'. This database is a repository of the information annually transmitted, since 2005, by Regions and Autonomous Provinces in accordance with the provisions of the national and European legislation on air quality improvement plans.[19] We focus only on energy efficiency and renewable resource measures implemented in the years 2005-2010. They are classified in the database as 'traditional policies' and 'renewable policies' respectively.

Starting from Table 1, we compute the treatment indicator T_i, which identifies the status of each province among the four mutually exclusive strategies S_0, S_E, S_R and $S_{E,R}$ (see Section 3). This variable is equal to zero if the province located in each region does not plan any kind of policy (i.e. if the 'no' decision of the implementation of the policy is

[17]The Italian National System, currently in place, is fully described in the document 'National Greenhouse Gas Inventory System in Italy' (ISPRA, 2016).

[18]It is worth noting that emission observations are also available for the years 1990, 1995, 2000, 2005 and 2010. We consider the most recent year for which data are available on the basis of the information about energy policy provided. On this point, see the following subsection.

[19]This information is freely available at the following link: $http : //www.isprambiente.gov.it/en/databases/air - and - atmospheric - emissions?set_language = en.$

jointly reported in the top and bottom parts of Table 1). It is equal to one if the province located in each region only adopts energy efficiency policies (i.e. if the 'yes' decision of the implementation of the policy is reported in the top part of Table 1). It is equal to 2 if both energy efficiency and a renewable energy policies are planned (i.e. if the 'yes' decision of the implementation of the policy is jointly reported in the two parts of Table 1), and, lastly, it is equal to three in the case when only a renewable energy policies are planned (i.e. if the 'yes' decision of the implementation of the policy is reported in the bottom part of Table 1). The treatment indicator T_i is employed in Subsection 5.1 in the multinominal probit model, from which the propensity scores are estimated. They are then used in the estimation of the average treatment effects.

Furthermore, starting from Table 2, we compute three distinct dummies in order to capture the effects of the sustainable energy measures planned on a local scale. In particular, a dummy is obtained when the province located in each region adopts a energy efficiency policy (i.e. if the 'yes' decision of the implementation of the policy is reported in the top part of Table 2) for more than one year in the period under investigation. A similar dummy is constructed for the case of renewable energy policies with reference to the bottom portion of Table 2, and a dummy indicating when these two types of policies are jointly implemented is derived analogously. These three dummies are then used in the estimation of the average treatment effects reported in Subsection 5.2. With regard to energy efficiency policies, the provinces of Perugia and Bolzano were excluded, as they planned this intervention only in 2009 and 2010, respectively. With regard to renewable energy policies, we exclude provinces located in Campania, as they adopted this policy only in the year 2005.

Lastly, when considering policies planned on a regional scale and on local and regional scale jointly presented in Tables 3 and 4, two additional groups composed by three dummy variables are again computed following the same criteria described above. More specifically, in the case of energy efficiency policies planned on a regional scale, provinces located in Veneto were excluded since these interventions were applied only in 2010. These two clusters of dichotomous variables were then used for the estimations of the average treatment effects reported in Subsection 5.3.

4.3 Explanatory variables

There are many factors that may influence local governments towards policy intervention in order to provide incentive for energy efficiency and promote renewable energies. In our empirical analysis, five distinct explanatory variables are included in the multinominal probit model as covariates to control for local heterogeneity.

The first set of variables are per capita GDP, population density and unemployment rate. These refer to the main economic characteristics of each province and are retrieved from Eurostat (regional statistics). In particular, per capita GDP captures the stage of development of each province, which can vary considerably between Italian provinces.

This variable is employed as an indicator of the resource available at the time of making the decision on whether to implement the policy.

Population density is also included in the estimations. The effects of this indicator on policy decisions are controversial, but there is a strand of the empirical literature which demonstrates that higher population density (or similarly, a higher population growth rate) might pose a challenge to the use of environmentally friendly energy sources. In that case, population density may have a negative impact on the adoption of these kinds of energy policies (see, for example, Huang et al., 2007).

The unemployment rate is considered as an indicator of the economic motives which may underlie local authority decisions to promote these kinds of energy policy (Sànchez-Braza and Pablo-Romero, 2014). In this case, the promotion of renewable and energy efficiency policies is a job creation engine, which can boost economic well-being, as demonstrated by Lehr et al. (2016).

Patents registered at the European Patent Office (EPO), measured in terms of number per million inhabitants, are used as a proxy of innovation, which is also a key issue in terms of policy intervention in the the light of the rapid rate of technological progress in sustainable energy. In fact, Johnstone et al. (2010) show that different policy instruments have heterogeneous effects on renewable energy technologies depending on their degree of technological maturity (Costantini et al., 2017). Moreover, as noted by Wüstenhagen and Menichetti (2012), technological improvement, deployment and economies of scale are also important in terms of cost reduction. In the case of Italian regions, Costantini et al. (2013) show that technological spillovers play a more effective role in improving environmental efficiency, with an increasing effect for more localized pollutants.

Lastly, as noted by RISE (2018), progress on the sustainable energy agenda depends not only on policies and effective institutional enforcement, but also on the ability to attract financing for sustainable energy investments. As a consequence, given that our sample period covers the years of the global financial crisis, and given that private investments have now become the largest source of capital for energy projects (Wüstenhagen and Menichetti, 2012), a proxy of the instability of financial markets is introduced into our estimations. The variable used to measure territorial differences in financing risk is the decay rate of the loan facilities in percentage points.

Data on these two last variables belong to 2030 Agenda for sustainable development project promoted by the UN-Assembly General (UN Resolution A7RES/70/1, New York), with the goal of ending poverty, protecting the planet and ensuring prosperity for all. In the case of Italy, these indicators are provided by ISTAT, which, like other national statistical institutes, has the task of contributing to the realization of this global project.

5 Results

5.1 Preliminary results

The decisions to implement sustainable energy policies depend not only on the features of each region or province, but also on the business environment. For an overview, we distinguish our provinces into four mutually exclusive groups, according to the type of policy strategy adopted (see Section 3): renewable energy policy adopters, efficiency energy policy adopters, both, and neither.[20]

Table 5 about here

Table 5 shows substantial differences among these four clusters in the years 2005 and 2015. On one hand, provinces adopting both these policies are in general characterized by a higher level of air emissions, are more developed, innovative and densely populated, with a lower degree of financial instability and a lower level of unemployment. On the other hand, provinces that do not implement any kind of policies are characterized by a lower level of economic development, higher unemployment and more critical financial conditions.

Estimates are computed using the multinominal probit model,[21] where, for each province i, the treatment indicator T_i is used as dependent variable (see the previous Subsection 4.2).

Table 6 about here

Table 6 summarizes the results obtained from the multinominal probit estimation of the propensity scores.[22] The specification of the multinominal probit model also includes SNAP dummies, in order to capture industry-specific fixed effects. All the variables included in the estimation exhibit the expected signs (see Subsection 4.3).

In particular, with regard to the variables introducing the main economic characteristics of each province, per capita GDP is positive, and the highest coefficient is observed in the case of the joint implementation of the two energy policies ($S_{E,R}$). This implies that economic growth fosters the adoption of these interventions. The estimated parameters related to population density and unemployment rate are negative, in line with the

[20]More specifically, these groups identify provinces applying the following strategies: S_R, S_E, $S_{E,R}$ and S_0.

[21]Similar results were also obtained by means of multinominal logit regressions, available upon request to the author.

[22]Multinominal probit estimations are computed for each database separately (one for each pollutant), given that the sample size of each dataset varies according to the SNAP items available (see Table A.1). However, estimates are consistent across these six different samples. In the paper, for the sake of brevity, we report and discuss only the findings related to the NMVOC emission database, but other findings are available upon request to the author.

evidence highlighted by the empirical literature. The variable used to proxy technological progress captures the positive impact of innovation on sustainable energy policies, while the coefficient associated with the series introducing financial risk is negative. This indicates that higher uncertainty in financial markets negatively affects the promotion of new policies. With the sole exception of per capita GDP, the estimated coefficients are always higher when only energy efficiency policies are implemented.

Propensity scores assigned to each province are obtained from the results shown by Table 6. We then proceed to estimate the causal effect of the matching technique following the nearest neighbor algorithm. We employ the variants 'common support' and 'without replacement' to avoid any matching bias and to improve matching quality. The matching procedure is computed with Stata 14.0 using the routine laid down by Leuven and Sianesi (2003). Alternative matching algorithms were tested, and their performance was generally consistent with our main findings.

In the following subsections, three distinct situations are considered: the case where sustainable energy policies are implemented only at local level, the case where sustainable energy policies are implemented only at regional level, and lastly, the circumstance where these interventions are adopted both at local and regional level.

5.2 Sustainable energy policies on a local scale

In this subsection, we consider the impact of sustainable energy policies on air pollution when they are planned on a *local scale*. In fact, the literature reports many studies highlighting the importance of local governments for the development of sustainable energy sources, since they are key players in the adoption of new energy models or of already-known solutions (Economou, 2010; Michalena and Angeon, 2010 and Comodi et al, 2012).

Our main goal is to estimate the average treatment effects (ATT) introduced by Equation 4, which captures the differences in terms of emission levels between the treated provinces and the matched ones. The analysis is performed using the propensity scores derived from results reported by Table 6, and by using the set of dummy variables obtained, as described in the previous Subsection 4.2, from the information in Table 2. The estimated treatment effects are reported as a percentage of the untreated outcome means, in order to measure the effectiveness of the different combinations of strategies in terms of pollution reduction. Main findings are reported in Table 7.

Table 7 about here

On one hand, our results show that energy efficiency policies alone are not effective, since the estimated coefficients are in general not statistically different from zero. This is the case when comparing provinces adopting energy efficiency policies with provinces that do not adopt any kind of policy (S_E/S_0), and when comparing provinces adopting energy efficiency policies with provinces that only adopt renewable ones (S_E/S_R).

On the other hand, renewable policies are successful in terms of emission reduction when they are adopted alone (S_R/S_0) and when they are considered jointly with energy efficiency interventions ($S_{E,R}/S_0$, $S_{E,R}/S_E$ and $S_{E,R}/S_R$). More specifically, in the case of the strategy S_R/S_0, the estimated effect is always negative and statistical significant, suggesting an average emission reduction equal to 65 per cent. This result holds independently of the types of pollutants taken into examination.

When renewable and energy efficiency policies are jointly applied, the combinations of policies $S_{E,R}/S_0$ and $S_{E,R}/S_E$ are generally more successful in the case of the local pollutants.[23] Lastly, estimations associated with the mix of policies $S_{E,R}/S_R$ are always negative, as expected, independently of the type of GHG emissions. However, it is worth noting that this latter policy mix is the most efficient when global pollutants are considered.

In general, in the case of *local* interventions, renewable policies either adopted alone (S_R/S_0) or combined with energy efficiency measures ($S_{E,R}/S_R$) are the best solution with respect to climate goals, since they work efficiently independently of the kind of emissions examined. Furthermore, their effects are significant in the case of global gases, which are the main focus of the climate agenda. In fact, UNFCCC (2015) shows that CO_2 is the largest GHG emission in Italy in 2014, and emissions account for 81.9 per cent of the total, followed by CH_4 and N_2O (10.3 and 4.4 per cent, respectively).

Finally, we evaluate the quality of matching between our treated (i.e., those provinces adopting only one type of policy intervention or both) and the control provinces (i.e., those provinces not adopting the policies or those applying only one of these two policies) by testing the so-called balancing hypothesis, that is, whether the observations with the same propensity score have the same distribution of observable characteristics, independent of the treatment (Rosenbaum and Rubin, 1983; Dehejia and Wahba, 2002).

Table 8 about here

Table 8 provides the results of these tests computed for each dataset related to each pollutant, and show that the median standardized bias drops significantly as expected after matching.

5.3 Sustainable energy policies when planned on a regional scale only and on a regional and local scale jointly

In this subsection we study the effect of sustainable energy policies on air pollution when these interventions are planned on a *regional scale* and when are *jointly* planned on a *regional and local scale.*

[23]Moreover, the strategy $S_{E,R}/S_E$ works for most of the global gases considered, although the highest emission reduction is observed in the case of the local pollutants.

As noted in Subsection 2.2, regional policies are indeed important determinants for efficient patterns of energy supply and demand, since energy targets are set at European level, but their implementation requires a strategy tailored by each Member State. In particular, in the case of Italy, the policymaker sets up the National Action Plan and the National Energy Strategy, which establish energy guidelines, which are then integrated by the Energy and Environmental Regional Plan and the Municipal Energy Plan, which are determined by regions and municipalities, respectively.

The empirical analysis is carried out in a similar way to that described in the previous subsection. Firstly, a set of dummy variables, derived from Table 3, indicating energy efficiency and renewable policies adopted on a regional scale in the years 2005-2010 are introduced. To model energy policies adopted jointly on regional and local scale in the same time period, three additional dummy variables are built in the same way (see Table 4).[24] As before, the empirical analysis is carried out by using the propensity scores derived from the findings shown in Table 6.

Tables 3 and 4 show that regions adopting energy efficiency policies are precisely the same regions which adopted renewable energy policies. The analysis in this subsection thus covers only the following combinations of strategies: S_R/S_0, $S_{E,R}/S_0$ and $S_{E,R}/S_R$. The ATT estimates reported in Tables 9 and 10, computed as a percentage of the untreated outcome means, show that these three combinations of strategies have a different impact on air pollutants.

Tables 9 and 10 about here

With regard to Table 9, in the case of global air gases, only renewable policies are effective in reducing these kinds of emissions, since the ATT coefficients are always negative and statistically significant when we compare provinces applying renewable policies with respect to those ones that do not apply any kind of intervention (S_R/S_0). This result also holds in the case of the local pollutants. When renewable and energy efficiency policies are jointly applied ($S_{E,R}/S_0$ and $S_{E,R}/S_R$), their impact is in general significant only in the case of the local pollutants.

This finding is again in line with the literature: as noted by Lehmann (2012), policy design becomes more complex in the case of non-uniformly mixed pollutants, like NO_x or SO_2, since the marginal damage caused by one pollution unit vary considerably between locations, depending on ecological, technical and socioeconomic conditions at the point of emission as well as at the point of reception. As a consequence, in these circumstances, a policy mix is recommended.

These results are generally confirmed when moving to consider policies planned both on a regional and local scale jointly (see Table 10). The performance of energy policies is indeed principally stronger in the case of local gases, while, when considering global pollutants, energy policies work only in the case of CO_2 and N_2O emissions.

[24]Details of these two sets of dummies are provided in Subsection 4.2.

Interesting evidence emerges when comparing findings shown in Tables 7, 9 and 10. In general, renewable energy policies are the most efficient in terms of emission reduction. This holds independently of the kind of pollutant considered and the nature of the intervention (local, regional or both). A similar conclusion is obtained when considering the combination of strategies $S_{E,R}/S_0$. Moreover, the combination of strategies $S_{E,R}/S_R$ ensures a considerable emission reduction for all the gases when policies are applied on a local scale and on a local and regional scale jointly, especially in the case of global pollutants. Lastly, CH_4 is the only pollutant in the sample for which only renewable policies, applied either at local or regional level, are effective in reducing its emissions.

To conclude, Tables 11 and 12 report the tests for balancing hypothesis computed for each pollutant and for each combination of strategies. They confirm the good performance of our matching procedure.

Tables 11 and Table 12 about here

6 Discussion

Several considerations can be made on the results described in the previous section. Our findings demonstrate that sustainable energy policies are particular efficient when they are implemented at local level or jointly at local and regional level. This is in line with the fact that energy policies depend on territorially-specific circumstances, showing different degrees of effectiveness in terms of stimulating deployment (IEA, 2016). Local environmental policies are particularly desirable (European Directive on Renewable Energy, 2009; Hermannsson and McIntyre, 2014), and in this respect, the decentralization process of energy policy and planning procedures has been particularly successful in Italy (Sarrica et al., 2018).[25]

Among sustainable energy interventions, renewable policies planned alone are the most efficient in terms of climate goals. This holds independently of the nature of the intervention (local, regional or both) and the kind of pollutant considered. Moreover, this is the only type of policy which ensures the expected pollution reduction when considering global air pollutants. This evidence is supported by the literature: Lehmann (2012) underlines that the negative externality generated by these kinds of gases may be corrected efficiently by a single emission-based policy, since the marginal damage produced by one pollution unit does not depend on the location of its emission and reception.

This finding also justifies the impressive growth in the renewable energy sector in Italy during the last decade. In fact, the total share of renewable energy on total primary

[25]For example, small scale interventions and projects for the installation of a PV system on roofing (and similar initiatives) were subject to Communication or Simplified Authorization Procedure, which is under municipality competence.

energy supply in all industries (heating and cooling, electricity and transport) has more than doubled, rising from 7.9 per cent in 2005 to 18.2 per cent 2015.[26]

Energy efficiency policies are a priority of the 2012 Energy Efficiency Directive,[27] given that they play a key role in lowering energy costs, reducing emissions and their impact on the environment, with positive repercussions also in terms of economic growth. However, their implementation encounters numerous obstacles given the presence of many barriers across all sectors, and they are mainly applied in towns in the North of Italy.[28]

This evidence may explain why energy efficiency policies alone are ineffective. Given that district heating systems in Italy use less than 10 per cent of renewable energy sources, fostering the production of energy efficiency measures is mandatory also in order to strengthen the incidence of renewable energy intervention. It is worth noting that different measures have been taken to reach this goal. For example, a tax credit mechanism for energy savings in the buildings sector was introduced for promoting the installation of solar thermal energy plants, highly-efficient heat pumps, low-enthalpy geothermal systems and biomass. This fiscal incentive was a voluntary scheme, and made it possible to subtract a considerable percentage of the costs incurred for specific energy efficiency upgrading interventions on existing buildings from income tax.[29] As noted by Sánchez-Braza and Pablo-Romero (2014), these tax bonuses have important repercussions in terms of agent's choices, since the big cost reduction in terms of tax payments is a strong incentive to choose renewable energy.

These actions integrate different support mechanisms used to foster the development of renewable energies in the years 2009-2012: a feed-in tariff and a premium scheme (called *conto energia*) for solar photovoltaic installations, a green certificate scheme and a feed-in tariff scheme for all the other renewable resources different from photovoltaic installations.[30] In 2013, these three support schemes were modified with the introduction of a new support scheme (called *conto termico*) for the heat sector, characterized by a price-based mechanism, and a sliding feed-in premium/feed-in-tariff scheme, which replaced the green certificate scheme.

Lastly, our findings show that the sustainable energy policies generally exert a considerable impact on air pollutants. As noted by IEA (2016), the period analyzed covers the years of the Global Financial Crisis, which had dramatic repercussions on the Italian economy. As a consequence, it is likely that the counter-cyclical fiscal policies imple-

[26]This evidence is very significant since it is close to reaching of the European Union's 20 per cent renewable energy target.

[27]This Directive established a set of binding measures to help the European Union reach its 20 per cent energy efficiency target by 2020.

[28]As reported by IEA (2016), 85 per cent of the heating volume is in Lombardy (45 per cent), Piedmont (27 per cent) and Emilia Romagna (14 per cent).

[29]This percentage was 55 per cent until 6 June 2013, and 65 per cent until 31 December 2015. The deductions must be spread over ten years.

[30]The feed-in tariff scheme covers all renewable resources with a capacity up to 1.0 megawatt (MW), 200 kilowatts (kW) for wind, with the exception of photovoltaic installations.

mented to fight the crisis, together with the emission reductions due to slower economic activity, have reinforced the effect of energy policies on the environment.

This is in line with a strand of the empirical literature showing that crises can be seen as an opportunity to replace carbon-intensive technologies by cleaner alternatives. In fact, the Global Financial Crisis in 2008 and its contagion to the real economy has reopened the discussion on the usefulness of environmental policies and actions in counter-cyclical packages. The fall in economic activity due to the crisis did lead to reductions in energy consumption and, thus, air emissions (particularly those related from fossil-fuel combustion and cement production) as demonstrated by Declercq et al. (2011), Sobrino and Monzon (2014) and Jalles (2019) among others. More specifically, Jalles (2019) empirically shows that, when an economy is hit by a negative shock, there is a reallocation of government spending composition towards social and public goods that tend to reduce pollution. This is confirmed by the fact that, since 2009, the renewable energy sector has grown considerably, with a share of renewable of total final consumption equal to 10 and 13.5 per cent in 2010 and 2013. Its dynamics suggests that Italy is on track to exceed its 2020 target of 17 per cent (IEA, 2016).

7 Conclusions

This paper assesses the impact of renewable energy and energy efficiency policies on six different air pollutants, whose emissions are measured in 2015, by using two novel datasets on greenhouse gases and sustainable energy policies adopted in Italy in the years 2005-2010. Given the rapid devolution of legislative and regulatory powers to the Regions, Provinces, and Municipalities, the empirical analysis is performed by using data disaggregated at province level, since provinces represent the smallest level of governance for which exhaustive and complete data are available.

The empirical analysis is performed using propensity score matching with multiple treatment, since our framework is characterized by the presence of two different energy policies, i.e. energy efficiency policy and renewable policy. These two policies can be applied by each province as mutually exclusive or joint strategies.

We found that the sustainable energy policies implemented by Italian provinces exert a considerable impact on air pollutants. In fact, the period analyzed covers the years of the Global Financial Crisis, which had dramatic repercussions on the Italian economy. As a consequence, the counter-cyclical fiscal policies implemented to fight the crisis, together with the emission reductions due to the collapse of economic activity, reinforced the effects of energy policies on the environment. This is in line with a strand of the empirical literature, which shows that crises can be seen as an opportunity to replace carbon-intensive technologies by cleaner alternatives.

Among sustainable energy interventions, renewable policies are the most efficient in terms of climate goals, while energy efficiency policies alone are ineffective, since they contribute to reducing air pollution only when adopted together with the renewable policies. Moreover, the effectiveness of these interventions depend on the type of pollutant to be reduced.

In terms of policy perspective, it is worth noting that developing a more competitive and sustainable energy market is one of the most significant challenges for Italy's future (IEA, 2016). Smarter investment in energy-related research activities should contribute to further improving the energy and resource efficiency of the economy and creating new sources of growth and positive externalities for the environment.

For example, the Eco-Innovation Plan constitutes an interesting case in this context, as it focuses on '*boosting innovation that results in or aims at reducing pressures on the environment and on bridging the gap between innovation and the market*' (European Commission 2011, 1). As a consequence, when the policymaker promotes innovation, she also has to consider its impact on the environment (Baiardi, 2014).

However, research and innovation in the energy sector is not at the required level, especially when compared to the other European countries, and despite the growing number of patent applications in energy efficiency and renewable energy technologies registered during recent years. This is partly because technological districts, the drivers of the innovation system in Italy, are concentrated only in large northern cities such as Bologna, Milan, Rome, Trieste, Turin, and Venice.

Finally, the attractiveness of sustainable energy investments is also crucial for progress on the sustainable energy agenda. Creditworthy utilities are the central player in the development of energy access, renewable energy and energy efficiency. Financial market are in fact generally affected by information gaps, institutional barriers, short time horizons, and non-separability of energy equipment (Brown, 2001). The dynamics of future energy prices is an additional worrying source of uncertainty, especially in the short term. Such uncertainties often lead to higher perceived risks, and therefore to more stringent investment criteria and a higher hurdle rate.

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Table 1: Sustainable energy policies planned in Italy either on a regional or local scale in the years 2005-2010.

	2005	2006	2007	2008	2009	2010
Energy efficiency policies						
Bolzano	No	No	No	No	No	Yes
Emilia Romagna	No	No	Yes	Yes	Yes	Yes
Liguria	No	No	No	No	Yes	Yes
Lombardy	Yes	Yes	Yes	Yes	Yes	Yes
Marche	No	No	No	No	Yes	Yes
Piedmont	Yes	Yes	Yes	Yes	Yes	Yes
Trento	No	No	No	No	Yes	Yes
Umbria	No	No	No	No	No	Yes
Valle d'Aosta	Yes	Yes	Yes	Yes	Yes	No
Veneto	No	No	No	No	No	Yes
Renewable energy policies						
Campania	Yes	No	No	No	No	No
Emilia Romagna	Yes	Yes	Yes	Yes	Yes	Yes
Liguria	Yes	Yes	Yes	Yes	Yes	Yes
Lombardy	Yes	Yes	Yes	Yes	Yes	Yes
Marche	Yes	Yes	Yes	Yes	Yes	Yes
Tuscany	Yes	No	Yes	Yes	Yes	No
Trento	No	Yes	Yes	Yes	Yes	Yes
Umbria	Yes	No	Yes	Yes	Yes	Yes
Valle d'Aosta	Yes	Yes	Yes	Yes	Yes	No
Veneto	Yes	Yes	Yes	Yes	Yes	Yes

Notes: 'Yes' ('No') indicates if the policy has been (has not been) implemented in that specific year. Energy policies had been adopted by provinces belonging to each (reported) region. Author's elaboration on ISPRA data.

Table 2: Sustainable energy policies only planned in Italy on a local scale in the years 2005-2010

	2005	2006	2007	2008	2009	2010
Energy efficiency policies						
Bolzano	No	No	No	No	No	Yes
Lombardy	Yes	Yes	No	No	No	No
Piedmont (Turin)	Yes	Yes	Yes	Yes	Yes	Yes
Trento	No	No	No	No	Yes	Yes
Umbria	No	No	No	No	Yes	No
Renewable energy policies						
Campania	Yes	No	No	No	No	No
Trento	No	No	Yes	Yes	Yes	Yes
Liguria	No	No	No	No	Yes	Yes
Lombardy	Yes	Yes	No	No	No	No
Marche	No	No	No	No	Yes	Yes
Umbria (Corciano)	No	Yes	Yes	Yes	Yes	No

Notes: 'Yes' ('No') indicates if the local policy has been (has not been) implemented in that specific year. Energy policies had been adopted by provinces belonging to each (reported) region, with the only exception of Piedmont and Umbria. In these two latter cases, energy policies were only applied by Turin and Corciano (province of Perugia). Author's elaboration on ISPRA data.

Table 3: Sustainable energy policies only implemented at regional level in Italy in the years 2005-2010

	2005	2006	2007	2008	2009	2010
Energy efficiency policies						
Lombardy	Yes	Yes	Yes	Yes	Yes	Yes
Marche	No	No	No	No	Yes	Yes
Valle d'Aosta	Yes	Yes	Yes	Yes	Yes	No
Veneto	No	No	No	No	No	Yes
Renewable energy policies						
Liguria	Yes	No	No	Yes	No	No
Lombardy	Yes	Yes	Yes	Yes	Yes	Yes
Marche	Yes	Yes	Yes	Yes	Yes	Yes
Tuscany	No	No	No	Yes	Yes	Yes
Umbria	Yes	Yes	Yes	No	No	Yes
Valle d'Aosta	Yes	Yes	Yes	Yes	Yes	No
Veneto	Yes	Yes	Yes	Yes	Yes	Yes

Notes: 'Yes' ('No') indicates if the regional policy has been (has not been) implemented in that specific year. Energy policies had been adopted by provinces belonging to each (reported) region. Author's elaboration on ISPRA data.

Table 4: Sustainable energy policies implemented at local and regional level in Italy in the years 2005-2010

	2005	2006	2007	2008	2009	2010
Energy efficiency policies						
Emilia Romagna	Yes	Yes	Yes	Yes	Yes	Yes
Liguria	Yes	Yes	Yes	Yes	Yes	Yes
Renewable energy policies						
Emilia Romagna	Yes	Yes	Yes	Yes	Yes	Yes
Liguria	No	No	Yes	Yes	No	No
Trento	No	No	No	No	No	Yes
Tuscany	Yes	Yes	Yes	Yes	Yes	No

Notes: 'Yes' ('No') indicates if the regional and regional policies have been (have not been) implemented in that specific year. Energy policies had been adopted by provinces belonging to each (reported) region. Author's elaboration on ISPRA data.

Table 5: Comparison of observable province adopters characteristics in the years 2005 and 2015

	Efficiency energy policy adopters	**Renewable energy policy adopters**	**Both**	**Neither**
Year 2005				
Greenhouse gases				
Global air pollutants				
CO_2 emissions	25,861.170	24,743.260	35,534.140	18,459.620
CH_4 emissions	251.763	180.799	272.079	217.747
N_2O emissions	11.017	10.333	12.267	8.579
Local air pollutants				
NMVOC emissions	169.226	123.711	143.371	379.869
NO_x emissions	123.409	114.282	133.836	109.352
SO_2 emissions	8.025	9.701	20.986	6.608
Economic conditions				
Per capita GDP	26,237.500	26,363.160	28,556.250	19,125.490
Population density	164.750	233.521	239.127	228.802
Unemployment rate	4.813	5.189	4.400	11.843
Patents	47.129	66.231	64.086	38.202
Decay rate of the loan facilities	1.275	1.211	1.041	1.731
Year 2015				
Greenhouse gases				
Global air pollutants				
CO_2 emissions	17,960.630	16,952.070	24,746.510	12,901.380
CH_4 emissions	219.013	160.415	224.182	155.755
N_2O emissions	9.883	9.074	10.125	6.866
Local air pollutants				
NMVOC emissions	132.913	91.658	112.467	315.373
NO_x emissions	79.362	73.735	84.370	64.656
SO_2 emissions	2.872	3.955	5.003	3.041
Economic conditions				
Per capita GDP	27,050.000	28,263.160	30,078.130	19,960.780
Population density	164.500	237.616	355.456	230.306
Unemployment rate	9.000	8.784	8.425	17.039
Patents	38.275	47.283	51.305	54.667
Decay rate of the loan facilities	2.375	4.258	3.997	5.068

Notes: Author's elaboration on Eurostat, ISPRA and ISTAT data.

Table 6: Multinominal probit regression on estimating the propensity score in the Italian provinces

	Efficiency energy policy adopters	**Both**	**Renewable energy policy adopters**
Per capita GDP	0.2932***	0.7744***	0.1310*
	(0.0947)	(0.0710)	(0.0725)
Decay rate of the loan facilities	-0.3011***	-0.2486***	0.0399
	(0.0526)	(0.0439)	(0.0394)
Patents	0.4616***	0.3666***	0.1426***
	(0.0498)	(0.0403)	(0.0423)
Population density	-1.0977***	-0.3484***	-0.0818*
	(0.1024)	(0.0508)	(0.0498)
Unemployment rate	-0.9727***	-1.5762***	-1.8191***
	(0.0879)	(0.0827)	(0.0817)
Constant	-1.4608***	-1.1361***	-0.9757***
	(0.0838)	(0.0785)	(0.0727)
Obs	8,019	8,019	8,019

Notes: Standard errors are in parentheses. A *(**)[***] indicates significance at the 10(5)[1] percentage level. SNAP dummies are included but not presented. Per capita GDP and population density data are related to the year 2005, while patents are referred to the year 2007. The variables decay rate of the loan facilities and unemployment rate are referred to the year 2010. Estimates are consistent across the six different samples. Explanatory variables are standardized.

Table 7: The multiple treatment effects of renewable and energy efficiency policy applied at local level on air pollutants

	Global pollutants			**Local pollutants**		
Treated/control	CO_2	CH_4	N_2O	NMVOCs	NO_x	SO_2
S_E/S_0	11.1773	3.1064	2.0709	0.4638	0.4305	4.8901
	(7.8906)	(3.7596)	(1.3502)	(0.4674)	(0.6050)	(3.7663)
S_R/S_0	-0.5722***	-0.6909***	-0.6612***	-0.6621***	-0.6259***	-0.6611*
	(0.2074)	(0.1431)	(0.1298)	(0.1178)	(0.0802)	(0.3773)
S_E/S_R	-5.6147	0.3705	2.5439	0.5236	0.7939	6.1407
	(5.7439)	(1.2523)	(1.7353)	(0.4019)	(0.7727)	(4.8085)
$S_{E,R}/S_0$	1.3213	0.2832	0.0047	-0.6528***	-0.5064***	-0.5311***
	(0.7896)	(0.8865)	(0.2509)	(0.1372)	(0.0833)	(0.2057)
$S_{E,R}/S_E$	-0.3619**	0.1051	-0.2570*	-0.6983***	-0.5614***	-0.5705**
	(0.1688)	(0.2003)	(0.1323)	(0.0923)	(0.068)	(0.2914)
$S_{E,R}/S_R$	-0.3974*	-0.5072***	-0.3316***	-0.4775***	-0.2893**	-0.2271
	(0.2136)	(0.1220)	(0.0933)	(0.1124)	(0.1125)	(0.2249)

Notes: The estimated treatment effects are reported as a percentage of the untreated outcome means. Robust standard errors under parenthesis. A *, **, *** indicates significance at 10, 5, 1 per cent level.

Table 8: Testing the balancing hypothesis for the nearest neighbor matching in the case of energy policies planned on a local scale

	Mean Bias Unmatched	Mean Bias Matched	Reduction in bias %	Mean Bias Unmatched	Mean Bias Matched	Reduction in bias %	Mean Bias Unmatched	Mean Bias Matched	Reduction in bias %
		CO_2			CH_4			N_2O	
S_E/S_0	32.4	0.0	99.9	32.4	0.2	99.5	32.4	0.1	99.8
S_R/S_0	71.6	1.2	98.4	71.6	1.1	98.4	71.6	1.0	98.6
S_E/S_R	90.6	1.9	97.8	90.6	1.9	97.9	90.6	1.9	97.8
$S_{E,R}/S_0$	146.5	0.2	99.9	146.5	0.1	99.9	146.5	0.2	99.9
$S_{E,R}/S_E$	36.4	1.3	96.4	36.4	1.1	96.9	36.4	1.2	96.6
$S_{E,R}/S_R$	106.6	0.9	99.1	106.6	1.4	98.6	106.6	1.5	98.6
		NMVOCs			NO_x			SO_2	
S_E/S_0	32.4	3.3	89.7	32.4	0.2	99.7	32.4	3.2	90.2
S_R/S_0	71.6	1.3	98.2	71.6	1.1	98.5	71.6	0.5	99.2
S_E/S_R	90.6	1.9	97.9	90.6	1.9	97.9	90.6	1.9	97.8
$S_{E,R}/S_0$	146.5	0.2	99.9	146.5	0.2	99.9	146.5	0.8	99.5
$S_{E,R}/S_E$	36.4	0.8	97.7	36.4	1.2	96.8	36.4	1.4	96.2
$S_{E,R}/S_R$	106.6	1.1	99.0	106.6	1.4	98.7	106.6	1.4	98.7

Notes: In the case of the strategy S_E/S_R , the kernel method has been used since the quality of the matching is higher with respect to the case of the nearest neighbor algorithm.

Table 9: The multiple treatment effects of renewable and energy efficiency policy applied at regional level on air pollutants

	Global pollutants			**Local pollutants**		
Treated/control	CO_2	CH_4	N_2O	NMVOCs	NO_x	SO_2
S_R/S_0	-0.5426**	-0.5900***	-0.6264***	-0.6637***	-0.5856***	-0.5264**
	(0.2552)	(0.2492)	(0.1450)	(0.1567)	(0.0738)	(0.2076)
$S_{E,R}/S_0$	0.5001	-0.1505	0.1743	-0.5529***	-0.4756***	-0.5546***
	(0.6016)	(0.9050)	(0.2088)	(0.0985)	(0.0649)	(0.2105)
$S_{E,R}/S_R$	-0.2378*	-0.1131	-0.0179	-0.6233***	-0.2841***	-0.5546***
	(0.1262)	(0.1637)	(0.1227)	(0.1009)	(0.0874)	(0.2104)

Notes: The estimated treatment effects are reported as a percentage of the untreated outcome means. Robust standard errors under parenthesis. A *, **, *** indicates significance at 10, 5, 1 per cent level.

Table 10: The multiple treatment effects of renewable and energy efficiency policy applied at regional and local level on air pollutants

	Global pollutants			**Local pollutants**		
Treated/control	CO_2	CH_4	N_2O	NMVOCs	NO_x	SO_2
S_R/S_0	-0.4731**	-0.4252	-0.6518***	-0.4343	-0.5721***	-0.5554***
	(0.2312)	(0.3727)	(0.1518)	(0.3094)	(0.0838)	(0.2002)
$S_{E,R}/S_0$	-0.4977	-0.1946	-0.4881***	-0.6865***	-0.6055***	-0.4367*
	(0.3442)	(0.2105)	(0.1296)	(0.0928)	(0.0530)	(0.2537)
$S_{E,R}/S_R$	-0.5126***	-0.0467	-0.4396***	-0.6699***	-0.5970***	-0.2387
	(0.1528)	(0.3039)	(0.1206)	(0.1311)	(0.0603)	(0.2017)

Notes: The estimated treatment effects are reported as a percentage of the untreated outcome means. Robust standard errors under parenthesis. A *, **, *** indicates significance at 10, 5, 1 per cent level.

Table 11: Testing the balancing hypothesis for the nearest neighbor matching in the case of energy policies planned on a regional scale

	Mean Bias		Reduction in bias	Mean Bias		Reduction in bias	Mean Bias		Reduction in bias
	Unmatched	Matched	%	Unmatched	Matched	%	Unmatched	Matched	%
	CO_2			CH_4			N_2O		
S_R/S_0	62.5	0.8	98.7	62.5	0.9	98.5	62.5	0.9	98.6
$S_{E,R}/S_0$	160.5	0.3	99.8	160.5	0.3	99.8	160.5	0.3	99.8
$S_{E,R}/S_R$	128.1	0.4	99.7	128.1	0.3	99.7	128.1	0.5	99.6
	NMVOCs			NO_x			SO_2		
S_R/S_0	62.5	1.5	97.6	62.5	1.0	98.3	62.5	0.4	99.4
$S_{E,R}/S_0$	160.5	0.3	99.8	160.5	0.3	99.8	160.5	0.3	99.8
$S_{E,R}/S_R$	128.2	0.3	99.8	128.1	0.4	99.7	128.1	0.7	99.5

Notes: The nearest neighbor algorithm has been employed in all the tests.

Table 12: Testing the balancing hypothesis for the nearest neighbor matching in the case of energy policies planned on a regional and local scale jointly

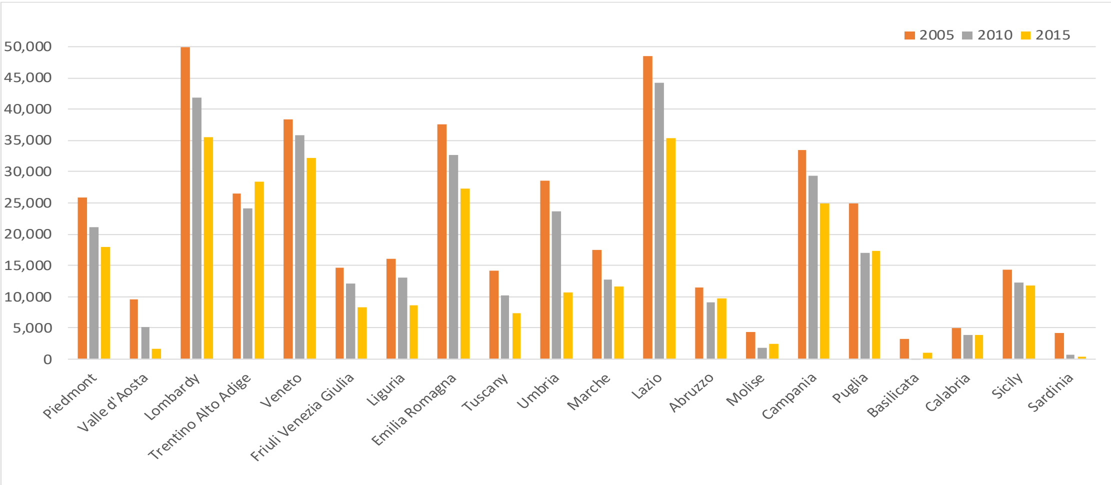
	Mean Bias Unmatched	Mean Bias Matched	Reduction in bias %	Mean Bias Unmatched	Mean Bias Matched	Reduction in bias %	Mean Bias Unmatched	Mean Bias Matched	Reduction in bias %
		CO_2			CH_4			N_2O	
S_R/S_0	59.8	0.4	99.4	59.8	0.6	99.0	59.8	0.7	98.8
$S_{E,R}/S_0$	114.6	1.2	98.9	114.6	1.3	98.8	114.6	1.0	99.1
$S_{E,R}/S_R$	39.9	0.5	98.8	39.9	1.5	96.4	39.9	1.4	96.4
		NMVOCs			NO_x			SO_2	
S_R/S_0	59.8	1.4	97.6	59.8	0.8	98.6	59.8	0.2	99.7
$S_{E,R}/S_0$	114.7	1.5	98.7	114.6	1.2	98.9	114.6	0.6	99.5
$S_{E,R}/S_R$	40.0	1.3	96.7	39.9	1.5	96.4	39.9	0.1	99.7

Notes: The nearest neighbor algorithm has been employed in all the tests.

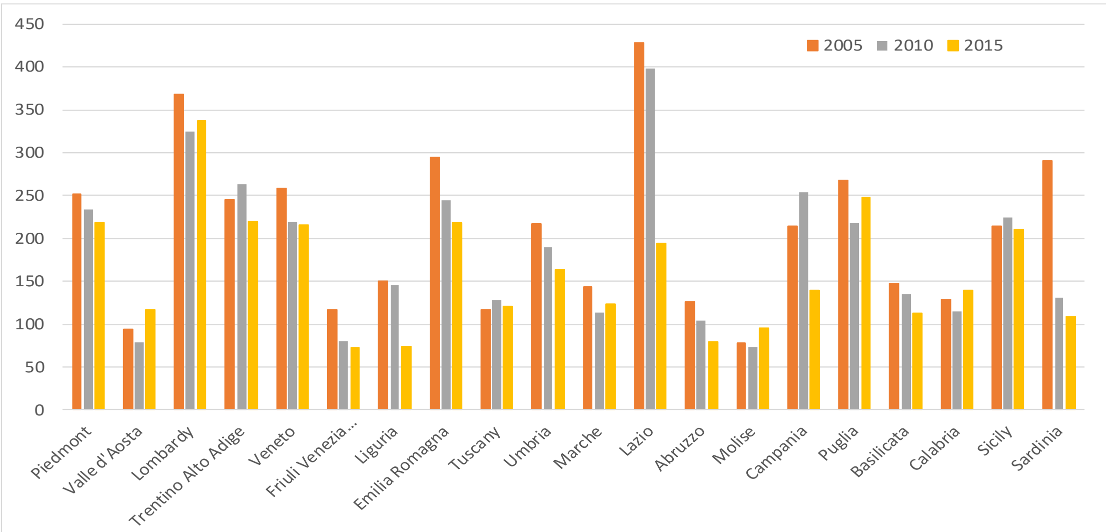
FIGURES

Figure 1: Global atmospheric pollutants in the 20 Italian regions in the years 2005, 2010 and 2015

CO_2 emissions in the Italian regions in the years 2005, 2010 and 2015



CH_4 emissions in the Italian regions in the years 2005, 2010 and 2015



N_2O emissions in the Italian regions in the years 2005, 2010 and 2015

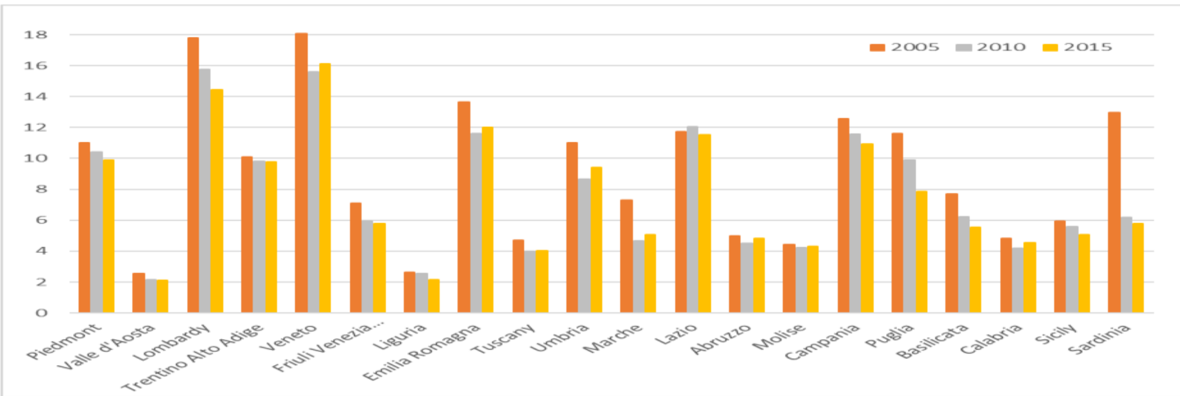
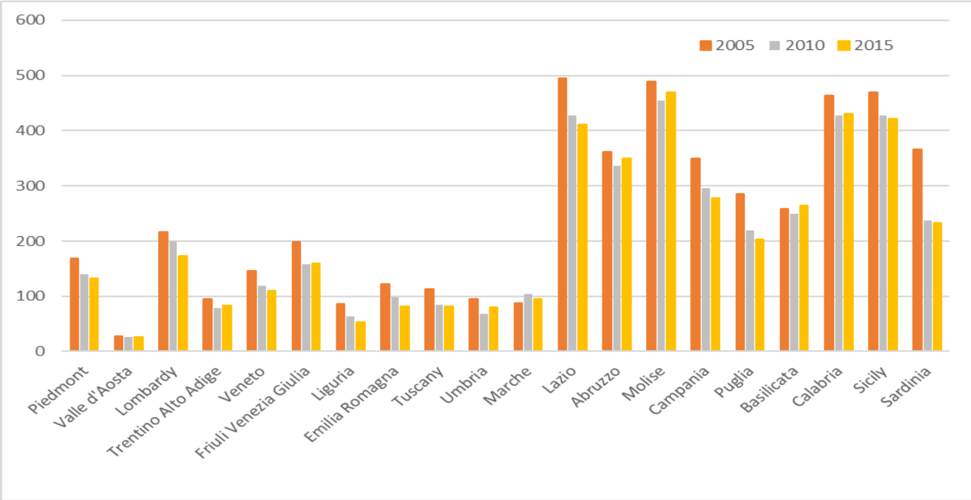
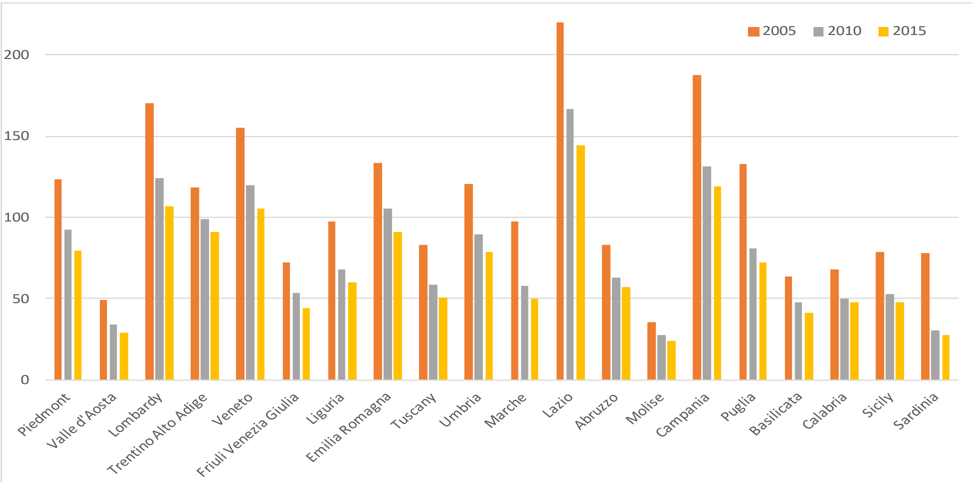


Figure 2: Local atmospheric pollutants in the 20 Italian regions in the years 2005, 2010 and 2015

NNMOCs emissions in the Italian regions in the years 2005, 2010 and 2015



NO_X emissions in the Italian regions in the years 2005, 2010 and 2015



SO_2 emissions in the Italian regions in the years 2005, 2010 and 2015

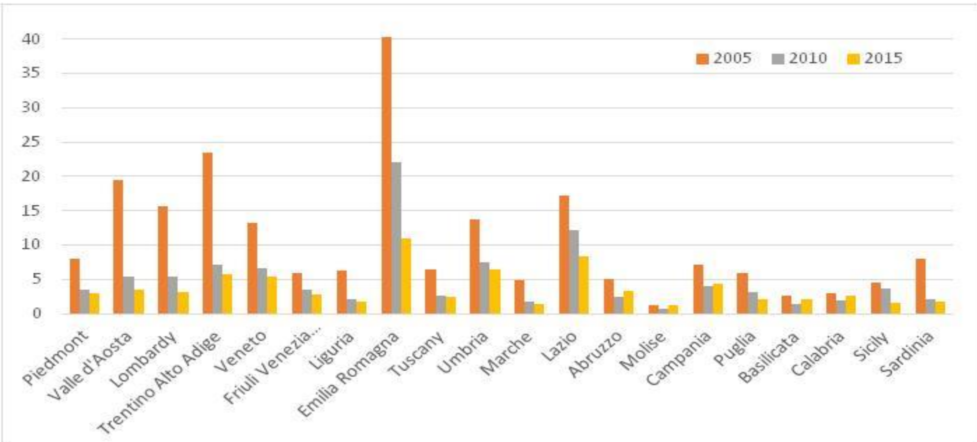
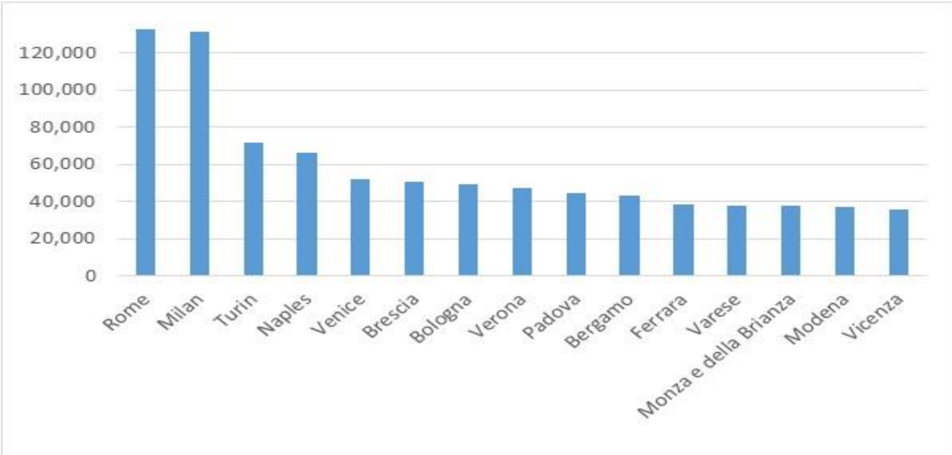
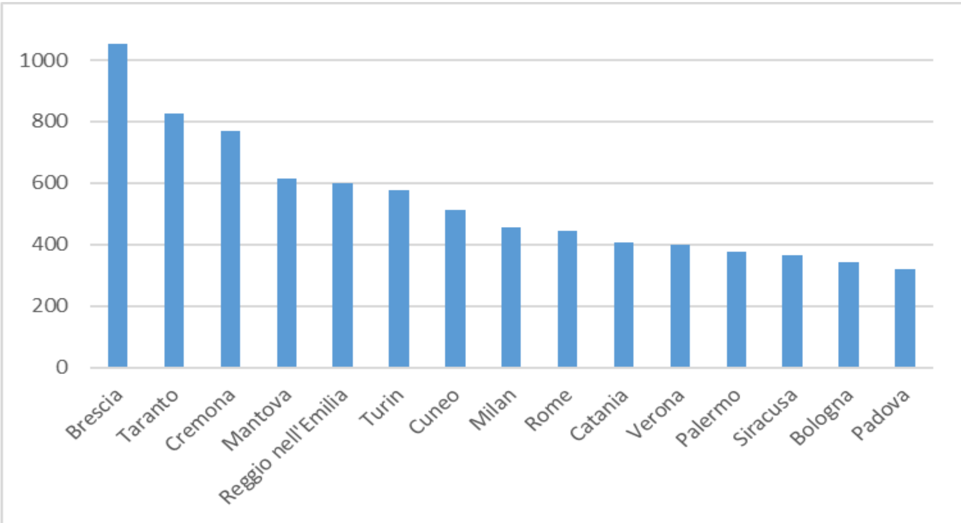


Figure 3: Global atmospheric pollutants in the first 15 Italian provinces in 2015

CO_2 emissions in the Italian provinces in 2015



CH_4 emissions in the Italian provinces in 2015



N_2O emissions in the Italian provinces in 2015

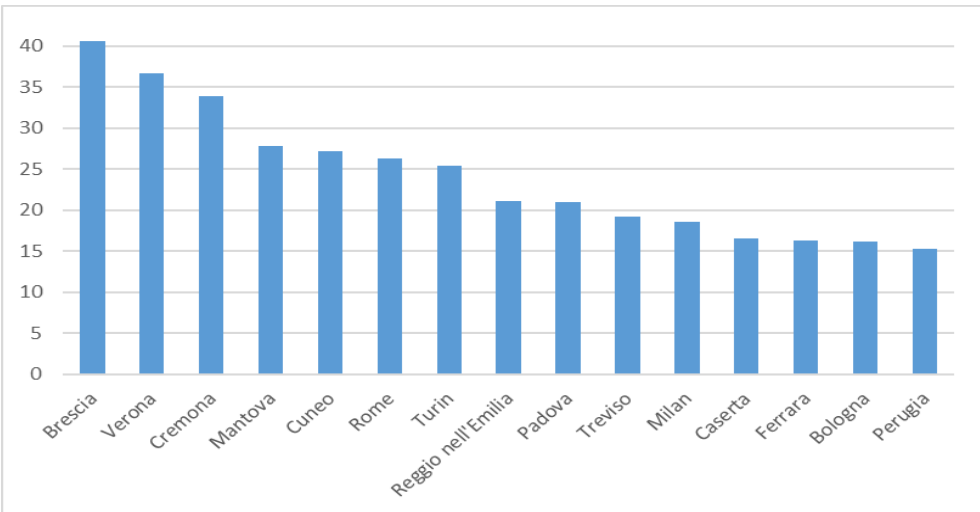
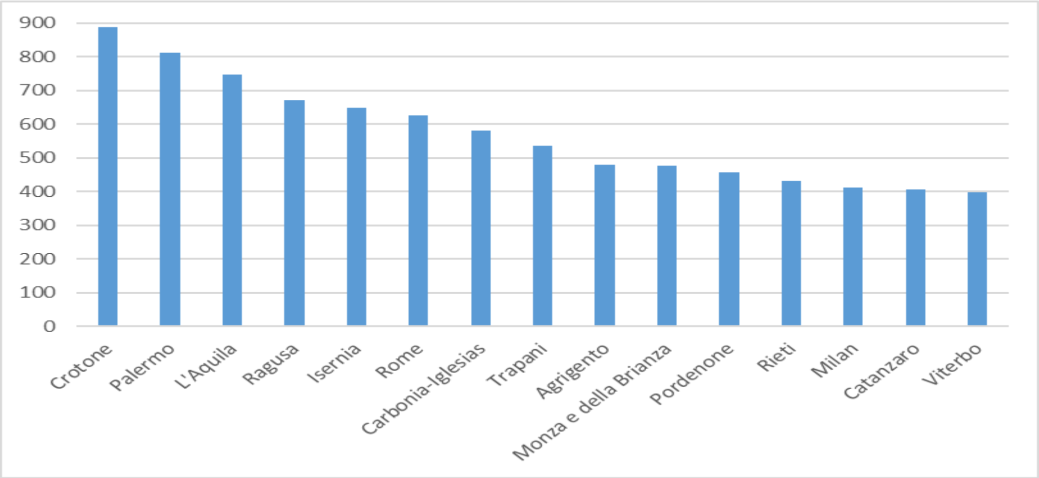
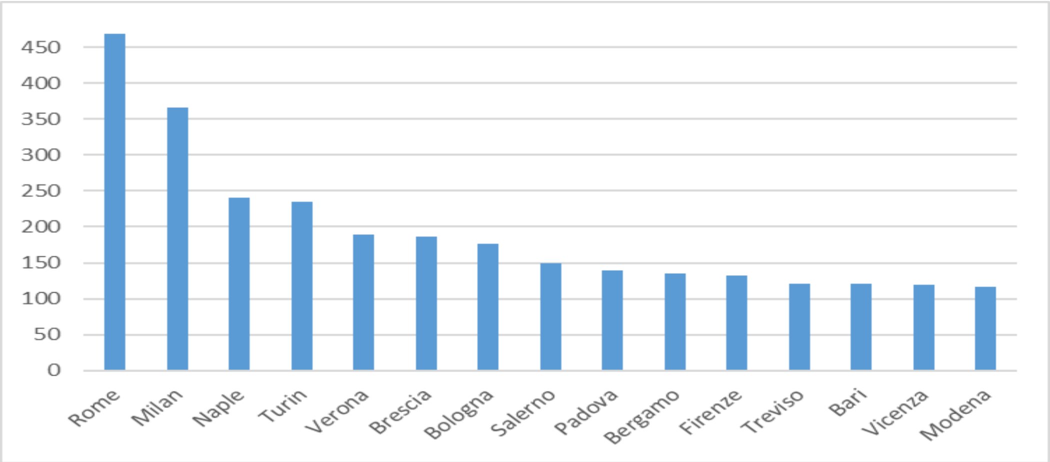


Figure 4: Local atmospheric pollutants in the first 15 Italian provinces in 2015

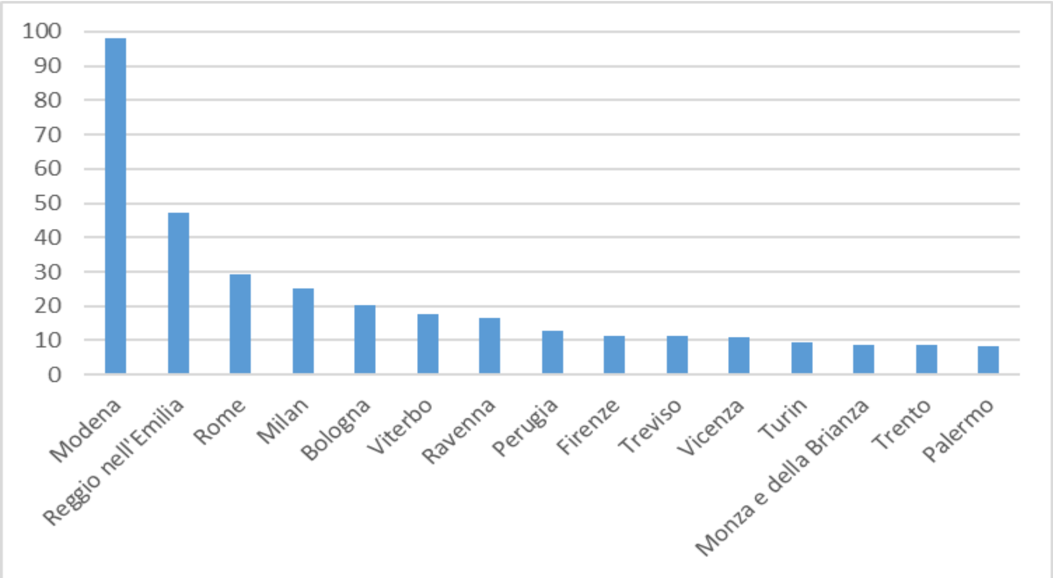
NMVOCs emissions in the Italian provinces in 2015



NO_X emissions in the Italian provinces in 2015



SO_2 emissions in the Italian provinces in 2015



Appendix A

Table A1 Pollutant description

Code	Acronym	Pollutant	GWP	Unit of measurement
001	SO_2	Sulphur dioxide	1	Mg
002	NO_x	Nitrogen oxides	1	Mg
003	NMVOCs	Non-methane Volatile Organic Compounds	1	Mg
004	CH_4	Methane	25	Mg
006	CO_2	Carbon dioxide	1	Mg
007	N_2O	Nitrous oxides	298	Mg

Table A2 List of the selected SNAP items for each pollutant

Macro Sector	Sector	SNAP item	Description	CO_2	CH_4	N_2O	NMVOCs	NO_x	SO_2
010000	**0100**	**010000**	**Combustion in industry and energy plants**	No	No	No	No	No	No
020000	**0200**	**020000**	**Non-industrial combustion plants**						
020000	***0201***	***020100***	***Commercial and institutional installations***						
020000	0201	02010001	Boilers with thermal power <50 MW (biomass)	No	Yes	Yes	Yes	Yes	Yes
020000	0201	02010003	Boilers with thermal power <50 MW (diesel)	Yes	Yes	Yes	Yes	Yes	Yes
020000	0201	02010004	Boilers with thermal power <50 MW (natural gas)	Yes	Yes	Yes	Yes	Yes	No
020000	0201	02010005	Boilers with thermal power <50 MW (LPG)	Yes	Yes	Yes	Yes	Yes	No
020000	0201	02010006	Boilers with thermal power <50 MW (others)	No	Yes	Yes	Yes	Yes	No
020000	***0202***	***020200***	***Residential installations***						
020000	0202	02020001	Boilers with thermal power <50 MW (biomass)	No	Yes	Yes	Yes	Yes	Yes
020000	0202	02020003	Boilers with thermal power <50 MW (diesel)	Yes	Yes	Yes	Yes	Yes	Yes
020000	0202	02020004	Boilers with thermal power <50 MW (natural gas)	Yes	Yes	Yes	Yes	Yes	No
020000	0202	02020005	Boilers with thermal power <50 MW (LPG)	Yes	Yes	Yes	Yes	Yes	No
020000	0202	02020006	Boilers with thermal power <50 MW (others)	No	Yes	Yes	Yes	Yes	No
020000	***0203***	***020300***	***Installations in agriculture, forestry and aquaculture***						
020000	0203	02030001	Boilers with thermal power <50 MW (biomass)	No	Yes	Yes	Yes	Yes	Yes
020000	0203	02030003	Boilers with thermal power <50 MW (diesel)	No	No	No	No	No	No
020000	0203	02030004	Boilers with thermal power <50 MW (natural gas)	No	No	No	No	No	No
020000	0203	02030005	Boilers with thermal power <50 MW (LPG)	Yes	Yes	Yes	Yes	Yes	No
020000	0203	02030006	Boilers with thermal power <50 MW (others)	No	Yes	Yes	Yes	Yes	No
030000	**0300**	**030000**	**Production processes (combustion in the manufacturing industry)**						
030000	0301	030100	Combustion in boilers, turbines and fixed internal combustion engines	Yes	Yes	Yes	Yes	Yes	Yes
030000	0302	030200	Non-contact process furnaces	No	No	No	No	No	No
030000	0303	030300	Combustion processes with contact						
030000	0303	030314	Flat glass	Yes	Yes	Yes	Yes	Yes	Yes
030000	0303	030317	Other glass	Yes	Yes	Yes	Yes	Yes	No

030000	0303	030319	Bricks and tiles	Yes	Yes	Yes	Yes	Yes	Yes
030000	0303	030320	Fine ceramic materials	Yes	Yes	Yes	Yes	Yes	Yes
040000	**0400**	**040000**	**Production processes (contactless combustion)**						
040000	***0401***	***040100***	***Processes in the oil industry***	No	No	No	No	No	No
040000	***0402***	***040200***	***Coal***	No	No	No	No	No	No
040000	***0403***	***040300***	***Processes in non-ferrous metal industries***	No	No	No	No	No	No
040000	***0404***	***040400***	***Processes in the inorganic chemical industries***	No	No	No	No	No	No
040000	***0405***	***040500***	***Gas distribution***	No	No	No	No	No	No
040000	***0406***	***040600***	***Processes in the wood industry, paper pulp, food, beverages and other industries***						
040000	0406	040618	Use of lime and dolomite	Yes	No	No	No	No	No
040000	0406	040620	Production and use of soda powder	Yes	No	No	Yes	No	No
050000	**0500**	**050000**	**Extraction and distribution of fossil fuels and geothermal energy**						
050000	***0501***	***050100***	***Extraction - first treatment of solid fossil fuels***	No	No	No	No	No	No
050000	***0502***	***050200***	***Extraction, first treatment and loading of liquid fossil fuels***	No	No	No	No	No	No
050000	***0503***	***050300***	***Extraction, first treatment and loading of gaseous fossil fuels***	No	No	No	No	No	No
050000	***0504***	***050400***	***Distribution of liquid fuels (except gasoline)***	No	No	No	No	No	No
050000	***0505***	***050500***	***Gas distribution***	No	No	No	No	No	No
050000	***0505***	***050502***	***Transportation and storage (except 050503)***	No	No	No	Yes	No	No
050000	***0505***	***050503***	***Service stations (including vehicle refueling)***	No	No	No	Yes	No	No
050000	***0506***	***050600***	***Gas distribution networks***						
050000	0506	050603	Distribution networks	Yes	Yes	No	Yes	No	No
050000	***0507***	***050700***	***Geothermal energy extraction***	No	No	No	No	No	No
060000	**0600**	**060000**	**Use of solvents and other products**						
060000	***0601***	***060100***	***Painting***						
060000	0601	060102	Car repairs	Yes	No	No	Yes	No	No
060000	0601	060103	Painting: building (except 060107)	Yes	No	No	Yes	No	No
060000	0601	060104	Painting: domestic use (except 060107)	Yes	No	No	Yes	No	No
060000	0601	060105	Painting: coatings	Yes	No	No	Yes	No	No

060000	0601	060106	Painting: boats	Yes	No	No	Yes	No	No
060000	0601	060107	Painting: wood	Yes	No	No	Yes	No	No
060000	0601	060108	Other industrial applications	Yes	No	No	Yes	No	No
060000	***0602***	***060200***	***Degreasing, dry and electronic cleaning***						
060000	0602	060201	Metal degreasing	Yes	No	No	Yes	No	No
060000	0602	060202	Dry cleaning	Yes	No	No	Yes	No	No
060000	***0603***	***060300***	***Synthesis or processing of chemical products***						
060000	0603	060303	Processing of polyurethane foam	Yes	No	No	Yes	No	No
060000	0603	060304	Processing of polystyrene foam (except 060504)	Yes	No	No	Yes	No	No
060000	0603	060305	Rubber processing	Yes	No	No	Yes	No	No
060000	0603	060306	Manufacture of pharmaceutical products	Yes	No	No	Yes	No	No
060000	0603	060307	Paint manufacturing	Yes	No	No	Yes	No	No
060000	0603	060308	Inks manufacture	Yes	No	No	Yes	No	No
060000	***0604***	***060400***	***Other use of solvents and related activities***						
060000	0604	060403	Printing industry	Yes	No	No	Yes	No	No
060000	0604	060404	Extraction of fats and edible and non-edible oils	Yes	No	No	Yes	No	No
060000	0604	060405	Application of glues and adhesives	Yes	No	No	Yes	No	No
060000	0604	060408	Domestic use of solvents (except painting)	No	No	No	No	No	No
060000	0604	060409	Deparaffinization of vehicles	No	No	No	No	No	No
060000	***0605***	***060500***	***Use of HFCs, N2O, NH3, PFC, SF6***						
060000	0605	060501	Anesthesia	No	No	Yes	No	No	No
060000	0605	060505	Fire extinguishers	No	No	Yes	No	No	No
060000	0606	060601	Explosives	No	No	Yes	No	No	No
070000	**0700**	**070000**	**Road transport**						
070000	***0701***	***070100***	***Cars***						
070000	0701	07010004	Cars (LPG)						
070000	0701	070101	Cars - Highways	Yes	Yes	Yes	Yes	Yes	Yes
070000	0701	07010101	Cars - Highways (Petrol)	Yes	Yes	Yes	Yes	Yes	Yes
070000	0701	07010102	Cars - Highways (Diesel)	Yes	Yes	Yes	Yes	Yes	Yes

070000	0701	07010103	Cars - Highways (LPG)	Yes	Yes	Yes	Yes	Yes	Yes
070000	0701	07010104	Cars - Highways (NG)	Yes	Yes	Yes	Yes	Yes	No
070000	0701	07010105	Cars - Highways (Eth)	Yes	No	No	Yes	Yes	No
070000	***0701***	***070102***	***Cars - Extra-urban roads***						
070000	0701	07010201	Cars - Extra-urban roads (Petrol)	Yes	Yes	Yes	Yes	Yes	Yes
070000	0701	07010202	Cars - Extra-urban roads (Diesel)	Yes	Yes	Yes	Yes	Yes	Yes
070000	0701	07010203	Cars - Extra-urban roads (LPG)	Yes	Yes	Yes	Yes	Yes	No
070000	0701	07010204	Cars - Extra-urban roads (NG)	Yes	Yes	Yes	Yes	Yes	No
070000	0701	07010205	Cars - Extra-urban roads (Eth)	No	No	No	No	No	No
070000	***0701***	***070103***	***Cars - Urban roads***						
070000	0701	07010301	Cars - Urban roads (Petrol)	Yes	Yes	Yes	Yes	Yes	Yes
070000	0701	07010302	Cars - Urban roads (Diesel)	Yes	Yes	Yes	Yes	Yes	Yes
070000	0701	07010303	Cars - Urban roads (LPG)	Yes	Yes	Yes	Yes	Yes	No
070000	0701	07010304	Cars - Urban roads (NG)	Yes	Yes	Yes	Yes	Yes	No
070000	0701	07010305	Cars - Urban roads (Eth)	No	No	No	No	No	No
070000	***0702***	***070200***	***Veicoli leggeri <3,5t***						
070000	***0702***	***070201***	***Light vehicles <3.5t - Motorways***						
070000	0702	07020101	Light vehicles <3.5t - Motorways (Petrol)	Yes	Yes	Yes	Yes	Yes	Yes
070000	0702	07020102	Light vehicles <3.5t - Motorways (Diesel)	Yes	Yes	Yes	Yes	Yes	Yes
070000	***0702***	***070202***	***Light vehicles <3.5t - Extra-urban roads***						
070000	0702	07020201	Light vehicles <3.5t -Extra-urban roads (Petrol)	Yes	Yes	Yes	Yes	Yes	Yes
070000	0702	07020202	Light vehicles <3.5t -Extra-urban roads (Diesel)	Yes	Yes	Yes	Yes	Yes	Yes
070000	***0702***	***070203***	***Light vehicles <3.5t - Urban roads***						
070000	0702	07020301	Light vehicles <3.5t - Urban roads (Petrol)	Yes	Yes	Yes	Yes	Yes	Yes
070000	0702	07020302	Light vehicles <3.5t - Urban roads (Diesel)	Yes	Yes	Yes	Yes	Yes	Yes
070000	***0703***	***070300***	***Heavy vehicles> 3.5t and buses***						
070000	***0703***	***070301***	***Heavy vehicles> 3.5t and buses - Motorways***						
070000	0703	07030101	Heavy vehicles> 3.5t and buses - Motorways (Petrol)	Yes	Yes	Yes	Yes	Yes	Yes
070000	0703	07030102	Heavy vehicles> 3.5t and buses - Motorways (Diesel)	Yes	Yes	Yes	Yes	Yes	Yes

070000	***0703***	***070302***	***Heavy vehicles> 3.5t and buses - Extra-urban roads***						
070000	0703	07030201	Heavy vehicles> 3.5t and buses - Extra-urban roads (Petrol)	Yes	Yes	Yes	Yes	Yes	Yes
070000	0703	07030202	Heavy vehicles> 3.5t and buses - Extra-urban roads (Diesel)	Yes	Yes	Yes	Yes	Yes	Yes
070000	***0703***	***070303***	***Heavy vehicles> 3.5t and buses - Urban roads***						
070000	0703	07030301	Heavy vehicles> 3.5t and buses - Urban roads (Petrol)	Yes	Yes	Yes	Yes	Yes	Yes
070000	0703	07030302	Heavy vehicles> 3.5t and buses - Urban roads (Diesel)	Yes	Yes	Yes	Yes	Yes	Yes
070000	***0704***	***070400***	***Mopeds and motorcycles <50 cm3***						
070000	0704	07040201	Mopeds and motorcycles <50 cm3 - Extra-urban roads (Petrol)	Yes	Yes	Yes	Yes	Yes	Yes
070000	0704	07040301	Mopeds and motorcycles <50 cm3 - Urban roads (Petrol)	Yes	Yes	Yes	Yes	Yes	Yes
070000	0705	07050101	Motorcycles> 50 cm3 - Motorways (Petrol)	Yes	Yes	Yes	Yes	Yes	Yes
070000	0705	07050201	Motorcycles> 50 cm3 - Extra-urban (Petrol)	Yes	Yes	Yes	Yes	Yes	Yes
070000	0705	07050301	Motorcycles> 50 cm3 - Urban (Petrol)	Yes	Yes	Yes	Yes	Yes	Yes
070000	***0706***	***070600***	***Gasoline engines - evaporative emissions***	No	No	No	No	No	No
070000	***0707***	***070700***	***Tire wear, asphalt and brake use***	No	No	No	No	No	No
080000	**0800**	**080000**	**Other mobile sources and mobile machinery (off-road transport)**						
080000	***0801***	***080100***	***Military - offroad transport***	Yes	Yes	Yes	Yes	Yes	Yes
080000	***0802***	***080200***	***Railway - diesel***	Yes	Yes	Yes	Yes	Yes	Yes
080000	0802	080202	Railcars	No	No	No	No	Yes	No
080000	0806	080600	Agriculture (off-road transport)	Yes	Yes	Yes	Yes	Yes	Yes
080000	0807	080700	Forestry (off-road transport)	Yes	Yes	Yes	Yes	Yes	Yes
080000	0808	080800	Industry (off-road transport)	Yes	Yes	Yes	Yes	Yes	Yes
080000	0809	080900	Gardening and other household activities (off-road)	Yes	Yes	Yes	Yes	Yes	Yes
090000	**0900**	**090000**	**Waste treatment and landfills**						
090000	***0902***	***090200***	***Waste incineration***	No	No	No	No	No	No
090000	***0904***	***090400***	***Landfill of solid waste***						
090000	0904	090401	Controlled landfill	No	Yes	No	Yes	No	No
090000	0904	090402	Uncontrolled landfill	No	Yes	No	Yes	No	No
090000	0904	090403	Other	No	Yes	Yes	Yes	Yes	No
090000	***0907***	***090700***	***Incineration of agricultural waste (except 10.03.00)***	Yes	Yes	Yes	Yes	Yes	Yes

090000	***0910***	***091000***	***Other waste treatments***						
090000	0910	091001	Industrial waste water treatment	No	Yes	Yes	No	No	No
090000	0910	091002	Waste water treatment in the residential and commercial sector	No	Yes	Yes	No	No	No
090000	0910	091005	Composting	No	No	No	Yes	No	No
100000	**1000**	**100000**	**Agriculture**						
100000	***1001***	***100100***	***Cultivations with fertilizers (except animal fertilizers)***	Yes	No	Yes	No	Yes	No
100000	***1002***	***100200***	***Cultivations without fertilizers***	No	No	Yes	No	Yes	No
100000	***1003***	***100300***	***Stubble combustion***	No	No	Yes	No	Yes	No
100000	***1004***	***100400***	***Animal breeding (enteric fermentation)***						
100000	1004	100401	Dairy cows	No	Yes	No	No	No	No
100000	1004	100402	Other cattles	No	Yes	No	No	No	No
100000	1004	100403	Sheeps	No	Yes	No	No	No	No
100000	1004	100404	Other pigs	No	Yes	No	No	No	No
100000	1004	100405	Horses	No	Yes	No	No	No	No
100000	1004	100406	Donkeys and mules	No	Yes	No	No	No	No
100000	1004	100407	Goats	No	Yes	No	No	No	No
100000	***1004***	***100411***	***Fur animals***						
100000	1004	100412	Sows	No	Yes	No	No	No	No
100000	1004	100414	Buffaloes	No	No	No	No	No	No
100000	1004	100415	Others	No	Yes	No	No	No	No
100000	***1005***	***100500***	***Animal breeding (organic compounds)***						
100000	1005	100501	Dairy cows	No	Yes	No	Yes	Yes	No
100000	1005	100502	Other cattles	No	Yes	No	Yes	Yes	No
100000	1005	100503	Other pigs	No	Yes	No	Yes	Yes	No
100000	1005	100504	Sows	No	Yes	No	Yes	Yes	No
100000	1005	100505	Sheeps	No	Yes	No	Yes	Yes	No
100000	1005	100506	Horses	No	Yes	No	Yes	Yes	No
100000	1005	100507	Laying hens	No	Yes	No	Yes	Yes	No
100000	1005	100508	Chickens	No	Yes	No	Yes	Yes	No

100000	1005	100509	Other poultry (turkeys, ducks, geese, etc.)	No	Yes	No	Yes	Yes	No
100000	***1005***	***100510***	***Fur animals***	No	Yes	No	No	Yes	No
100000	1005	100511	Goats	No	Yes	No	No	Yes	No
100000	1005	100512	Donkeys and mules	No	Yes	No	No	Yes	No
100000	1005	100515	Others	No	Yes	No	No	Yes	No
100000	1009	100900	Animal breeding (nitrogen compounds)	No	No	Yes	No	No	No
110000	1100	110000	Other emissions and absorption						
110000	***1101***	***110100***	***Unmanaged deciduous forests***	No	No	No	No	No	No
110000	***1102***	***110200***	***Unmanaged coniferous forests***	No	No	No	No	No	No
110000	***1103***	***110300***	***Forest fires***	No	Yes	Yes	Yes	Yes	Yes
110000	***1104***	***110400***	***Grasslands and other types of low vegetation***	No	No	No	No	No	No
110000	***1105***	***110500***	***Wetlands (marshes, marshes)***	No	No	No	No	No	No
110000	***1106***	***110600***	***Water***	No	No	No	No	No	No
110000	***1107***	***110700***	***Animals***	No	No	No	No	No	No
110000	***1108***	***110800***	***Volcanoes***	No	No	No	No	No	No
110000	***1109***	***110900***	***Gas seeps***	No	No	No	No	No	No
110000	***1110***	***111000***	***Lighting bolt***	No	No	No	No	No	No
110000	***1112***	***111200***	***Managed deciduous forests***	No	No	No	Yes	No	No
110000	***1131***	***113100***	***Forests***						
110000	1131	113101	Living biomass (FL-FL)	Yes	No	No	No	No	No
110000	1131	113102	Dead organic matter (FL-FL)	Yes	No	No	No	No	No
110000	1131	113103	Soils (FL-FL)	Yes	No	No	No	No	No
110000	*1132*	*113200*	*Crops*						
110000	1132	113201	CL remaining CL	Yes	No	No	No	No	No
110000	***1133***	***113300***	***Grasslands***						
110000	1133	113301	GL remaining GL	Yes	No	No	No	No	No
110000	1133	113302	Land converting to GL	Yes	No	No	No	No	No
110000	***1135***	***113500***	***Urban settlements***						
110000	1135	113502	Land converting to SL	Yes	No	No	No	No	No

110000	1137	113700	Harvested wood products	Yes	No	No	No	No	No

Notes: “Yes” or “No” indicate data availability.