Do sustainable energy policies matter for reducing air pollution?

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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 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 treatments, 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 effective in terms of climate goals especially when implemented 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 energy policies was reinforced by the counter-cyclical fiscal policies implemented to counter the Global Financial Crisis in 2008.

Research Data Related to this Submission

There are no linked research data sets for this submission. The following reason is given:
Data will be made available on request

Cover Letter of the paper "Do sustainable energy policies matter for reducing air pollution?"

(JEPO-D-19-02542)

February 7, 2020

Dear Professor Marilyn A. Brown,

Herewith enclosed the revised version of the manuscript entitled "Do sustainable energy policies matter for reducing air pollution?", written by myself.

Kind Regards,

Donatella Baiardi

Highlights

- The impact of sustainable energy policies on air pollutants is studied in Italy;
- Two different interventions are analysed: energy efficiency and renewable policies;
- Propensity score matching with multiple treatments is employed in the analysis;
- Renewable policies are the most effective in terms of climate goals;
- Energy efficiency policies applied alone are instead ineffective.

Do sustainable energy policies matter for reducing air pollution?

February 7, 2020

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 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 treatments, 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 effective in terms of climate goals especially when implemented 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 energy policies was reinforced by the counter-cyclical fiscal policies implemented to counter the Global Financial Crisis in 2008.

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

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

1 Introduction

Nowadays, sustainable energy is at the heart of economic growth and the climate change agenda. Attention to environmental conditions and the exigency 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 ones 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 diffusion of energy efficiency and renewable energy measures. 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 and efficiency energy 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]

[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. For additional information, see $https://europeanclimate.org/roadmap-2050-project-$

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 an energy importer, 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 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

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launched/.

[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 also favored by the 2008 economic recession.

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; Arbolino et al., 2019).

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

[5] Provinces of Italy (NUTS3) are administrative divisions of a regions (NUTS2). Currently, there are 110 provinces within the 20 regions in Italy.

dioxide (SO_2). Policy variables are obtained from another database provided by ISPRA named '*Air quality improvement measures*'. We focus our attention only on energy efficiency and renewable resource measures implemented 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.

Several considerations can be drawn from our main results. In fact, we find that (*i*) renewable policies are the most effective in terms of climate goals and their impact on air emissions is stronger when these interventions are implemented on a local scale; (*ii*) energy efficiency policies alone are ineffective, since they contribute to reducing air pollution only when they are implemented together with renewable policies; (*iii*) the effec-

[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.

tiveness of these policies depends on the type of pollutant to be reduced; (*iv*) the positive effects of sustainable energy policies on air pollution have been probably 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.

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 air pollution. Section 4 introduces the data used in the subsequent analysis. Section 5 shows the main empirical results when energy policies are implemented 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 their marginal damage does not depend on the location of emission and reception (Lehmann, 2012). 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.[7] In these cases, the marginal damage produced by one unit of pollution varies between locations, depending on ecological, technical and socioeconomic conditions at the point of the location and reception of emission (Lehmann, 2012).

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 greater use of renewable sources (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

[7] Table A1 provides pollutant description in Appendix A.

are in turn responsible to the formation of photo-oxidants and photochemical smog. SO_2 emissions come from volcanic eruption, the combustion of sulfur-containing fuels, and the extraction of gasoline from oil. Together with nitrogen oxides, SO_2 emissions provoke the acidification of soil and water.

Figure 1 about here

In general, the most polluted regions are those located along the Po Valley, in the North of Italy. Consider, for example, the case of CO_2. As shown in Figure 1, this gas exhibits the highest concentrations in Lombardy and Veneto (35,504 and 32,160), more than double the national average (14,826) in 2015. In the North of Italy, high emissions are also recorded in Piedmont, Emilia Romagna and Trentino Alto Adige, and in the South of Italy, Lazio and Campania are in general the most polluted regions. Similar figures are observed for all the other gases,[8] with the sole exception of NMVOCs emissions.

Figure 2 about here

NMVOCs is an interesting case, since, as shown in Figure 2, this is the only gas in the sample exhibiting a higher concentration in Southern than Northern regions. SO_2 emissions are, however, very high in Emilia Romagna, especially in 2005 and 2010, while very low levels are recorded in 2015 in all the regions.

All the pollutants show a decreasing trend in the decade 2005-2015.[9] More specifically,

[8] For more details, see Figures A1-A4 in Appendix A.

[9] On this point, see Figures A5 and A6 in Appendix A.

SO_2, NO_x and CO_2 present a yearly average decrease equal to 7.79, 4.60 and 4.07 per cent, respectively, in the years 2005-2015, while the remaining gases record an average decrease of about 2 per cent in the same time period.[10]

Lastly, it worth noting that Rome and Milan are the most polluted provinces independently of the pollutants considered. Brescia, Padova, Turin, Verona and Bologna are other provinces exhibiting very high levels of pollution when global gases are considered, and the same holds for Florence, Modena, Palermo and Viterbo in the case of local gases.[11]

2.2 Sustainable energy policies in Italy

The legislative framework for energy policies has considerably changed during recent decades. It is constituted by four integrated levels. At the top there are the European Union directives, then transposed at the 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 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

[10]In these latter cases, the reduction is equal to -1.99, -1.85 and -1.75 for N_2O, NMVOCs and CH_4, respectively.

[11]See Figures A7 and A8 in Appendix A.

legislate in compliance with state guidelines. (For a detail description of energy governance in Italy, see Sarrica et al., 2018).[12] The rapid devolution of legislative and regulatory powers to the Regions has been favored after the 2001 reform of the Italian Constitution, which reorganized regulatory competencies 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.[13] 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

[12]National energy targets 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.

[13]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/*.

role of local institutions for the development of initiatives aimed of decreasing greenhouse gas emissions and the production of cleaner energy.[14] 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 (Comodi 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 energy sector in Italy.

With regard to energy efficiency policies, we consider those interventions, implemented 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).

[14]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.

Similarly, with regard to renewable resource policies, we consider those interventions, implemented 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 renewable energy (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).[15]

In Italy, sustainable energy policies were implemented by many regions in the years 2005-2010. Figure 3 reports the cases of energy efficiency and renewable energy policies adopted either at regional or local level.

Figure 3 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. For more details see Table A2 in Appendix A.

In the following empirical analysis, these two policies are analyzed alternatively and

[15]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.

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). Furthermore, we consider sustainable energy policies implemented in three different circumstances: at local level, at regional level, and both at local and regional level (see Tables A3, A4 and A5 in Appendix A). It is worth noting that energy efficiency policies are implemented by the same regions that also adopt renewable energy policies. This is the case of Lombardy, Marche, Valle d'Aosta and Veneto when considering policies adopted on a regional scale, and of Emilia Romagna and Liguria in the case of policies at local and regional level.

3 Propensity score matching with multiple treatments: methodology

In the literature, causal inference has been employed for public policy evaluation. This approach is based on the comparison between 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).

The first step is 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), a generalized propensity score matching approach with multiple treatments is used in our empirical analysis. Indeed, this framework makes it possible to isolate the effects of different public interventions on the variable of interest and, contemporaneously, to control other features that can affect it.[16]

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 implemented 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).

[16]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.

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 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:

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

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 the independence of Y_i with respect to the treatment T_i is assumed, conditional on a set of explanatory variables (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:

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

Equation (2) indicates that the outcome of provinces receiving treatment m can be proxied by the outcome of provinces that actually undergo treatment l, in the light of their analogous macroeconomic features. In particular, the matching procedure identifies couples of provinces with similar macroeconomic features, with the only difference being their application (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:

$$p^m(X) = P(S = m|X) \quad (3)$$

More specifically, in our framework, Equation (3) introduces the probability of a province adopting certain energy policies conditioned on the set of explanatory variables. 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.[17] Therefore, by jointly considering Equations (2) and (3), we obtain Equation (4), which is the heart of our estimation strategy:

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

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.

[17]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.

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*,[18] a database retrieved by the Italian Institute for Environmental Protection and Research (ISPRA).[19] They are disaggregated 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.[20] A complete list of the selected items belonging

[18]They can be downloaded from the following link: *http : //www.sinanet.isprambiente.it/it/sia − ispra/inventaria.*

[19]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.

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

to each macrosector emitting air pollution is provided in Appendix B (Table B1).

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.[21] 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).[22]

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).

[21]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.

[22]For more detail, see again Table B1 in Appendix B.

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.[23] 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 Figure 3, we compute the treatment indicator T_i, which identifies the status of each province for 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 is located in a region which does not implement any kind of policy (i.e. the 'No policy' situation in the map). It is equal to one if the province is located in a region which only adopts energy efficiency policies (i.e. 'Energy efficiency policy only'). It is equal to 2 if both energy efficiency and renewable energy policies are implemented (i.e. 'Both the two policies'), and, lastly, it is equal to three when only renewable energy policies are implemented (i.e. 'Renewable energy policy only').[24] The treatment indicator T_i is employed in Subsection 5.1 in the

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

[24]These cases correspond to *(i)* the 'no' decision of the implementation of the policy jointly reported in the top and bottom parts of Table A2 and in the case of all the provinces belonging to the remaining

multinominal probit model, from which the propensity scores are estimated. They are then used in the estimation of the average treatment effects.

Furthermore, we compute three distinct dummies in order to capture the effects of the sustainable energy measures implemented on a local scale. A dummy is obtained when the province located in each region adopts a energy efficiency policy for more than one year in the period under investigation.[25] A similar dummy is constructed for the case of renewable energy policies,[26] and, analogously, when these two types of policies are jointly implemented.[27] 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 applied 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 implemented on a regional scale and on local and regional scale jointly, two additional groups of dummy variables are again computed fol-

regions not reported in the same table; *(ii)* the 'yes' decision of the implementation of the policy reported in the top part of Table A2; *(iii)* the 'yes' decision of the implementation of the policy jointly reported in the two parts of Table A2; *(iv)* the 'yes' decision of the implementation of the policy reported in the bottom part of Table A2.

[25]This holds if the 'yes' decision of the implementation of the policy is reported in the top part of Table A3 in Appendix A.

[26]See the bottom portion of Table A3 in Appendix A.

[27]With reference to Table A3 in Appendix A, this occurs when the 'yes' decision of the implementation of the policy is jointly reported in the two parts of the table.

lowing the same criteria described above (see Tables A4 and A5 in Appendix A). In these latter cases, regions adopting energy efficiency policies are the same ones which adopt renewable policies. Consequently, the dummies refer only to strategies S_R and $S_{E,R}$. More specifically, in the case of energy efficiency policies implemented 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.

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.[28]

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

Table 1 about here

Table 1 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,[29] where, for each province i, the treatment indicator T_i is used as dependent variable (see the previous Subsection 4.2).

Table 2 about here

The multinominal probit estimation results of the propensity scores are presented in Table 2.[30] The specification of the multinominal probit model also includes SNAP dummies, in

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

[30]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 B.1 in Appendix B). 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.

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 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 in Table 2. 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.

It is worth noting that, before proceeding with the estimation of the average treatment effects, a preliminary analysis was performed in order to empirically assess the possible presence of any spatial spillovers in the adoption of the analyzed sustainable energy policies among provinces.[31] This was done by means of the Moran's I test, a popular measure of spatial autocorrelation. Results are available upon request to the author and show that policy decisions are not spatially correlated.

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 implemented 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 Equa-

[31]The presence of spatial spillovers violates the stable unit treatment value (SUTVA) assumption associated with the treatment effect analysis.

tion 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 2, and by using the set of dummy variables obtained, as described in the previous Subsection 4.2, from the information in Table A3 in Appendix A. 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 3.

Table 3 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.[32] Lastly, estimations associated with the mix of policies $S_{E,R}/S_R$ are always negative, as expected, independently of the type of emissions.

However, it is worth noting that the magnitude of the estimated coefficients in the case of S_R/S_0 is mainly higher than the ones obtained when the strategies $S_{E,R}/S_0$, $S_{E,R}/S_E$ and $S_{E,R}/S_R$ are applied. This result supports the well-known Jevons' paradox, according to that even if the promotion of different types of policies implies higher energy efficiency and saving (as in the last three cases described above), the quantity demanded and so the consumption of energy in turn rise (rebound effect), with unexpected negative repercussions in terms of pollution (Gosh and Blackhurst, 2014). This suggests that the joint adoption of energy efficiency and renewable policies is counterproductive (Alcott, 2005).

In general, in the case of *local* interventions, renewable policies implemented alone (S_R/S_0) are the best solution with respect to climate goals, since their effectiveness is independent 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).

[32]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.

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 4 about here

Table 4 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 implemented 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 implemented on a *regional scale* and when are *jointly* implemented on a *regional and local scale.*

As noted in Subsection 2.2, regional policies are indeed important determinants in terms 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 A4 in Appendix A, 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 A5 in Appendix A).[33] As before, the empirical analysis is carried out by using the propensity scores derived from the findings shown in Table 2.

Given that regions adopting energy efficiency policies are precisely the same regions which adopt renewable energy policies, the analysis in this subsection 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 5 and 6, computed as a percentage of the untreated outcome means, show that these three combinations of strategies have a different impact on air pollutants.

Tables 5 and 6 about here

With regard to Table 5, 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

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

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. Moreover, as in the results shown in Table 3, the Jevons' paradox is still persistent.

When moving to consider policies implemented both on a regional and local scale jointly (see Table 6), the performance of energy policies is 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. Furthermore, Jevons' paradox is less evident in Table 6, since it holds only in two specific cases (i.e. N_2O and SO_2 emissions).

Interesting evidence emerges when comparing findings shown in Tables 3, 5 and 6. In general, renewable energy policies are the most effective in terms of emission reduction. This holds independently of the kind of pollutant considered and the nature of the intervention (local, regional or both). Moreover, the distortions due to the Jevons' paradox generally disappear when the two energy policies are adopted on a local and regional scale jointly in the cases of CO_2, NMVOCs and NO_x.

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 7 and 8 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 7 and 8 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 effective 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, 2009/28/EC; 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).[34]

Among sustainable energy interventions, renewable policies implemented alone are the most effective in terms of climate goals. This holds independently of the nature of the intervention (local or regional) 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

[34] 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.

that the negative externality generated by these kinds of gases may be corrected 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 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.[35]

Energy efficiency policies are a priority of the 2012 Energy Efficiency Directive, 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.[36]

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 en-

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

[36]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).

ergy 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.[37] 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.[38] 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 con-

[37]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.

[38]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.

siderable 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 implemented 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 contraction of economic activity due to the Global Financial Crisis in 2008 implied 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 and policy implications

This paper assesses the impact of renewable energy and energy efficiency policies on six different air pollutants by using two novel datasets on air gases and sustainable energy policies adopted in Italy in the years 2005-2015. 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 are the lowest level of governance for which complete data are available.

The empirical analysis is performed using propensity score matching with multiple treatments, 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 have a considerable impact on air pollutants, but energy efficiency policies applied alone are ineffective, since they contribute to reducing air pollution only together with the renewable policies. Therefore, the policymaker should encourage the adoption of sustainable energy policies in general, and of renewable energy policies in particular, since emission levels in provinces adopting these interventions are more than halved compared to those observed in provinces not adopting any policies. This generally holds independently of the type of pollutants taken into consideration and the level of territorial disaggregation at which they are applied.

However, it is worth noticing that some limits on the effectiveness of the joint adoption of energy efficiency and renewable policies emerge from the empirical findings, with relevant policy implications. In fact, the Jevons' paradox is observed in the case of policies implemented at local and at regional level, thus implying that, when energy efficiency and renewable policies are jointly adopted, the reduction in terms of emissions is often lower compared to where only one type of policies is implemented. This is particularly important in terms of policy planning especially in those peripheral areas, like the regions in the South of Italy, which did not implement any energy policies in the considered time period. In fact, the joint adoption of the two types of energy policies analyzed is recommended only when interventions are applied at local and regional level jointly, and for reducing specific pollutants (such as CO_2, NMVOCs or NO_x). In all the other cases, renewable policies alone appear to be the best way to fight climate change.

The policymaker should also stress the importance of closer cooperation and coordination between regional and local authorities, especially in peripheral areas. This aspect is also crucial to the successful realization of the shift towards a low-carbon economy in all sectors, the preservation and protection of the environment, and the promotion of resource efficiency climate change adaptation (Cohesion Policy, 'A Sustainable Europe' target). Moreover, the policymaker should also strengthen the role of local authorities in this context, since, as recognized in the literature in various European countries including Italy, '*they are traditionally active in the energy market both as shareholders in local energy utilities and as public properties owners* ' (Comodi et al., 2012, p. 737).

Furthermore, it is worth noting that empirical studies based on detailed, complete and highly disaggregated data on air pollution and (particularly) on energy policies implemented at local level are difficult, since statistical information is frequently available only on national websites, where the knowledge of the local language is often required. Given the importance of energy policies in terms of climate change mitigation, the establishment of think tanks and research centers aiming to bring together experts on these topics from different European countries should be encouraged, in order to give a more organic and all-inclusive view of the evolution of policies at European and national level, their effects on pollution, and enable information to be shared more easily worldwide.

Finally, individuals' concern about the seriousness of climate change is important in this context. In fact, given the close connection between citizens and local authorities, and the fundamental role of local authorities in adopting sustainable energy policies, scientific evidence about the effect of the successful implementation of sustainable energy policies in terms of emission reduction need to be disseminated as broadly as possible to public opinion, through academic and non-academic channels. From this point of view, leading academic journals on energy economics should grant the widest possible access to any articles on this topic, and advanced training courses should be promoted so that local authorities can be kept better informed on the evolution of the discipline.

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Tables

February 2, 2020

Table 1: Comparison of observable province adopters characteristics in the years 2005 and 2015

	Efficiency energy policy adopters	**Renewable energy policy adopters**	**Both**	**Neither**
Year 2005				
Air pollutants				
Global air pollutants				
CO_2	25,861.170	24,743.260	35,534.140	18,459.620
CH_4	251.763	180.799	272.079	217.747
N_2O	11.017	10.333	12.267	8.579
Local air pollutants				
NMVOCs	169.226	123.711	143.371	379.869
NO_x	123.409	114.282	133.836	109.352
SO_2	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				
Air pollutants				
Global air pollutants				
CO_2	17,960.630	16,952.070	24,746.510	12,901.380
CH_4	219.013	160.415	224.182	155.755
N_2O	9.883	9.074	10.125	6.866
Local air pollutants				
NMVOCs	132.913	91.658	112.467	315.373
NO_x	79.362	73.735	84.370	64.656
SO_2	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 2: 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 3: 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 4: Testing the balancing hypothesis for the nearest neighbor matching in the case of energy policies implemented on a local 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_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 5: 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***	-0.5161**
	(0.2552)	(0.2492)	(0.1450)	(0.1567)	(0.0738)	(0.2180)
$S_{E,R}/S_0$	0.5001	-0.1505	0.1743	-0.5529***	-0.4756***	-0.4368*
	(0.6016)	(0.9050)	(0.2088)	(0.0985)	(0.0649)	(0.2537)
$S_{E,R}/S_R$	-0.2378*	-0.1131	-0.0179	-0.6233***	-0.2841***	-0.4942**
	(0.1262)	(0.1637)	(0.1227)	(0.1009)	(0.0874)	(0.2138)

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 6: 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***	-0.4010**
	(0.3442)	(0.2105)	(0.1296)	(0.0928)	(0.0530)	(0.1924)
$S_{E,R}/S_R$	-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 7: Testing the balancing hypothesis for the nearest neighbor matching in the case of energy policies implemented 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.

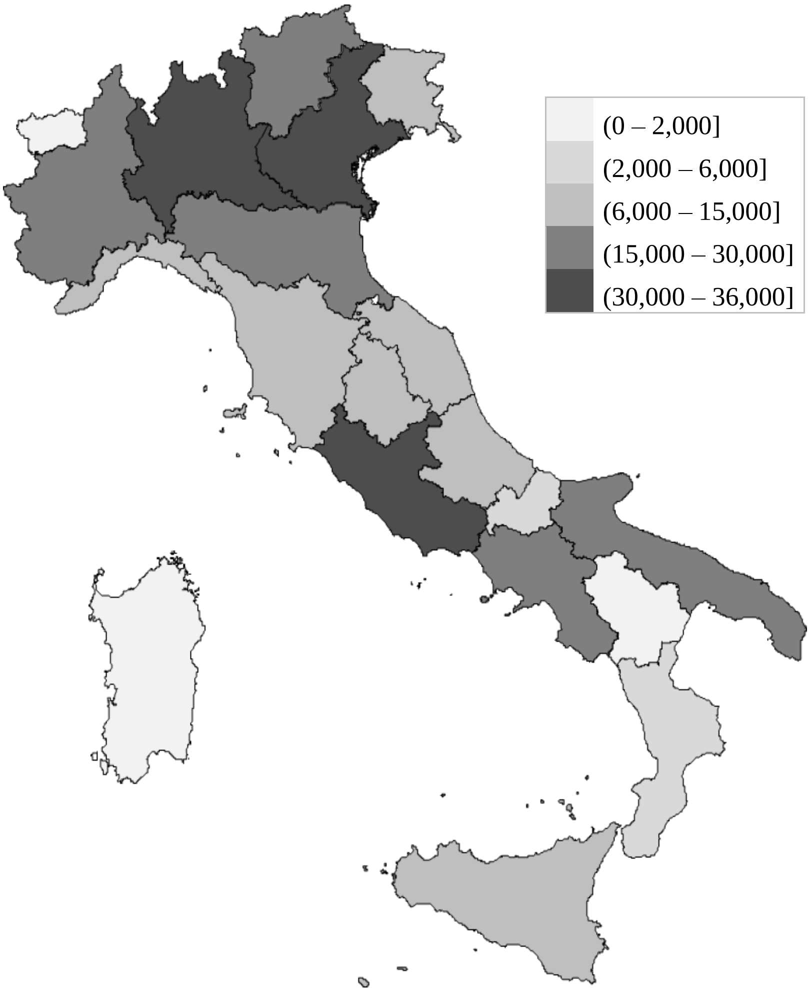
Table 8: Testing the balancing hypothesis for the nearest neighbor matching in the case of energy policies implemented on a regional and local scale jointly

	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	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.

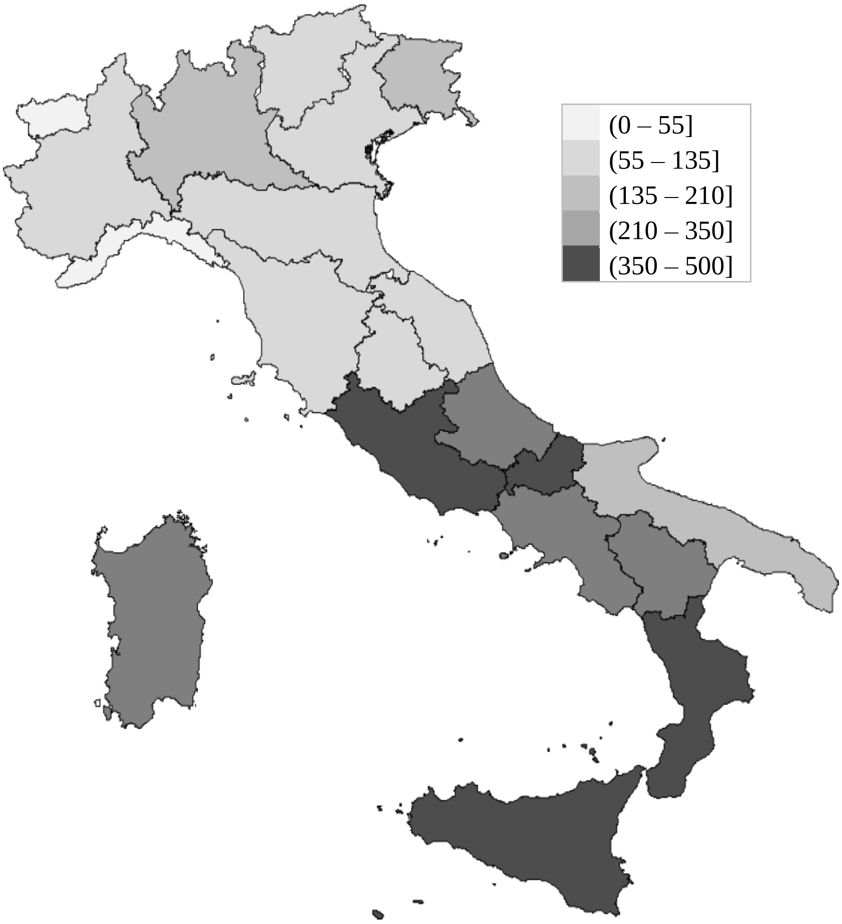
FIGURES

Figure 1: CO_2 in the 20 Italian regions in 2015



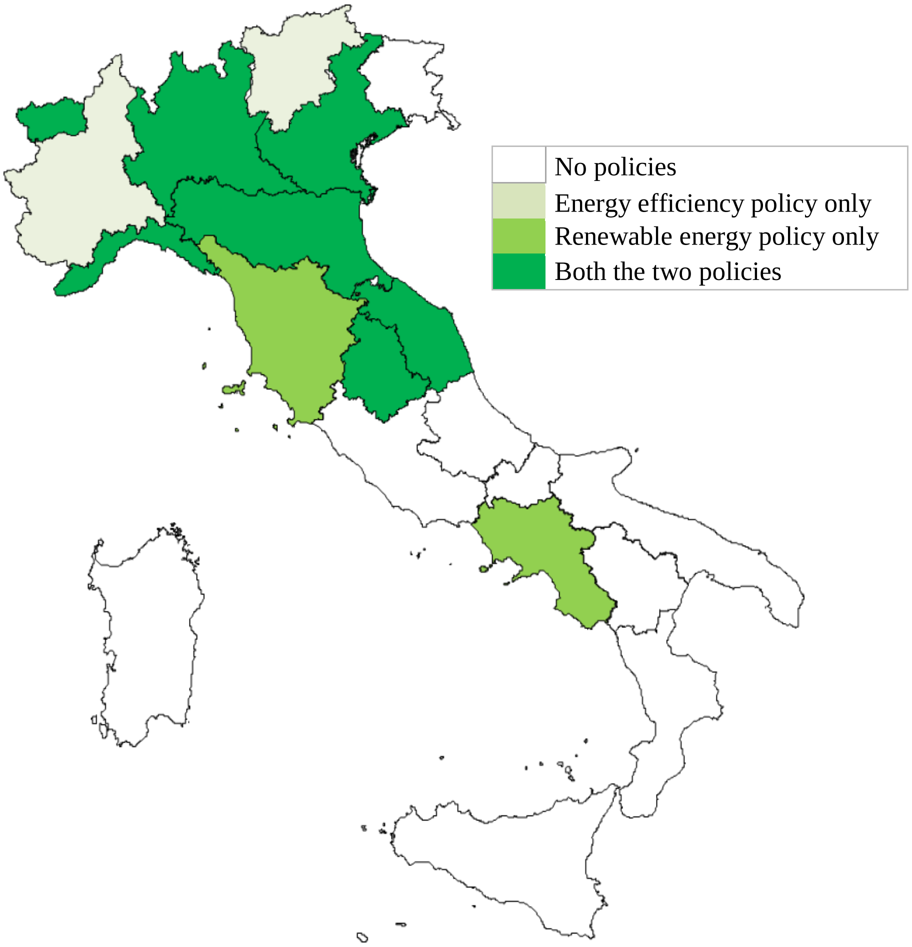
Notes: Emissions are measured in myriagram (Mg). Author's elaboration on ISPRA data

Figure 2: NMVOCs in the 20 Italian regions in 2015



Notes: Emissions are measured in myriagram (Mg). Author’s elaboration on ISPRA data

Figure 3 – Sustainable energy policies implemented in Italy either on a regional or local scale in the years 2005-2010



Notes: Author's elaboration on ISPRA data

Appendix A

Appendix B

Reply to the Referees' comments on our paper " Do sustainable energy policies matter for reducing greenhouse gas emissions?" (Manuscript Number: JEPO-D-19-02542)

I would first like to thank the Reviewers for their comments and suggestions which have helped me to improve my paper in many directions. I hope that the new version of the manuscript follows all their indications.

Reply to Reviewer #1

Paper Overview

I really enjoyed reading your paper. Congratulations…. You did a great job!!!! I only suggest a minor revision of your section 7 of Conclusions and Policy implications.

A researcher feels very excited when he gets indicators that become a tool for helping the world to be a better home for human mankind. Congratulations, you did that!!!! Your methodology and analysis were great; however, when you reach the summit of your conclusions, you want to give the reader more than you offered in your abstract and in your objectives. This is common!!!!

You clearly stated as your objective: the analysis of two sustainable energy policies: energy efficiency policies and renewable energy policies. Great! I was expecting to learn more of this specific topic from your findings!!!!

Comment #1

However, at the end of your paper, I got confused, I felt like there was unneeded noise, I think that you should delete the following: You state: "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)."

My opinion: it is not necessary to mention it. You did not talk neither about innovation nor about the market….. these are other concepts…… I felt lost when reading this. This idea is not derived from your analysis and I think that it does not need to appear here.

Reply to Comment #1

As suggested, I deleted the paragraph.

Comment #2

You state: "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.*

My opinion: The objective of your research was not to talk about the level of research and innovation, but about the implementation of sustainable energy policies. I felt lost again. You did not mention in the paper that you were going to analyze "the drivers of the innovation system in Italy"….. I think that this is not a conclusion of your analysis.

Reply to Comment #2

I deleted the paragraph.

Comment #3

You state: "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."

My opinion: I think that you raised a huge amount of issues at the end of the paper that are not supported by your analysis. Indeed they sound logical, but they were not the purpose of your paper……!!! I never expected to find at the end of your paper: not a ROI analysis of energy investments, not the characteristics of a utility, not the characteristics of the financial markets….. or an analysis of the impact of future energy prices in a ROI analysis…… As an enthusiastic researcher and with our experience we have the temptation to advice the reader of a lot of worthy things to do and incentivize the readers to walk a required path in order to progress towards a sustainable energy agenda.

Reply to Comment #3

I deleted the paragraph.

Comment #4

I understand your enthusiasm!!! However, I would recommend you to rethink this section. You stated in your paper that "no policies have been implemented by the southern regions of Italy "…. This would be a great opportunity for you, based in the results of your great analysis, to talk in your final section about all the great things that Italy or any other country could do in order to get impressive results if the "energy efficiency policies" are combined with the "renewable energy policies". Talk about the benefits of your findings, talk about the possibility to replicate this research in other regions of Italy, other regions of Europe, or even in other countries, talk about *the limitations of your findings and the potential areas for future research….. I was expecting more of these type of reflections than making noise with a lot of new concepts that were not analyzed in the paper (and could sound ambitious for the reader)…..!!! You have a wonderful research, take the opportunity to share with your readers what benefits we could get from your interesting findings. Inspire your readers with your results: encourage them in doing more research, in promoting governments to increase this type of policies, encourage people in charge (as you stated that local authorities are more close to people) to engage in this type of policies… etc) !!!!*

Congratulations for your effort, you did a great job. I invite you to re-write your section 7. Hopefully we will see your paper published very soon and could be an inspiration to walk through the path of sustainable energy policies in the world. Good luck!!!

Reply to Comment #4

Following your suggestion, I re-wrote Section 7 by emphasising the implications of my results. I recalled the importance of renewable energy policies for fighting climate change, since they work very well independently of the type of pollutants taken into consideration and the level of territorial disaggregation at which they are applied.

However, some limits on the effectiveness of the joint adoption of energy efficiency and renewable policies emerge from the empirical findings, with relevant policy implications. In fact, when energy efficiency and renewable policies are jointly adopted, the reduction in terms of emissions is often lower compared to when only one type of policy is applied. This counterintuitive result, known in the literature as Jevons' paradox, is observed in the case of policies implemented at local and at regional level, thus implying that, when energy efficiency and renewable policies are jointly adopted, the reduction in terms of emissions is often lower compared to where only one type of policies is implemented. I now also supplement the discussion of my results with this finding. See the first paragraph on page 28, and the last paragraph on page 30, and the first and second paragraphs on page 31.

This is particularly important in terms of policy planning especially in those peripheral areas, like the regions in the South of Italy, which did not implement any energy policies in the considered time period. In fact, the joint adoption of the two energy policies analysed is recommended only when interventions are applied at local and regional level jointly for reducing specific pollutants (such as CO_2, NMVOCs and NO_x). In all the other cases, renewable policies alone work very well to fight climate change.

Given the recognized importance of energy policies in terms of climate change mitigation, the establishment of think tanks and research centers to bring together experts from different European countries should be encouraged. These initiatives should provide a more organic and all-inclusive view of the evolution of policies at European and national level, their effects on pollution, and enable information to be shared more easily worldwide.

Finally, more attention should be given to the evolution of individuals' concern about the seriousness of climate change. In fact, given the close connection between citizens and local authorities, and the fundamental role of local authorities in adopting energy policies, academic evidence on energy policies should be disseminated as broadly as possible to public opinion, through academic and non-academic channels. Leading academic journals on energy economics should grant the widest possible access to any article they publish, while advanced training courses should be promoted so that local authorities can be kept better informed on the evolution of the discipline.

Last, but not least, I would like to thank you for your enthusiasm about my work. This is the dream of every researcher. Thank you again.

Reply to Reviewer #2

Paper Overview

A very well-crafted paper with a strong and relevant policy focus. The issue addressed is essential in advancing knowledge on energy policies that enhances environmental quality and to gauge whether these policies achieve their intended impact. While I do not have any major criticisms about the paper, except for a few editorial remarks, it would be good if the following suggestions/queries are responded to, if possible.

Comment #1

Primary concern: Could there be any spatial spillovers (and heterogeneity) in driving the adoption of renewable energy (RE) and energy efficiency (EF) policies among provinces? If spatial effects are present in the treatment assignment, then spatial effects violate the stable unit treatment value (SUTVA) assumption associated with the framework for empirical treatment effect analysis. The probability of being treated (i.e. adopting RE or EF or both policies) may be linked to the degree of spatial correlation. That is, there could be policy mimicking by neighboring provinces/regions/localities! How would this spatial treatment indicator (possibly driven information diffusion; peer effects, etc.) then explain GHG emissions?

Failure to incorporate spatial components, if present, may result in inconsistent estimates, biased inference, and incorrect understanding of the causal process. Of course, this is an empirical issue that needs to be tested and/or argued in order to not to over(under) estimate the impact of these policies. Is there any reason to believe that the issue of spatial spillovers might not be the case in this specific context (please motivate)?

Reply to Comment #1

I empirically assess the possible presence of any spatial spillovers in the adoption of the analyzed sustainable energy policies using Moran's I test. This is a popular measure of spatial autocorrelation, which considers how related the values of a variable are based on the locations where they were measured. In order to do this, I compute the greatest Euclidean distance between provinces by considering their latitude and longitude. In our sample, it is equal to 26.52. The Euclidean distance is then useful for the generation of a weights matrix capturing distances between provinces, which is then employed in Moran's I test.

Moran's I test is run in the following cases: *i)* adoption of a renewable energy policy (S_R); *ii)* adoption of a energy efficiency policy (S_E); *iii)* joint adoption of these two policies ($S_{E,R}$); *iv)* the treatment indicator T_i employed in Subsection 5.1 in the multinominal probit model, from which the propensity scores are estimated. I also performed the test distinguishing between policies applied at local, regional or local and regional level. Results are provided in the following table, showing the Moran's I statistics, its *z* statistics and the associated *p-value*.

I cannot reject the null hypothesis that there is zero spatial autocorrelation at the conventional critical level in any of the cases. Consequently, policy decisions (and thus the estimated probabilities of being treated) are not spatially correlated. I now briefly report the main findings on this issue in the last new paragraph of Subsection 5.1.

	Moran'I statistics	**z**	**p-value**
Energy policies implemented at local or regional level			
S_R	-0.010	-0.807	0.210
S_E	-0.009	0.009	0.497
$S_{E,R}$	-0.009	-0.569	0.285
T_i (*Treatment indicator in the multinominal probit model*)	-0.009	0.169	0.433
Energy policies implemented at local level			
S_R	-0.009	-0.453	0.325
S_E	-0.009	-0.186	0.426
$S_{E,R}$	-0.009	-0.536	0.296
Energy policies implemented at regional level			
S_R	-0.010	-0.667	0.252
$S_{E,R}$	-0.010	-1.116	0.132
Energy policies implemented at local and regional level jointly			
S_R	-0.009	-0.413	0.340
$S_{E,R}$	-0.009	-0.536	0.296

Notes: The treatment indicator T_i is an ordinal variable equal to 0, 1, 2 and 3, identifying the status of each province among the four mutually exclusive strategies S_0, S_E, S_R and $S_{E,R}$. When energy policies are implemented at regional level and at local and regional level jointly, regions adopting energy efficiency policies are the same that adopt renewable policies. Author's elaboration on ISPRA data.

Comment #2

Rather than having Tables 1-4 and Figures 1-4 in the main text, which may unnecessarily clutter the paper, I would suggest that these tables and figures be kept in the appendix. It would be insightful and maybe more informative to instead see a map (e.g. a heat map of a selected GHG emission) of Italy indicating the distribution of provinces with and without RE and EF policies over the policy period.

Reply to Comment #2

Tables 1-4 and Figures 1-4 have been moved into the new version of Appendix A. They are now labelled as Tables A2-A5 and Figures A5-A8.

In Subsection 2.1, the new Figures 1 and 2 show the heat maps for CO_2 and NMVOCs emissions in Italy. These pollutants are selected as the two most interesting cases among the global and local pollutants analyzed. The new Figures A1-A4 in Appendix A also show the heat maps for the remaining pollutants.

In Subsection 2.2, the new Figure 3 replaces the former Table 1 (now Table A2 in Appendix A), and indicates the territorial adoption (or not adoption) of sustainable energy policies in the years 2005-2010.

Comment #3

On page 11, line 20 - author refers to Table A2 in Appendix A. As far as I am concerned, there neither Appendix A nor any Tables indicated to be contained in Appendix A. Please check! However, there is Appendix B which is LaTeX (tex) file of the entire manuscript.

Reply to Comment #2

I apologize for this error. The Appendix is now uploaded as Appendix B. In the revised version of the manuscript Table B1 corresponds to the previous Table A2.

Reply to Reviewer #3

Main comment

For a possible resubmission, the you will have to make a match between the title and the content of the paper. Indeed, the title makes believe that the work relates to GHGs only. Yet within the paper, I quickly realize that the author addresses three GHGs and three pollutants. Thus, I invite you to correct this problem.

Reply to Comment

Following your suggestion, I have changed the title of the paper to: “Do sustainable energy policy matter for reducing air pollution?”.

Declaration of interests

The author declares that she has no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

CRediT author statement

Donatella Baiardi: Conceptualization, Methodology, Software, Data curation, Writing- Original draft preparation, Investigation, Writing- Reviewing and Editing.

Tables