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# It only works if you believe in it: How climate change awareness affects the effectiveness of energy initiatives

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ABSTRACT

The aim of this paper is to empirically assess the role of climate change awareness in determining the success or failure of energy initiatives in promoting investments in renewable, solar and wind energies. Energy initiatives are classified into two categories: market-based energy policies and energy legislation. The analysis relies on a panel dataset of 53 countries, covering the period from 2004 to 2022, and the estimation strategy is performed using the two-step version of the system GMM estimator. We examine how different levels of climate change awareness affect the marginal effects of energy initiatives. We observe a positive and significant impact of climate change awareness on the effectiveness of both market-based energy policies and energy legislation. We also find that market-based renewable and solar energy policies are ineffective or even counterproductive for low levels of awareness and become effective when awareness is high. A similar pattern is observed for energy legislation in the case of solar energies. We also identify countries where climate change awareness is sufficiently high to ensure that energy initiatives are effective and others where it is not. In this last group of countries, increasing climate change awareness is a necessary condition for the success of energy initiatives and a powerful lever to support the energy transition.

## 1. Introduction

International agencies and the scientific community agree almost unanimously that climate change is the most serious problem the world is facing and that more effort should be made to meet the target of net zero emissions as quickly as possible. Concern about climate change and its potential socioeconomic impacts has prompted increasing attention to the energy sector, which is the main driver of environmental degradation. The Covid-19 pandemic and the global energy crises also emphasized the importance of the transition to renewable energy (Khan et al., 2021; Liu et al., 2022; Hille, 2023). Since 2022, 26 out of 31 developed economies and 45 out of 103 developing and emerging countries have promoted higher energy efficiency, thus increasing electricity generation.[1]

Renewable energy projects are capital intensive, depending closely on the level of investments. Therefore, governments are required to support the energy transition (IEA, 2018; Zheng et al., 2023). As shown in Fig. 1, global investments in renewable energies increased by about 100 percent in the years 2015–2023. In particular, in the years 2020–2023, the average rate of growth was about 35 percent in advanced economies and China, which together accounted for more than 80 percent of the total increase in clean energy investments. These dynamics are driven especially by solar and wind energies, which nearly doubled their share of global electricity generation from 2018 to 2023, and currently account for more investments than electricity grids (IEA, 2023, 2024a).

However, more efforts are still needed to stimulate investments in cleaner energy. *Energy initiatives* can be done in two complementary directions. On the one hand, *market-based energy policies*, such as feed-in tariffs, renewable portfolio standards, quotas, tax incentives, tender or reverses, and pollution abatement on renewables, are important in promoting investments in different sources of renewable energy (Abban and Hasan, 2021). On the other hand, stronger legal bases and legislation are required to fight climate change. In fact, as noted by Liu and Feng (2023, p. 3), '*the legal system acts like a black box that can 'filter' out environmental policies that do not produce transformative responses*'. *Energy legislation*, whose effect is '*the result of a political will, embodied in a strategic path of development of green energy sources*' (Marques and Fuinhas, 2012, p. 114), is therefore essential for the government to

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[1] According to the International Energy Agency, annual global renewable electricity capacity additions are risen to more than 500 gigawatts in 2023. Solar and wind power account for more than two-thirds of the renewable additions (IEA, 2023).

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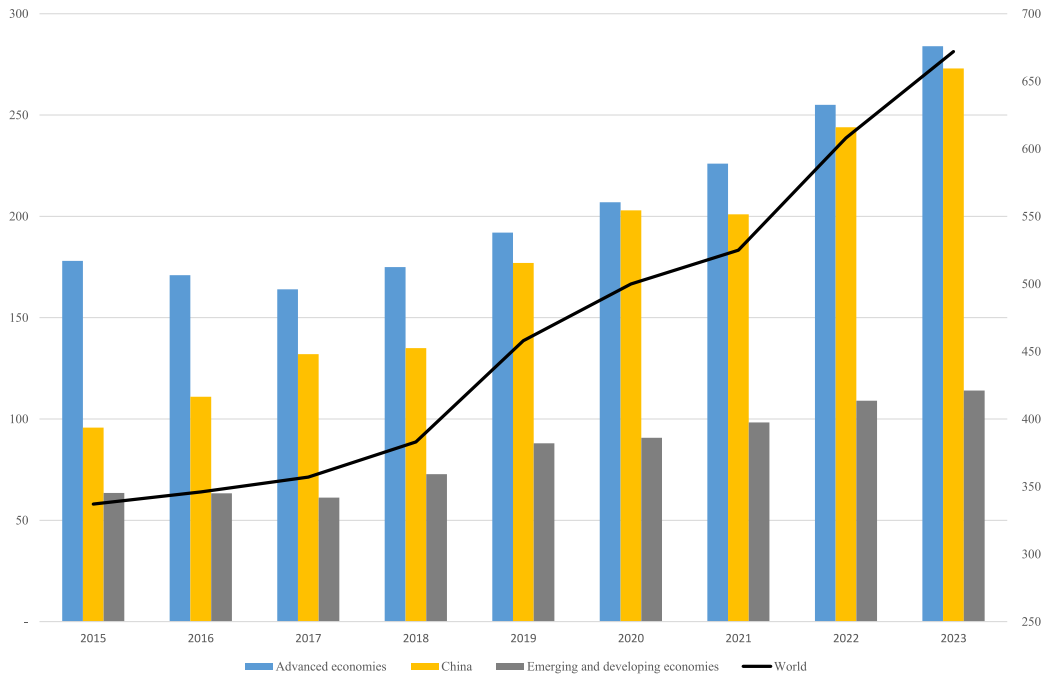



**Fig. 1.** Global energy investments in renewable energies in the years 2015–2023.
*Notes*: Authors' elaboration on International Energy Agency data. Data are measured in billion USD (2022).

achieve climate goals. In light of this, we distinguish *market-based energy policies* and *energy legislation* and we indistinctly refer to both of them as *energy initiatives* throughout this paper.

Despite these theoretical bases, the empirical evidence on the effect of both market-based energy policies and energy legislation is often ambiguous. Many studies find that energy initiatives have a positive impact on investments in renewable energies, but others find non-significant or even (unexpectedly) negative effects. Polzin et al. (2019) provide a systematic review of these results. A possible explanation for these contradictory conclusions can be found in other findings related to renewable energy. An extensive literature shows the importance of climate change awareness in the success of the transition from fossil to renewable energy (Sadorsky, 2009; Marques et al., 2010; Aguirre and Ibikunle, 2014). Many studies thus conjecture that climate change awareness is also significant for the success or the failure of energy initiatives (Fahmy, 2022; Sokołowski and Heffron, 2022).

This may be because the costs of energy initiatives are usually short-term, certain and monetary, whereas their benefits are often long-term, uncertain and non-monetary (Baiardi and Menegatti, 2011; Polzin et al., 2015; Andor et al., 2018; Azhgaliyeva et al., 2020). All this suggests that only when people are aware of climate change and believe in the need of energy transition, there is a real chance that such initiatives will be successful.

This study aims to empirically assess the impact of climate change awareness on the success or failure of energy initiatives in promoting investment in renewable energy sources. Specifically, we conjecture that higher levels of climate change awareness increase the marginal effects of energy initiatives. More strongly, we also conjecture that low levels of climate change awareness may imply that energy initiatives are not effective or even counterproductive, while high levels of climate change awareness imply that they are effective. To our knowledge, this analysis is novel and could provide a possible explanation for the ambiguous results on the effectiveness of energy initiatives found in the literature (Delmas and Montes-Sancho, 2011; Romano et al., 2017; Sokołowski and Heffron, 2022).

This study also includes other aspects of novelty. First, from a methodological perspective, it applies an interaction analysis to estimate the marginal effects corresponding to different levels of climate change awareness, in line with the framework proposed by Brambor et al. (2006). This kind of analysis and its interpretation in terms of research hypotheses is, to our knowledge, new in the literature on different sources of renewable energies.

Second, unlike most studies, where the empirical setting is based on a static approach to the impact of energy initiatives, our estimation strategy is based on a dynamic GMM technique.[2]

Third, our analysis distinguishes between market-based energy policies and energy legislation, according to the taxonomy mentioned above.

Fourth, the empirical framework considers investments in renewable energies as a whole, as well as its two most promising components: solar and wind energies. This also means that our analysis is enriched by explicitly including energy initiatives specific to these two energy sources. Note that, for the sake of simplicity, we use the expression investments in sustainable energies when we indistinguishably refer to investments on one of these energy sources.

Fifth, we use Google Trend Data to proxy climate change awareness (Baiardi, 2023), whereas most of the literature studying this issue uses CO2 emissions from a macroeconomic perspective.

The paper proceeds as follows. Section 2 reviews the relevant literature. Section 3 presents the model and the research hypotheses. Section 4 describes the data and the stylized facts. Section 5 presents the results. Section 6 discusses the main findings. Section 7 concludes and provides some policy implications. Finally, Appendix A provides more details about the data. Appendix B reports additional information on the estimation strategy. Appendix C provides the robustness checks of the main results.

## 2. Literature review

This section is organized as follows. Section 2.1 reviews the main findings on market-based energy policies. Section 2.2 analyzes the role of the energy legislation. Section 2.3 investigates how climate change awareness and policy actions may interact.

[2] A significant exception is the very recent paper by Hassan et al. (2024).

### 2.1. Market-based energy policies

In this subsection, we briefly review the main, somewhat mixed, findings in the empirical literature studying market-based energy policies. The OECD countries and the United States are the cases most frequently studied in the past. The more recent literature considers a broader sample of countries thanks to greater availability of data.

Johnstone et al. (2010) and Popp et al. (2011) focus on how technological progress and energy policies affect the deployment of renewable energy. In particular, Johnstone et al. (2010) examine a panel of 25 OECD countries in the years 1978–2005 and find that only certain policy instruments, such as feed-in-tariffs for solar energy technologies and renewable energy certificates for innovation in wind energy, have a significant impact on innovations in renewable energy. Popp et al. (2011) find that technological innovations affect the use of renewable energy technologies and that more stringent environmental policies increase investments in renewable energies in a sample of 26 OECD countries in the years 1991–2004. Similar conflicting findings on the same issue were made by Dong (2012) and Best and Burke (2018).

Aguirre and Ibikunle (2014) analyze a panel of 38 countries at different stages of economic development in the time period 1990–2010. They find that negotiated agreements, voluntary approaches, fiscal and financial instruments have different, and in some cases *negative*, effects on the contribution of renewables to the energy supply. They also find that environmental concern is an important driver of renewable investments.

Polzin et al. (2015) examines added renewable installed capacity from different sources among private institutional investors in a sample of OECD countries in the period 2000–2011. They find that grants and subsidies are more effective for solar panels because of their impact on the financial constraint, and that feed-in-tariffs and renewable portfolio standards are effective for solar and wind energies because of their impact on the risk/return profile.

Nicolini and Tavoni (2017) analyze the effectiveness of policy support for renewable electricity in promoting renewable energy production in France, Germany, Italy, Spain, and the United Kingdom in the years 2000–2010. They focus on two distinct policy tools: feed-in tariffs and tradable green certificates, and find that these policies positively affect installed capacity. Similar conclusions are reached by Kersey et al. (2021) for the Caribbean islands in the period 2000–2018 and by Liu et al. (2019) in a panel dataset that covers 29 countries in the period 2000–2015.

Romano et al. (2017) examine the effects of green policies on investments in renewable energy in a panel of 56 countries in the period 2004–2013. The analysis distinguishes between developing and developed countries and finds that the effect is generally positive in developing countries and negative in developed countries. This result is in line with Jenner et al. (2013), Kilinc-Ata (2016) and García-Álvarez et al. (2017), who demonstrate that high tariffs and quotas could negatively affect the adoption of renewable energy in European countries and the United States.

Abban and Hasan (2021) investigate how environmental tax and feed-in tariffs affect total (non-hydro), solar and wind electricity capacity in 60 countries in the period 2007–2017. They find that no policy affects total (non-hydro) renewable electricity capacity, while feed-in tariffs are positively correlated with solar and wind electricity capacity in both developed and developing countries.

Escoffier et al. (2021) provide evidence of a positive impact of feed-in tariffs on the development of solar electric energy capacity in 39 economies in the years 1997–2016. In particular, they show an increase of 0.44 percentage points per year in countries implementing the policy compared to countries not implementing it.

Kilinc-Ata and Proskuryakova (2024) study the effects of different types of energy policies (including feed-in tariffs, quotas, tenders, and tax incentives) on investments in renewable energy in 16 Asia-Pacific economies in the period 2000 to 2021. Their results show that feed-in tariffs, quotas, and tenders play an important role in the green energy transition, while tax incentives do not. Zhang et al. (2025a) compute a renewable energy marketization transition index by selecting the keywords of market-oriented renewable energy policy texts in 30 provinces of China in the years 2011–2021, and analyze the impact of this index on renewable energy investments. Their findings show that the marketization process has had an inhibitory effect on wind energy investments in resource-scarce areas, while it had a positive effect on investments in solar energies.

The United States are often investigated for their leading role in the establishment of renewable energy policies since the late 1990s, especially in terms of solar energy (Wiser et al., 2011). Crago and Koegler (2018) find that rebates, sales tax waivers, the price of solar renewable energy credits, and renewable portfolio standards increased solar photovoltaic capacity, solar isolation, and electricity prices in 13 states in the United States in the years 2005–2013. Joshi (2021) provides evidence that renewable portfolio standards positively influence the total installed renewable electricity capacity (non-hydro) and the share of solar and wind energy capacity in the United States in the years 1990–2014. Menz and Vachon (2006) reach a similar result with regard to the effect of renewable portfolio standards on the development of wind energy. However, Delmas and Montes-Sancho (2011) find mixed evidence on the impact of energy policies in promoting the use of renewable electricity. In particular, they find a negative and significant effect of a renewable portfolio standard on investments in renewable capacity. Similarly, Shrimali and Kniefel (2011) find that the impact of a renewable portfolio standards depends on the type of renewable: it is negative for combined renewables, wind, and biomass and positive for geothermal and solar.

### 2.2. Energy legislation

Energy legislation is the embodiment of the concept of the environmental rule of law in a country (Heffron et al., 2018) and steers the transition to energy by driving the formulation and application of policies (Iacobuta et al., 2018; Huhta, 2022). Energy legislation is a key tool for governments to achieve climate change goals (Abraham-Dukuma, 2020; Eskander and Fankhauser, 2020).

The second strand of the empirical literature thus concerns the links between the growth of renewable energy sources and energy legislation. Studies are generally focused on specific countries or groups of different economies. The results generally show that this relationship is positive.

With reference to studies focused on a single country, Dursun and Gokcol (2014) show that encouraging energy legislation has a positive effect on the deployment of wind energy in Turkey. Similarly, Obeng-Darko (2019) notes that the insufficient level of energy legislation impedes the development of renewable energy and thus the production of electricity in Ghana. Similar conclusions are reached for Taiwan (Liou, 2010).

With reference to China, Kong et al. (2020) and Bao et al. (2021) highlight the importance of stricter environmental legislation in reducing pollution and managing the energy market. By means of a quasi-natural experiment, Cao et al. (2024) analyze the effects of the introduction of a series of policies associated with the Renewable Energy Law of the People's Republic of China, which has been a pivotal tool in legal and institutional efforts to promote green growth and combat climate change. Specifically, they find that the implementation of these series of renewable energy policies ensures innovation-driven sustainable development and establishes a strong legal barrier to the energy revolution in China. Similar results are also reached by Zhang et al. (2025b), whose study investigates the effectiveness of the Renewable Energy Law at the city level by using a staggered difference-in-differences model, a mediating effect model, and a moderated effect model. The results show that energy legislation positively affects green

technological innovations and, therefore, the capacity to renewable energy through different mediating effects related to financial constraints, corporate green governance, and information asymmetry.

With reference to cross-country studies, Marques and Fuinhas (2012) analyze a panel of 23 European countries in 1990–2007, where renewable energy legislation is measured by the cumulative number of interventions recorded by the International Energy Agency in the same period of time. The main findings suggest that the use of renewable energy is generally associated with the strengthening of existing policies, as well as with institutional development, project-based initiatives and strategic planning.[3]

Ländner et al. (2019) show that the energy law is relevant in terms of investment decisions in European countries. They note that stronger energy legislation ensures higher flexibility options and a investor-friendly environment.

Marques et al. (2019) investigate the impact of different energy initiatives on electricity generation and installed renewable energy capacity in a sample of 46 countries in the period 1996–2007. They find that direct investments, incentives, policy support and research and development policies are more effective during the initial stages of market diffusion.[4]

Barnea et al. (2022) analyze a sample of 96 countries in the period 2010–2019. For each country and year, they measure the magnitude of a certain type of initiative by using the number of instruments of that type of initiative in place at that year. They find that high levels of electoral democracy and government effectiveness are key for the development of renewable energy capacities in a country. They also show that regulation has a positive effect on renewable energy deployment, especially during the early stages of renewable technologies.

Liu and Feng (2023) find that energy legislation significantly promotes renewable electricity generation in the years 2001–2020, especially in upper-middle-income and high-income countries. They also find that legislation passed by a parliament is more effective than executive orders issued by the government. Furthermore, Liu and Feng (2023) also show that solar and wind energies are more affected by policies than other renewable resources.

Charfeddine and Rahman (2025) analyze a sample of 63 countries, providing evidence of threshold effects for both energy legislation and market-based energy policies on various measures of energy efficiency.[5] In particular, policies are effective only once a certain threshold is reached; below this threshold, such policies can have detrimental effects on environmental quality. These findings are valid regardless of the stage of development of the countries analyzed. Lastly, Ftiti et al. (2025) investigate the mix of sources of energy capacity in 25 OECD countries during the period 1989–2019. Their results show that environmental management policies are a key driver in supporting the transition from non-renewable to renewable energies.

### 2.3. Climate change awareness

The importance of climate change awareness increased significantly, especially after the 2016 Paris Agreement, which constitutes a landmark in the multilateral climate change process (Fahmy, 2022). The transition towards cleaner energy, in fact, requires concrete efforts that are related to citizen concern about climate change (Krueger et al., 2020).

Sadorsky (2009), Marques et al. (2010) and Aguirre and Ibikunle (2014) find that higher levels of environmental concern increase renewable energy investments. All of these works proxy such awareness by means of CO2 emissions. Anderson et al. (2017), Bakaki et al. (2020) and Schaffer et al. (2022) show that countries are more likely to adopt environmental policies when environmental awareness is particularly high. Similarly, Kowalska-Pyzalska (2018a) and Best et al. (2019) find that pro-environmental attitudes are an important factor in the willingness to switch to green electricity tariffs and install rooftop solar panels in households in Poland and Australia, respectively. Cristiano et al. (2023) note that environmental awareness goes hand in hand with the willingness to pay for green roofs in Mediterranean areas, with additional benefits to the urban environment. Hoyle and Rhodes (2025) investigate the factors shaping public support for net-zero climate policy instruments in Canada. They find that climate change awareness is a relevant predictor for all the policies examined.

These findings have many implications for all the actors involved in the sustainable transition, i.e., policymakers, firms, and consumers.

With regard to policymakers, environmentally friendly policies require structural reforms, which often encounter public resistance. In fact, climate measures tend to be costly in the short run, and the benefits are subject to great uncertainty especially in the long run (Andor et al., 2018). Given that benefits materialize only over time, the perceptions of consumers and producers of environmental conditions are key to supporting climate measures and preventing free-riding (Hassan et al., 2024). This is also in line with Ioannidis et al. (2023), who note that the significant share of renewables in the energy mix achieved in Greece is due to the fact that citizens have been shown to be aware of environmental and climate change issues, and therefore are more likely to pay an additional cost to obtain green energy.

With regard to producers, greater attention to the environment implies the use of new resource-saving business models based on remanufacturing, recycling, waste savings, and energy efficiency (Esposito et al., 2017). In this regard, Testa et al. (2016) show that firms are more likely to adopt pro-environmental behavior in Italy if top managers are more aware of environmental problems. Similar findings were made by Tang et al. (2018) and Kitsis and Chen (2021) in China and the United States, respectively.

With regard to consumers, greater climate change awareness increases the demand for green products (Kowalska-Pyzalska, 2018b; Motz, 2021). Evidence in the same direction is found for the purchase of electric vehicles (Vergis and Chen, 2015), although this conclusion is not always confirmed (Austmann and Vigne, 2021).

## 3. Model and research hypotheses

This section presents the empirical model that explores the relationship between various types of energy initiatives and investments in sustainable energies, as well as the potential influence of climate change awareness on this relationship. The estimation model is structured as follows:

$$Y_{it} = \alpha_i + \beta_0 Y_{it-1} + \beta_1 X_{it} + \beta_2 X_{it} Z_{it-j} + \beta_3 Z_{it-j} + \Gamma D_{it} + \eta_i + \tau_t + \epsilon_{it} \quad (1)$$

where, for each country $i$ in each year $t$, $Y_{it}$ is investments in sustainable energies, $Y_{it-1}$ is the same variable lagged once, $X_{it}$ is the specific energy initiative variable, $Z_{it-j}$ is climate change awareness lagged at time $t - j$, and $D_{it}$ is a set of control variables capturing cross-country heterogeneities.[6] The variables $\eta_i$ and $\tau_t$ are, respectively, country-specific and time-specific effects, and $\epsilon_{it}$ is the error term.

In Eq. (1), energy initiatives have both a direct effect on investments in sustainable energies (captured by Coefficient $\beta_1$) and an effect mediated by the interaction with climate change awareness (captured

[3] Marques and Fuinhas (2012) also find that incentives and subsidies increase the contribution of renewables to total primary energy supply, while the opposite is true for quota obligations and tradable certificates.

[4] They also analyze market-based instruments, and find that these interventions are effective only in the long run.

[5] Specifically, they distinguish between financial energy efficiency policies, regulatory energy efficiency policies, and strategic energy efficiency policies. The first category corresponds to our definition of market-based energy policies, while the latter two fall under our definition of energy legislation.

[6] Note that $\Gamma$ is a vector of parameters.

by Coefficient $\beta_2$). In addition, climate change awareness is also introduced in isolation as a control variable to ensure that estimates of the Coefficients $\beta_1$ and $\beta_2$ are unbiased and consistent.

As shown by Brambor et al. (2006) and according to Vogel et al. (2021) and Doğan et al. (2022), Eq. (1) implies that the marginal effect of energy initiatives on investments in sustainable energies is given by:

$$\frac{dY_{it}}{dX_{it}} = \beta_1 + \beta_2 Z_{it-j} \tag{2}$$

In other words, Eq. (2) implies that the marginal effect of energy initiatives is a linear function of the level of climate change awareness.

Following the empirical literature reviewed in Sections 2.1 and 2.2, two distinct types of energy initiatives are analyzed: market-based energy policies. and energy legislation. For each type of initiative, two distinct research hypotheses are formulated.

The first hypothesis conjectures a positive effect of climate change awareness on the marginal effect of market-based energy policies. It is formalized as follows:

**Hypothesis 1.** The marginal effect of market-based energy policies on investments in sustainable energies increases when climate change awareness increases.

The influence of climate change awareness on market-based energy policies can also be formalized in a stronger way, assuming that the effectiveness of these policies depends on the level of climate change awareness. Specifically, we hypothesize that market-based energy policies may be ineffective, or even counterproductive, when climate change awareness is low, but become effective when a sufficient level of climate change awareness has been attained. This implies that interventions are effective only once awareness reaches a certain threshold. This hypothesis is formalized as follows:

**Hypothesis 2.** Market-based energy policies have a null (or even negative) marginal effect on investments in sustainable energies for low levels of climate change awareness and a positive marginal effect for high levels of climate change awareness.

Given the linearity of Eq. (2), a positive value for Coefficient $\beta_2$ (i.e, $\beta_2 > 0$) is a necessary and sufficient condition for Hypothesis 1 to hold and it is a necessary but not sufficient condition for Hypothesis 2 to hold. This implies that if Hypothesis 2 is satisfied, Hypothesis 1 is satisfied too, but there are cases where Hypothesis 1 is satisfied and Hypothesis 2 is not. This clearly means that Hypothesis 2 is a stronger assumption than Hypothesis 1.

A specific test is conducted for each of the above hypotheses. A test on Hypothesis 1 is simply a test on the sign of Coefficient $\beta_2$. The hypothesis is confirmed if $\beta_2$ is positive and significant and rejected otherwise. A test on Hypothesis 2 is conducted by estimating the linear function in Eq. (2), together with its 95 percent confidence interval, for each level of climate change awareness. Hypothesis 2 is confirmed if the entire confidence interval lies below the value 0 or includes the value 0 for low levels of awareness and lies above the value 0 for high levels of awareness. Hypothesis 2 is rejected if such a pattern does not emerge. When Hypothesis 2 holds, our analysis makes it possible to determine for which levels of climate change awareness market-based energy policies have a statistically significant positive effect on investments in sustainable energies, obtaining a threshold level of awareness starting from which the policies become effective.

Similar effects should occur for energy legislation. According to this conjecture, the following research hypothesis can be introduced:

**Hypothesis 3.** The marginal effect of energy legislation on investments in sustainable energies increases when climate change awareness increases.

A stronger hypothesis on the effects of climate change awareness on energy legislation can also be formalized as follows:

**Hypothesis 4.** Energy legislation has a null (or even negative) marginal effect on investments in sustainable energies for low levels of climate change awareness and a positive marginal effect for high levels of climate change awareness.

Like Hypothesis 2, Hypothesis 4 suggests that energy legislation is effective when there is a high level of climate change awareness and that it may ineffective, or even counter-productive, when this level is low.

As described for Hypotheses 1 and 2, Hypothesis 4 implies Hypothesis 3 but not vice versa. Moreover, Hypothesis 3 can be tested by examining the sign of Coefficient $\beta_2$ in the same way described above for Hypothesis 1. Similarly, Hypothesis 4 can be tested by studying the confidence interval of the function in Eq. (2) in the same way as described above for Hypothesis 2.

## 4. Data

The sample consists of a panel dataset of 53 countries in the years 2004–2022. Country selection was made starting from the 60 countries in Abban and Hasan (2021), which were chosen to ensure representation across all continents and regions. However, 11 of these countries were excluded due to the poor quality and limited availability of data on climate change awareness.[7] To partially offset this reduction and given that the availability of market-based energy policies data is limited to OECD countries (see Section 4.2), Iceland, Luxembourg, Slovakia and Slovenia have also been included in the dataset.

In Appendix A, Table A.1 lists the countries and their level of development according to the World Bank classification (2024 Edition), while Table A.2 reports the sources of the variables described in the following subsections. In Appendix B, Appendix B.1 assesses the possible presence of unit roots in the panels. Related results justify the transformation of the variables in first differences in the estimations when necessary.

### 4.1. Investments in renewable energies

Investments in renewable energies are proxied by renewable electricity capacity, which corresponds to the maximum net generating capacity of power plants and other installations that use renewable energy sources to produce electricity installed at the end of each calendar year. Data are measured in megawatts (MW) and retrieved from IRENA database (2023 Edition). The use of this proxy is widespread in the empirical literature (Abban and Hasan, 2021), because it '*tracks investment without being biased by forces the investor cannot foresee or control*' (Jenner et al., 2013, p.389).

Investments in renewable energies include hydropower, marine, wind, solar, bio-energy and geothermal sources. Hydropower, solar and wind sources are the most relevant component of global electricity generation. More precisely, according to IEA (2024b), solar and wind power are the fastest-growing sources of electricity in 2024. They are expected to surpass hydroelectric generation by 2030, despite a 65% increase in installed hydroelectric capacity (excluding pumped storage), rising from 761,767 MW to 1,260,883 MW in the years 2004–2022 (IRENA, 2023).

When analyzing the 2030 forecast for global renewable growth, IEA (2024b) also states that hydrogen remains a negligible driver for the growth of new renewable capacity. At the same time, the use of electricity to produce hydrogen may significantly increase demand for electricity, but '*the scale and timing are highly uncertain because they are*

[7] The excluded countries are: Bangladesh, Ghana, Kenya, Morocco, Nigeria, the Russian Federation, Singapore, Sri Lanka, Tunisia, Ukraine, and Vietnam.

*contingent on how quickly different hydrogen production pathways and use develop*' (IEA, 2024c, p.43).

According to this discussion, the empirical analysis is performed by considering not only investments in renewable energies, but also its two most promising components, i.e. investments in solar and wind energies.[8] Therefore, investments in renewable, solar and wind energies are alternately used as dependent variables. These three variables are transformed into natural logarithms and employed in first differences.

### 4.2. Policy variables

With regard to *market-based energy policies*, three distinct categories are considered separately and classified as follows: renewable, solar and wind energy policies.

Market-based renewable energy policies are proxied by means of a market-based index, which is a component of the OECD Environmental Policy Stringency Index.[9] This indicator explicitly considers policies that put a price on pollution, such as: CO2 Trading Scheme, Renewable Energy Trading Scheme, CO2 Taxes, Nitrogen Oxides Tax, Sulphur Oxides Tax and Fuel Tax.[10]

Market-based solar (wind) energy policies are, instead, computed as the ratio between the level of the price support for solar (wind) energy technologies from feed-in tariffs and renewable energy auctions, and the global levelized cost of electricity.[11] These variables are measured in USD/kilowatt-hour, are retrieved from OECD (2020 Edition), and refer to long-term contracts which guarantee a price to be paid to a producer of a pre-determined source of electricity per kWh fed into the electricity grid.

With regard to *energy legislation*, three variables are considered separately to capture policies and measures which '*define strategies and outline specific programs to promote [...] renewable sources inside a country or a set of countries*' (Marques and Fuinhas, 2012, p. 110). Data are retrieved from the Climate Policy Database, a comprehensive policy package which gathers information on climate-related policies and is updated periodically. It covers 198 countries, and collect more than 6000 policies.

The following criterion is adopted for the construction of these three variables. The item 'policy type' is selected by considering the three keywords 'Renewables', 'Solar', and 'Wind' alternatively. For each category, the number of policies implemented in each country of the sample is computed for each year and the three variables corresponding to legislation on renewables, solar and wind energy are thus constructed.

All the variables described in this subsection are introduced in levels in the estimation strategy.

### 4.3. Climate change awareness

Due to the current increase in the use of the Internet, Google Trend has recently emerged as an extensive source of data for the analysis of public interest and social trends (Nghiem et al., 2016; Mavragani and Ochoa, 2019; Baiardi, 2023; Dabbous et al., 2023; Arin et al., 2024; Grechyna, 2025). Climate change awareness is proxied by means of Google Search Volume Index (SVI) data.[12] For each country, raw data are available monthly for the period 2004–2022.[13]

Similarly to Vergis and Chen (2015) and Austmann and Vigne (2021), the keyword used in the research analysis is '*climate change*' (code: 0d063v). Google Trends provides two kinds of data: *topic* and *search* terms.[14] We use *topic* in order to address potential issues with misspelling and searches in different languages (Choi et al., 2020).[15]

The index is rounded to an integer ranging from 0, the period with the lowest popularity, to 100, the period with the highest popularity.[16] Lower values of the index thus suggest lower climate change awareness and higher values suggest greater climate change awareness.

Lastly, for each country of the sample, we compute average yearly values starting from the first monthly Google SVI observation, and these are transformed into natural logarithms. Given that energy initiatives require time to become effective (Polzin et al., 2015; Barnea et al., 2022), lagged values of climate change awareness are used. Note that the use of lags also rules out reverse causality issues. In fact, Polzin et al. (2015) show that the installations of new energy plants can influence perceptions of environmental problems. Climate change awareness is thus lagged for five years in all the estimates. For robustness checks, estimates obtained using the same variable lagged for three years are shown in Appendix C.

### 4.4. Control variables

A large number of explanatory variables are included in the empirical estimates in order to capture cross-country heterogeneities in terms of structural and policy factors. Most of these variables are retrieved from World Development Indicators by Word Bank (2023 Edition).

First, per capita GDP in current US dollars is introduced to capture the stage of development of each country. It is also considered as a proxy of the capability of a country to finance the construction of new infrastructures in sustainable energy sources, which is expensive and thus requires huge investment (Best and Burke, 2018; Hao and Shao, 2021; Barnea et al., 2022). Per capita GDP is expected to have positive effect on investments in sustainable energies.

Land availability is crucial when a country is densely populated. Renewable energy plants, such as photovoltaic panels and wind turbines, require a larger amount of land in proportion to the amount needed for the production of non-renewable energy sources. Consequently, a higher population density may increase the likelihood of the 'not in my backyard' syndrome (Bigerna and Polinori, 2019). This implies that local communities may (seek to) prevent the construction of sustainable energy facilities in their neighborhood (Hyland and Bertsch, 2018; Diógenes et al., 2019; Barnea et al., 2022). Higher population density, computed as the midyear population divided by land area in square kilometers, is thus expected to have a negative effect on investments in sustainable energies.

Access to clean fuel and technology for cooking has a significant impact on climate, public health, economic, and social issues. Cooking with traditional stoves and solid fuels contributes to the emissions of carbon dioxide, methane, and particulates, especially in developing countries (ESMAP, 2018). The access to clean fuels and technologies for cooking is computed as the proportion of the total population

[8] Investments in solar energy includes solar photovoltaic and concentrated solar power, while investments in wind energies include onshore and offshore wind sources.

[9] The OECD Environmental Policy Stringency Index is a country-specific and internationally-comparable composite indicator measuring the stringency of environmental policy, and is based on 13 environmental policy instruments, mainly related to climate and air pollution.

[10] Data on CO2 Trading Schemes and CO2 taxes are converted to USD/tonne CO2 to enable comparison. Similarly, data on Nitrogen Oxides Tax, Sulphur Oxides Tax and Fuel Tax are converted to USD/tonne NOx, USD/tonne SOx and USD/tonne Litre, respectively.

[11] Solar energy policies account include only solar photovoltaic measures, while exclude concentrated solar power.

[12] Empirical literature alternatively used either survey data or CO2 emissions as a proxy of climate change awareness at country level (Marques et al., 2010, 2011; Damette and Marques, 2019; Baiardi, 2023).

[13] Downloaded data consist of a sample of all Google searches (Woloszko, 2020; Cebrián and Domenech, 2023).

[14] Tasks were automated via R package *gtrendsR* (Massicotte and Eddelbuettel, 2016).

[15] See also the official Google Search blog: https://search.googleblog.com/2013/12/an-easier-way-to-explore-topics-and.html, and https://support.google.com/trends/answer/4365533?hl=en.

[16] Technical details are provided in Appendix A.2.

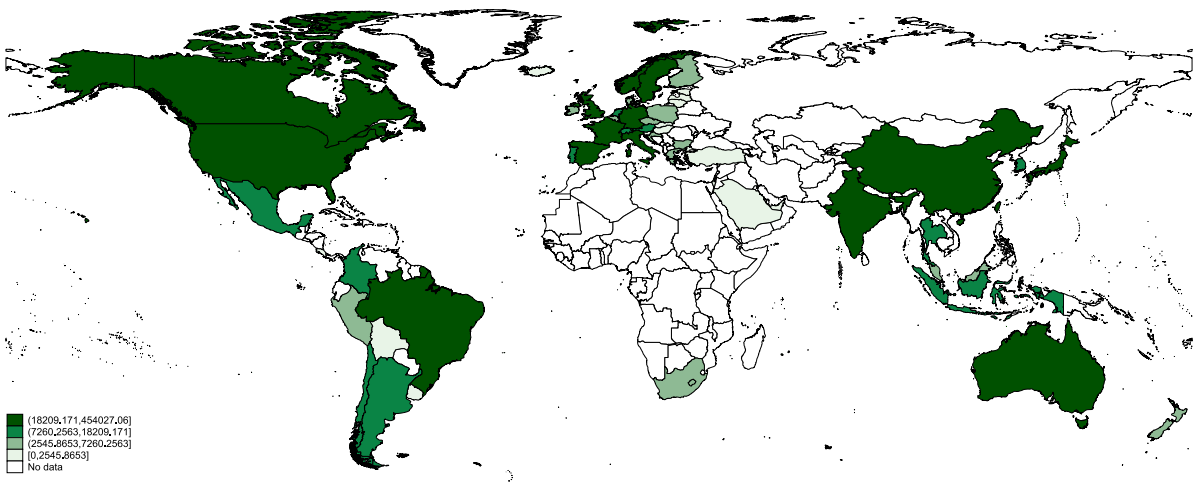



**Fig. 2.** Investments in renewable energies in the years 2004–2022.
*Notes*: Authors' elaborations on International Renewable Energy Agency (IRENA) data. Average in the years 2004–2022 is reported at the country level.

primarily using clean fuels (with the exclusion of kerosene) and clean technologies for cooking.

Agriculture is responsible for methane emissions and is a relevant energy user (IEA, 2023). Thus, renewable energy production should be a useful opportunity for diversification in this industry (Sutherland and Holstead, 2014). Agriculture is introduced into the estimates by means of the crop production index, which shows agricultural production for each year relative to the base period 2014–2016. It includes all crops except fodder crops. This indicator is expected to positively affects investments in sustainable energies.

Finally, Marques et al. (2010), Aguirre and Ibikunle (2014) and Nicolini and Tavoni (2017) show that countries sometimes aim to invest in sustainable energies in order to reduce their energy dependence on foreign countries. Electricity net imports are thus included in the estimates. They are computed as the difference between electricity imports and electricity exports for each country and year. It is expected that an improvement in a country's net electricity imports negatively affects investments in sustainable energies. Data are in billion kilowatt-hour, retrieved from the U.S. Energy Information Administration, and then transformed in first differences.

### 4.5. Stylized facts

The pattern of energy investments has shifted the world towards a more electrified, renewable-rich energy system in the recent decades (IEA, 2023). China, the United States, Brazil and Germany are the top performers, with an installed average renewable electricity capacity equal to 454,027, 187,951, 109,936, and 82,120 MW, respectively (Fig. 2).

China particularly plays a leading role in shaping global energy trends. It is the leading world supplier of solar and wind energy, followed by the United States and Germany (Figs. 3 and 4).[17] Among Asian countries, India also plays an increasing role on the world's energy markets.[18] This trend is expected to continue at an elevated rate, with investments in solar and wind power generation accounting for almost 90 percent of all new renewable energy installations in the medium term (IEA, 2022). In fact, 19 countries show a growth rate above 3 percent in the years 2004–2022, while Belgium, Estonia, Israel, the Netherlands, Saudi Arabia and the United Arab Emirates show an average growth over 20 percent.

The expansion of renewable capacity is closely tied to ambitious targets and policy incentives. Developed countries are taking the lead in market-based energy policies, while China and India, together with the advanced economies of the sample, are top performers in energy legislation. This suggests that a high income level is not a necessary prerequisite for a comprehensive institutional framework (ESMAP, 2018).

Lastly, we provide some data on climate change awareness derived from Google Trend analysis (Fig. 5).

According to these data, Colombia, France and Switzerland are the countries with the highest levels of awareness (3.72, 3.70 and 3.55, respectively), whereas the lowest levels are recorded in Peru (3.38), the Eastern European countries (1.82, on average), Bolivia (1.75) and Indonesia (1.60).

## 5. Empirical findings

### 5.1. The estimates

Eq. (1) is estimated by applying the two-step version of the system GMM estimator proposed by Blundell and Bond (1998). This approach ensures unbiased and consistent estimates of the coefficient of interest in the presence of potential measurement errors, cross-sectional dependence and endogeneity problems of the explanatory variables, mainly due to the correlation between the lagged dependent variables and the error term.

In particular, climate change awareness, country and time effects are treated as strictly exogenous regressors, thus constituting the set of variables used as standard instruments.[19] The remaining right-hand side variables in Eq. (1) are used as bases for 'GMM-style' instrument sets. Their specific sources of endogeneity are analyzed in Appendix B.3 of Appendix B.

Moreover, some of the variables used in the empirical analysis exhibit missing data. Estimates are based only on observations for which all variables included in the model are observed. Observations with missing values are thus automatically excluded from the estimation. Given these premises, estimates have been conducted with

[17] In the years 2004–2022, investments in solar energy were on average equal to 86,561, 30,284 and 29,359 Megawatts in China, Germany and the United States, while investments in wind energy account for about 113,708, 63,386 and 39,257 in China, the United States and Germany, respectively.

[18] In the years 2004–2022, India ranked fifth and fourth in terms of investments in solar and wind energies investing 13,469 and 21,637 Megawatts, respectively.

[19] Details related to the selection of the country and time fixed effects included in the estimates are provided in Appendix B.2 of Appendix B.

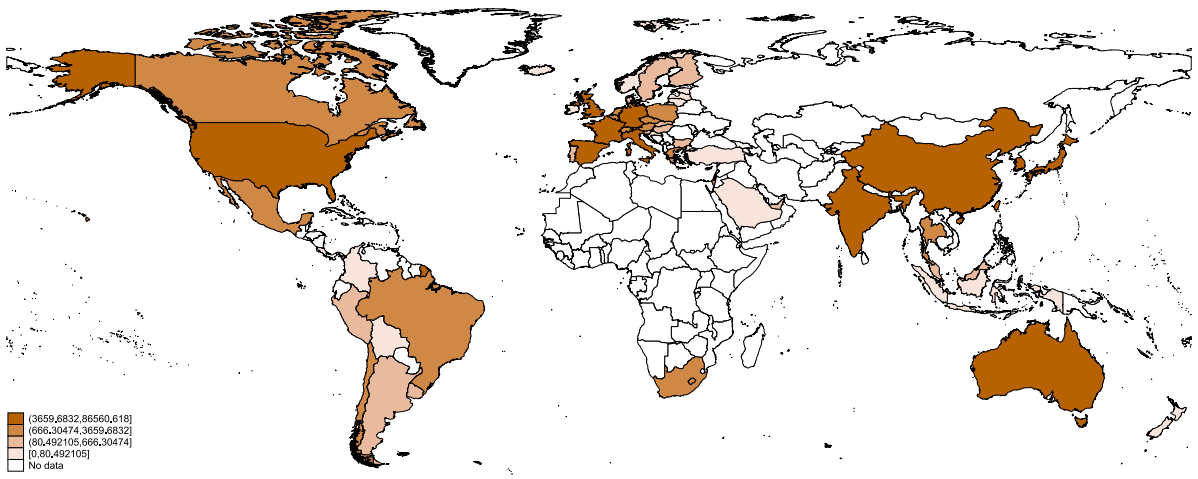



**Fig. 3.** Investments in solar energies in the years 2004–2022.
*Notes*: Authors' elaborations on International Renewable Energy Agency (IRENA) data. Average in the years 2004–2022 is reported at the country level.

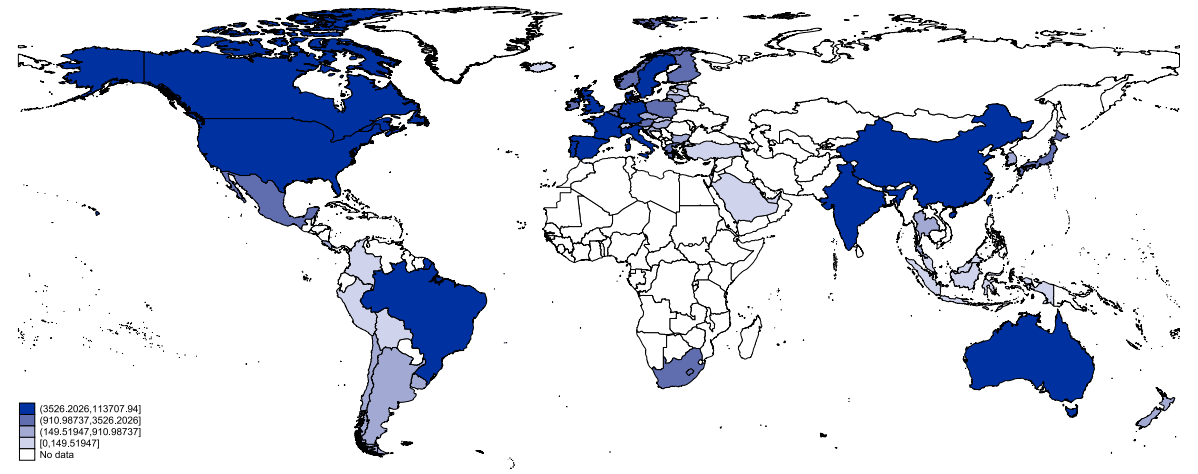



**Fig. 4.** Investments in wind energies in the years 2004–2022.
*Notes*: Authors' elaborations on International Renewable Energy Agency (IRENA) data. Average in the years 2004–2022 is reported at the country level.

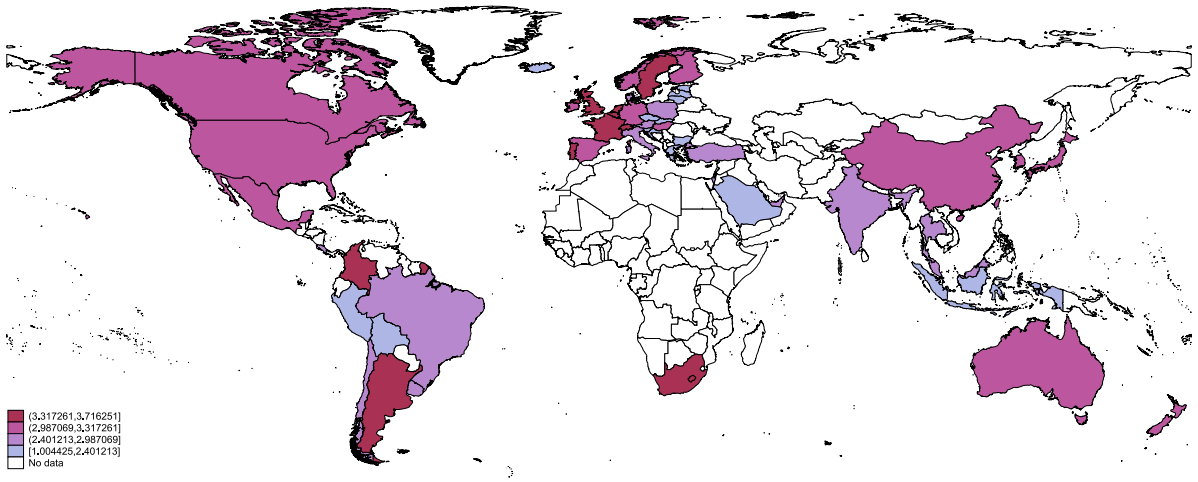



**Fig. 5.** Climate change awareness in the years 2004–2022.
*Notes*: Authors' elaborations on Google Trend data. Average in the years 2004–2022 is reported at the country level.

**Table 1**
Estimates of Eq. (1) for market-based energy policies.

| | (1) Investments in renewable energies | (2) Investments in solar energies | (3) Investments in wind energies |
|---|---|---|---|
| *Coefficient* $\beta_0$ | | | |
| Investments in renewable energies ($t-1$) | 0.3596*** | – | – |
| | (0.0930) | | |
| Investments in solar energies ($t-1$) | – | 0.4650*** | – |
| | | (0.0501) | |
| Investments in wind energies ($t-1$) | | | −0.0169 |
| | | | (0.1029) |
| *Coefficient* $\beta_1$ | | | |
| Market-based renewable energy policies | −0.0814* | – | – |
| | (0.0454) | | |
| Market-based solar energy policies | – | −3.1630*** | – |
| | | (0.716) | |
| Market-based wind energy policies | | | −2.0736* |
| | | | (1.059) |
| *Coefficient* $\beta_2$ | | | |
| Market-based renewable energy policies × Climate change awareness ($t-5$) | 0.0287** | – | – |
| | (0.0137) | | |
| Market-based solar energy policies × Climate change awareness ($t-5$) | – | 1.1368*** | – |
| | | (0.2420) | |
| Market-based wind energy policies × Climate change awareness ($t-5$) | – | – | 0.7117** |
| | | | (0.3529) |
| *Coefficient* $\beta_3$ | | | |
| Climate change awareness ($t-5$) | −0.0238 | −0.0492 | −0.0849 |
| | (0.0167) | (0.0507) | (0.0621) |
| *Control variables* | | | |
| Per capita GDP | 0.0356 | 0.0760 | −0.2667 |
| | (0.0379) | (0.2050) | (0.2257) |
| Population density | 8.1287*** | −39.7939*** | −39.5691* |
| | (2.5898) | (8.3170) | (22.8872) |
| Access to clean fuels and technologies for cooking | −0.1857 | −0.8845 | −2.7004 |
| | (0.1373) | (1.6023) | (3.0449) |
| Crop production index | −0.0027 | 0.2681** | 0.0068 |
| | (0.0152) | (0.1363) | (0.0900) |
| Electricity net imports | −0.0003 | 0.0018 | −0.0010 |
| | (0.0002) | (0.0018) | (0.0015) |
| Constant | 0.8435 | 4.6615 | 10.8489 |
| | (0.5792) | (6.8054) | (14.4007) |
| Observations | 372 | 431 | 440 |
| Number of cross-sections | 31 | 43 | 42 |
| Number of instruments | 34 | 37 | 34 |
| Arellano-Bond test for first-order autocorrelation (z-statistics) | −2.4084 | −3.0268 | −1.6333 |
| Arellano-Bond test for first-order autocorrelation (p-value) | 0.0160 | 0.0025 | 0.1024 |
| Arellano-Bond test for second-order autocorrelation (z-statistics) | −1.4732 | 0.3269 | −1.0896 |
| Arellano-Bond test for second-order autocorrelation (p-value) | 0.1407 | 0.7437 | 0.2759 |
| Sargan test ($\chi^2$) | 8.8248 | 3.9366 | 1.6214 |
| Sargan test (p-value) | 0.9848 | 1.0000 | 1.0000 |
| Hansen test ($\chi^2$) | 21.5601 | 20.2968 | 13.7707 |
| Hansen test (p-value) | 0.3648 | 0.4395 | 0.6833 |
| Extracted principal components from GMM-style instruments | 28 | 26 | 24 |
| Portion of variance explained by the components | 0.8037 | 0.7693 | 0.7338 |
| Kaiser-Meyer-Olkin measure of sampling adequacy | 0.9017 | 0.8514 | 0.8209 |

*Notes*: Significance levels: *p < 0.1, **p < 0.05, ***p < 0.01. Standard errors in parentheses. Dependent variables are in computed as the first differences of each series (transformed in natural logarithms). The same transformation is applied for per capita GDP, population density and the crop production index. Market-based energy policies, climate change awareness (proxied by means of Google Trend data and lagged for five years) and the access to clean fuels and technologies for cooking are in levels (transformed in natural logarithms, with the exception of market-based energy policies). The electricity net imports are used in first differences. Time dummies for the years 2010, 2012 and 2016 are included in Column 1, while time dummies related to the years 2009, 2010, 2011, 2012, 2016, 2019 and 2020 are included in Columns 2 and 3. A dummy for high-income countries is included in all the estimates. The instruments are used by the first-difference and level equations when renewable and solar energies are considered; only by the first difference equation when wind energy is analyzed.

careful attention to the number of instruments employed, which have been collapsed (Roodman, 2009) and the 'GMM-style' instruments are replaced with their principal components (Kapetanios and Marcellino, 2010).

The empirical results are organized as follows: Tables 1 and 2 report the estimates related to market-based energy policies and energy legislation.

In both tables, the dependent variable in Column 1 is investments in renewable energies, while investments in solar and wind energies are the dependent variables in Columns 2 and 3 respectively. Note that this subsection discusses only the sign and the significance of the autoregressive terms, of energy initiatives and of climate change awareness (captured by Coefficients $\beta_0$, $\beta_1$ and $\beta_3$ of Eq. (1), respectively), and of the other control variables (captured by the vector of coefficients $\Gamma$). Moreover, diagnostic statistics are also analyzed.

**Table 2**
Estimates of Eq. (1) for energy legislation.

| | (1) Investments in renewable energies | (2) Investments in solar energies | (3) Investments in wind energies |
|---|---|---|---|
| *Coefficient* $\beta_0$ | | | |
| Investments in renewable energies ($t-1$) | −0.1805*** | – | – |
| | (0.0261) | | |
| Investments in solar energies ($t-1$) | – | 0.3633*** | – |
| | | (0.0175) | |
| Investments in wind energies ($t-1$) | | | −0.0341** |
| | | | (0.0154) |
| *Coefficient* $\beta_1$ | | | |
| Renewable energy legislation | −0.0561*** | – | – |
| | (0.0201) | | |
| Solar energy legislation | – | −0.4950** | – |
| | | (0.2217) | |
| Wind energy legislation | – | – | −1.1726*** |
| | | | (0.3250) |
| *Coefficient* $\beta_2$ | | | |
| Renewable energy legislation × Climate change awareness ($t-5$) | 0.0135*** | – | – |
| | (0.0051) | | |
| Solar energy legislation × Climate change awareness ($t-5$) | – | 0.1679** | – |
| | | (0.0658) | |
| Wind energy legislation × Climate change awareness ($t-5$) | – | – | 0.3364*** |
| | | | (0.1014) |
| *Coefficient* $\beta_3$ | | | |
| Climate change awareness ($t-5$) | 0.0216*** | 0.0658*** | 0.0381* |
| | (0.0073) | (0.0177) | (0.0210) |
| *Control variables* | | | |
| Per capita GDP | 0.3212*** | 0.8410*** | −0.0538 |
| | (0.0763) | (0.1335) | (0.1164) |
| Population density | 1.5620 | 0.2496 | −18.4167*** |
| | (2.4401) | (7.7119) | (5.5029) |
| Access to clean fuels and technologies for cooking | −0.0543 | −1.5102*** | −2.7690*** |
| | (0.1254) | (0.2224) | (0.6232) |
| Crop production index | −0.1413*** | −0.1534** | −0.0527** |
| | (0.0255) | (0.0671) | (0.0261) |
| Electricity net imports | 0.0000 | −0.0001 | −0.0015 |
| | (0.0003) | (0.0011) | (0.0009) |
| Constant | 0.2094 | 6.6898*** | 12.6074*** |
| | (0.5603) | (0.9728) | (2.7492) |
| Observations | 610 | 573 | 565 |
| Number of cross-sections | 51 | 51 | 50 |
| Number of instruments | 41 | 47 | 46 |
| *Diagnostic statistics* | | | |
| Arellano-Bond test for first-order autocorrelation (z-statistics) | −1.6249 | −3.4878 | −2.2447 |
| Arellano-Bond test for first-order autocorrelation (p-value) | 0.1042 | 0.0005 | 0.0248 |
| Arellano-Bond test for second-order autocorrelation (z-statistics) | 0.4836 | 0.8230 | −0.0076 |
| Arellano-Bond test for second-order autocorrelation (p-value) | 0.6287 | 0.4105 | 0.9940 |
| Sargan test ($\chi^2$) | 33.4990 | 20.7313 | 5.7528 |
| Sargan test (p-value) | 0.0552 | 0.8687 | 1.0000 |
| Hansen test ($\chi^2$) | 24.8530 | 27.2740 | 32.7888 |
| Hansen test (p-value) | 0.3042 | 0.5569 | 0.2436 |
| Extracted principal components from GMM-style instruments | 28 | 37 | 36 |
| Portion of variance explained by the components | 0.7536 | 0.7720 | 0.7444 |
| Kaiser-Meyer-Olkin measure of sampling adequacy | 0.8148 | 0.8096 | 0.8122 |

*Notes*: Significance levels: *p < 0.1, **p < 0.05, ***p < 0.01. Standard errors in parentheses. Dependent variables are in computed as the first differences of each series (transformed in natural logarithms). The same transformation is applied for per capita GDP, population density and the crop production index. Energy legislation variables, climate change awareness (proxied by means of Google Trend data and lagged for five years) and the access to clean fuels and technologies for cooking are in levels (transformed in natural logarithms, with the exception of energy legislation variables). The electricity net imports are used in first differences. Time dummies related to the years 2009, 2010, 2011, 2012, 2016, 2019 and 2020 are included. A dummy for high-income countries is included in all the estimates. Following Cao et al. (2024) and Zhang et al. (2025b), a dummy for China is included in Column 1. The instruments are used by the first-difference and level equations when renewable and wind energies are considered; only by the level equation when solar energy is analyzed.

Coefficient $\beta_0$ is highly statistically significant with the exception of Column 3 in Table 1, meaning that investments in each energy source in the previous year are a determinant of current investments. This justifies the use of a dynamic estimator to compute Equation (1). Specifically, this parameter is positive when investments in renewable and solar energies are analyzed,[20] and is negative when investments in wind energy are considered. With regard to renewable energy, these results are in line with Hassan et al. (2024) when testing the effect of environmental policy on renewable energy consumption. However, they are novel in the context of solar and wind energy, as, to our knowledge, no empirical studies to date have employed a dynamic panel approach in these fields.

A preliminary examination of Coefficient $\beta_1$ shows that it is always negative and statistically different from zero. Under our assumptions, this coefficient only measures a part of the marginal effect shown in Eq. (2), whereas the whole effect also depends on Coefficient $\beta_2$ and on the level of climate change awareness. Coherently with this, a negative and significant value for Coefficient $\beta_1$ only indicates that, for null or very low levels of climate change awareness, energy initiatives are ineffective or even counter-productive. A similar analysis applies when climate change awareness is examined in isolation (Coefficient $\beta_3$).[21]

With regard to the other control variables, when the signs of the estimated parameters are statistically significant, they are mainly in line with the literature reviewed in Section 4.4.

Diagnostic statistics are provided at the bottom of Tables 1 and 2. Specifically, the number of instruments considered is always lower than the number of cross-sections, with the exception of the estimates reported in the first column of Table 1, where it is close to the number of countries included in the analysis.[22] Then, the Arellano-Bond test for first-order autocorrelation rejects (as expected) the null hypothesis at the conventional significance 5 percent level in most cases, with the exception of Column 3 in Table 1 and Column 1 in Table 2. At the same time, the Arellano-Bond test for second-order autocorrelation does not reject (as expected) the null hypothesis at the conventional significance levels in all the estimates considered. The absence of second-order autocorrelation suggests that our results should be unbiased for the presence of omitted variables correlated over time.

The Sargan test assesses the exogeneity of the instruments, while the Hansen $J$ statistic tests whether instruments are valid. These two conditions are always satisfied with a significance level of 5 percent, thus suggesting that there is a low probability of omitted variables in our estimates. Lastly, the Kaiser-Meyer-Olkin measure of sampling adequacy[23] and the number of extracted principal components from GMM-style instruments are provided, together with the portion of variance explained by the components, which is higher than 73 percent.

Finally, different robustness analyzes, performed in order to check our results, are reported in the Appendix C. Specifically, Tables C.1 and C.2 provide alternative estimates of Eq. (1) when climate change awareness is lagged for three years, instead of the five-year lag used in Tables 1 and 2. Regarding investments in renewable energies, an additional robustness check has been performed by withdrawing investment in geothermal power (Table C.3). In this analysis, estimates are proposed both when climate change awareness is alternatively lagged for three and five years. Additionally, we re-estimate Equation (1) using as instruments all available lags of the endogenous variables starting from the second. Results are reported in Tables C.4 and C.5. All these robustness analyses strongly confirm the results related to renewable and solar energies shown in Tables 1 and 2. They also indicate that these estimates are not affected by problems due to endogeneity and omitted variables.[24] Less clear conclusions are instead observed, as discussed in detail in the next subsection, for wind energy.

### 5.2. Testing hypotheses

This subsection discusses the results of our tests on the research hypotheses introduced in Section 3. Hypotheses 1 and 3 assess the influence of climate change awareness on the marginal effect of market-based energy policies and energy legislation respectively, and hypothesize that a higher level of climate change awareness implies a larger effect. This can be directly tested by examining the sign and the significance of Coefficient $\beta_2$.

Specifically, Coefficient $\beta_2$ is positive and significant in all regressions shown in Table 1. This means that the marginal effect of market-based energy policies is increasing in climate change awareness, supporting Hypothesis 1. Similar findings are observed for energy legislation, as reported in Table 2, supporting Hypothesis 3. These conclusions hold for all three types of investments examined.

The validity of Hypotheses 1 and 3 considered together generally shows the existence of a clear positive effect of climate change awareness on the effectiveness of both market-based energy policies and energy legislation.

Hypotheses 2 and 4 respectively state that energy policy and energy legislation are ineffective or even counterproductive for low levels of climate change awareness, and effective for high levels. They are tested by examining Equation (2) and studying its 95 percent confidence interval. This analysis is provided in Fig. 6 for market-based energy policies and in Fig. 7 for energy legislation.

Note that each figure includes three diagrams, referring to renewable energy, solar energy and wind energy (Panels a, b and c, respectively). In each diagram, the estimates of Eq. (2) are drawn with a solid line, ranging from the lowest to the highest value of climate change awareness in our dataset (−0.18 and 4.31, respectively). The 95 percent confidence interval is included in the two dotted lines. When all lines are below zero, the marginal effect is negative, suggesting that energy initiatives may be counterproductive. When the zero line lies within the confidence interval, the direction of the marginal effect is ambiguous, which implies that the initiatives may be ineffective. Lastly, when all lines are above zero, the marginal effect is positive and energy initiatives are effective.

With reference to market-based energy policies (Panel a of Fig. 6), renewable energy policies are potentially ineffective for levels of climate change awareness below 3.64, and effective for values higher than this threshold. In Panel (b) of Fig. 6, solar energy policies are counterproductive when climate change awareness is lower than 2.38, have ambiguous effects for values between 2.38 and 3.16, and are effective when climate change awareness is higher than 3.16. Both diagrams confirm Hypothesis 2. On the other hand, with reference to wind energy policies (Panel c of Fig. 6), the direction of the marginal effect is ambiguous for any value of climate change awareness. In this case, Hypothesis 2 cannot be confirmed. The robustness analysis shown in Table C.1 and Fig. C.1 confirms that Hypothesis 2 holds for market-based renewable and solar energy policies.

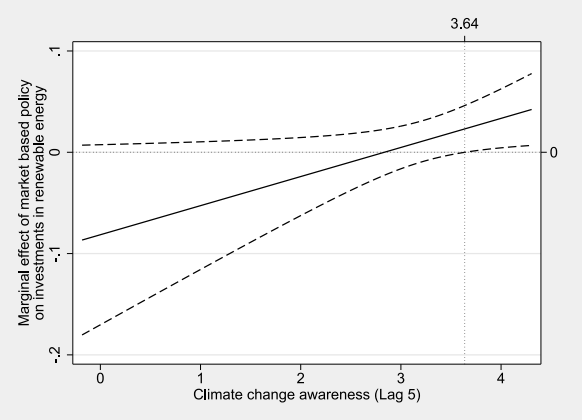
[20] The only exception is constituted by Column 1 in Table 2.

[21] This coefficient is significant and negative in Table 1 (market-based energy policies) for wind energy and significant and positive in Table 2 (energy legislation) for renewable and solar energy.

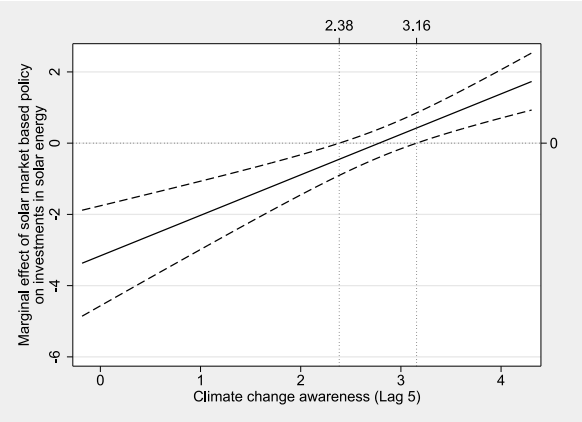
[22] See Appendix B.2 of Appendix B.

[23] It varies from 0 to 1; low values indicate that overall the variables have too little in common to warrant a principal component analysis. This is not the case in our estimates.

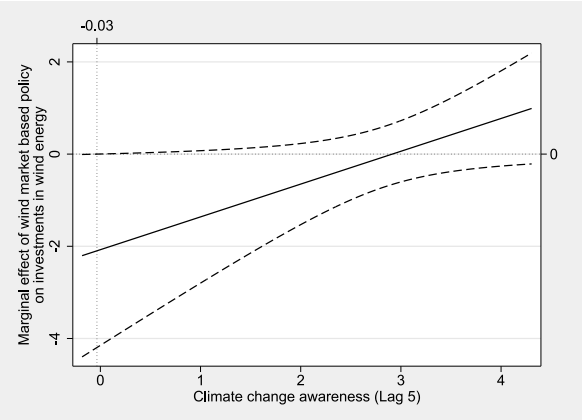
[24] To check for multicollinearity, the correlation matrix of the explanatory variables in Eq. (1) is computed. The correlation coefficients range from −0.1804 to 0.4087. These very low values suggest the absence of multicollinearity. Moreover, alternative computations of the estimates provided in this section are obtained by means of the panel OLS estimator with the inclusion of the dummies reported in Appendix B.2 in Appendix B. They are used to calculate the Variance Inflation Factors (VIFs) for each independent variable. In each regression, the arithmetic average of all the VIFs is always less than 2. These results further confirm the absence of multicollinearity and are available upon request to the authors.




**(a)** Renewable energy

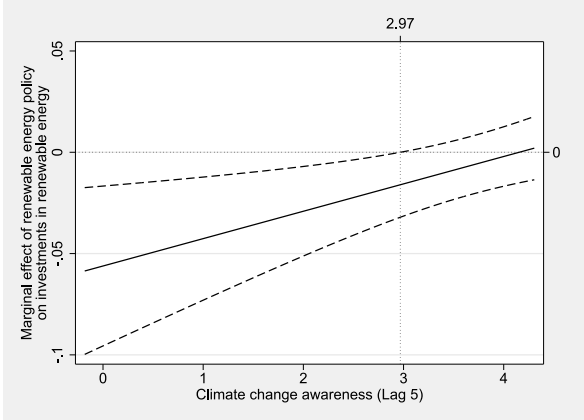



**(b)** Solar energy

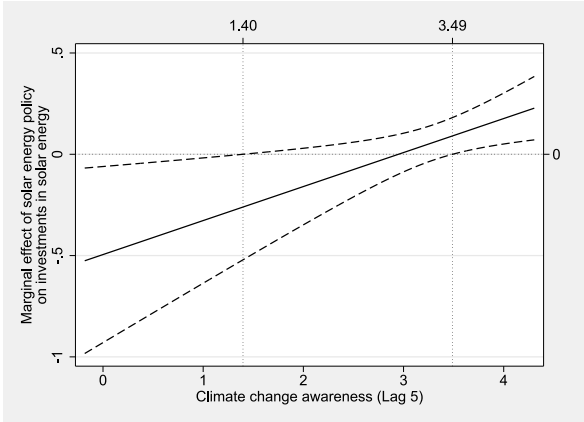



**(c)** Wind energy

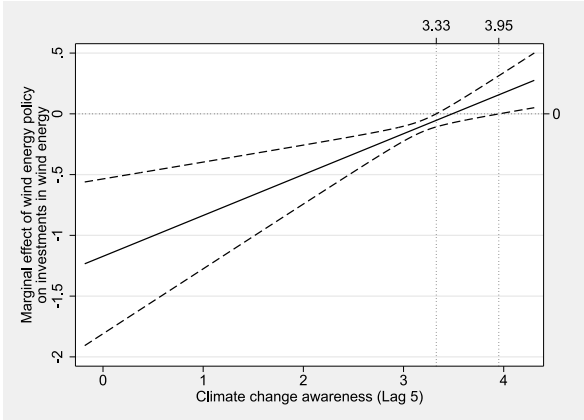
**Fig. 6.** Marginal effects of market-based energy policies for different levels of climate change awareness.
*Notes*: The solid line represents the estimates of the function in Eq. (2), while the two dotted lines correspond to the upper and lower bounds of the 95 percent confidence interval. These estimates are computed starting from the results reported in Table 1.




**(a)** Renewable energy




**(b)** Solar energy




**(c)** Wind energy

**Fig. 7.** Marginal effects of energy legislation for different levels of climate change awareness.
*Notes*: The solid line represents the estimates of the function in Eq. (2), while the two dotted lines correspond to the upper and lower bounds of the 95 percent confidence interval. These estimates are computed starting from the results reported in Table 2.

With regard to energy legislation, the findings are less clear. The diagrams in Fig. 7 suggest that Hypothesis 4 is not confirmed for renewable energy (Panel a). Hypothesis 4 instead holds when solar and wind energy are considered (Panels b and c, respectively). However, the robustness analysis in Appendix C (Table C.2 and Fig. C.2) only confirms this conclusion for solar energy.

## 6. Discussion

Our findings show that, when market-based energy policies are considered, high levels of climate change awareness are key to the effectiveness of renewable and solar energy policies. This conclusion always holds for Hypotheses 1 and 2 and is widely confirmed also for Hypothesis 3 and, for solar energy, for Hypothesis 4.

The conclusions are less clear in the case of wind energy for which there is substantial support for Hypotheses 1 and 2 but not for Hypotheses 3 and 4. One possible explanation is that the adoption of wind energy faces a variety of technical, economic, financial, institutional, and social barriers (Diógenes et al., 2020).[25] Most importantly, a very significant barrier for wind energy is the frequent opposition to wind farms by the population living in the area where the farm should be located and by some environmental associations, which is usually motivated by the alleged impact of wind energy plants on landscape and biodiversity and by their high land use (Langer et al., 2018; Stokes et al., 2023). This motivation is particularly important for our results. In fact, if there are opinions against the adoption of wind energy among green activists, it is clear that there exist groups of people who are aware of climate change but contrast investments in wind energy. This implies, in turn, that the positive linkage between climate change awareness and wind energy capacity may not exist or at least be largely weaker than for the other types of sustainable energies analyzed.

When Hypothesis 3 is satisfied, specific values for climate change awareness clearly distinguish cases in which a market-based energy policy is effective and cases in which it is ineffective or even counterproductive. Specifically, market-based renewable energy policies are effective when climate change awareness is higher than 3.64. Fig. 8 shows that, in 2022,[26] this occurs only in a small group of advanced economies (in purple): Italy (3.91), France (3.81), Switzerland (3.69), Portugal (3.69), Germany (3.66) and Israel (3.66). In contrast, renewable policies may be not effective in the remaining economies (in orange).

With reference to market-based solar energy policies, Fig. 9 indicates where these policies are effective (purple), potentially not effective (orange) and counterproductive (light green). The countries in purple show a level of climate change awareness higher than 3.16. This is the case of western European countries, Japan, Israel and the United Arab Emirates, as well as Argentina, China, Columbia, Mexico, and Turkey among developing economies.

Market-based solar energy policy is, on the other hand, potentially not effective when the level of climate change awareness is not sufficiently high, i.e., when its values range from 2.38. to 3.16. This is, for example, the case of Malaysia (2.89), the United States (2.83) and India (2.71). Lastly, this type of intervention is counterproductive in Australia (2.20), in some Eastern European countries, in some Latin American and Asian countries.

With reference to solar energy legislation, our results indicate that it is effective with climate change awareness higher than 3.49. When climate change awareness is instead lower than 1.40, solar energy legislation negatively affects investments in solar energy. Fig. 10 indicates that solar energy legislation encourages investments in solar energy in 12 countries in 2022: Italy (3.91), France (3.81), Switzerland (3.69), Portugal (3.69), Germany (3.66), Israel (3.66), China (3.64), Belgium (3.61), Japan (3.58), Ireland (3.50), and the Netherlands (3.50). In contrast, in a small number of countries, this type of initiative has negative effects: Estonia (1.39), Iceland (1.39), Slovakia (1.39), and Bolivia (0.70).

Overall, these results show that the performance of energy initiatives varies between countries. In particular, the impact of energy initiatives is not significant or even counterproductive in many countries. This finding is in line with those of Aguirre and Ibikunle (2014), Romano et al. (2017) and Zheng et al. (2023), and implies that energy initiatives may have detrimental effects on investments in sustainable energies. Similar evidences are reported for the United States by Delmas and Montes-Sancho (2011) and Shrimali and Kniefel (2011) and for Australia by Ming et al. (2024).

In this respect, our results contribute to explaining the puzzling evidence reported in the previous literature. In fact, we find that one possible reason for policy failure in some countries is the low level of climate change awareness. This has a clear implication for policy. Since energy initiatives will be effective only when a certain threshold level of awareness is reached, it is necessary to improve the communication and dissemination of scientific results on the impact of climate change before these initiatives are implemented.

In order to shed more light on this issue, a more explicit examination of the role of climate change awareness in investments in sustainable energies can be provided. More formally, starting from Eq. (1), the marginal effect of climate change awareness on investments in sustainable energies is the following:

$$\frac{dY_{it}}{dZ_{it-j}} = \beta_3 + \beta_2 X_{it} \tag{3}$$

This effect is positive when the right-hand side of Eq. (3) is positive, i.e., when the following condition holds:

$$\beta_3 + \beta_2 X_{it} > 0 \tag{4}$$

Moreover, actions that increase climate change awareness may be even more effective than energy initiatives when the right-hand side of Eq. (3) is greater than the right-hand side of Eq. (2), i.e. when

$$\beta_3 - \beta_1 + \beta_2 (X_{it} - Z_{it-j}) > 0. \tag{5}$$

If $\beta_2 > 0$, this occurs when the level of energy initiatives is high and climate change awareness is low.[27]

Wald tests can be used to assess Inequalities (4) and (5). Results in Table 3 show that the effect of increasing climate change awareness on investments in sustainable energies is potentially stronger than the effect of new initiatives in energy legislation. The same evidence, however, is not found for market-based energy policies.[28] As the value of the right-hand side of (3) depends on the level of variable $X$, this may be due to the fact that the average value of market-based energy policies is too low. This last reasoning highlights one of the key conclusions of our work: the size of investments in sustainable energies depends on the interaction between the adoption of energy initiatives and the level of awareness.

In this respect, our analysis allows us to quantify the potential positive effect of an increase in climate change awareness on the effectiveness of energy initiatives. First, consider that the quantity in Eq. (3) is the elasticity of investments in sustainable energies with respect

[25] These barriers potentially exist also for other types of sustainable energies but they tend to be stronger for wind energy (Eleftheriadis and Anagnostopoulou, 2015; Oryani et al., 2021).

[26] This is the last year of our dataset.

[27] Specifically, this holds when $X_{it} - Z_{it-j}$ is higher than $\frac{\beta_1 - \beta_3}{\beta_2}$.

[28] It is worth noting that we evaluate the marginal effect of environmental awareness at the average level of market-based energy policies across countries. Unreported results indicate that small positive effects are observed also at the 75th percentile and at the maximum level of market-based energy policies. For the sake of brevity, these calculations are omitted.

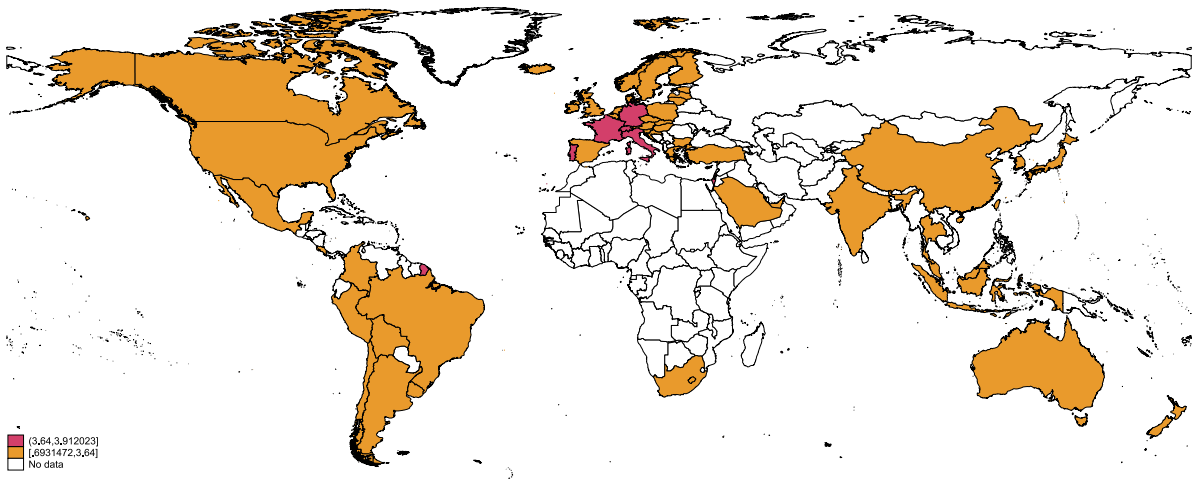



**Fig. 8.** The effectiveness of market-based renewable energy policies according to climate change awareness level in 2022.
*Notes:* Author's elaborations on data retrieved from International Renewable Energy Agency (IRENA) and Google Trend. Market-based renewable energy policies effective in purple. Market-based renewable energy policies potentially not effective in orange. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

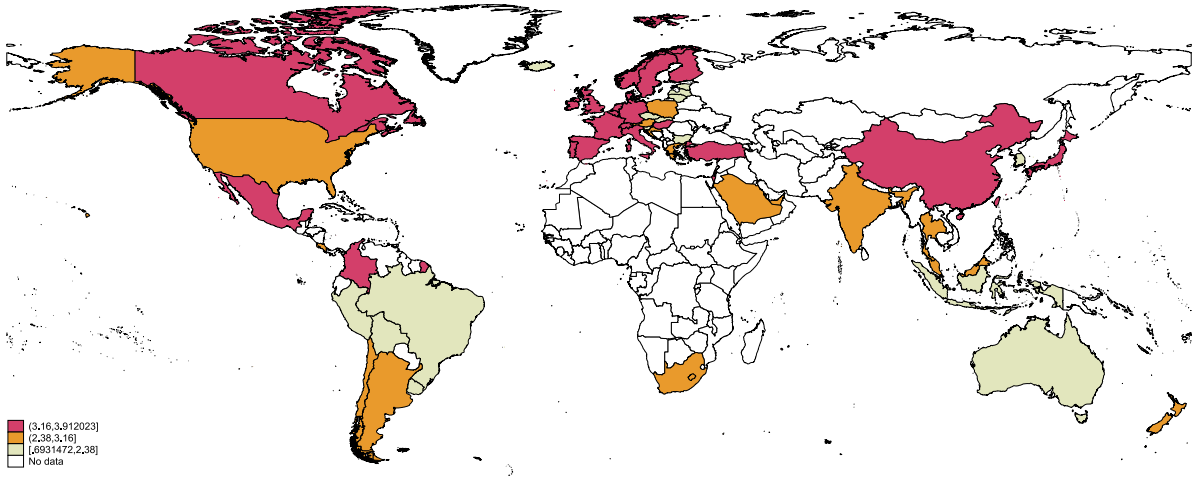



**Fig. 9.** The effectiveness of market-based solar energy policies according to climate change awareness level in 2022.
*Notes:* Authors' elaborations on data retrieved from International Renewable Energy Agency and Google Trend. Solar market-based energy policies are effective (purple), potentially not effective (orange) and counterproductive (light green). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

**Table 3**
Testing inequalities (4) and (5).

| | Inequality (4) | Inequality (5) |
|---|---|---|
| Market-based renewable energy policies | 0.0161 | 0.0145 |
| | (0.0118) | (0.0166) |
| Market-based solar energy policies | 0.0988 | 0.0403 |
| | (0.0612) | (0.2366) |
| Market-based wind energy policies | −0.0415 | 0.0236 |
| | (0.0450) | (0.3417) |
| Renewable energy legislation | 0.0247*** | 0.0427*** |
| | (0.0074) | (0.0134) |
| Solar energy legislation | 0.0821*** | 0.1080** |
| | (0.0165) | (0.0540) |
| Wind energy legislation | 0.0628*** | 0.2948*** |
| | (0.0215) | (0.0508) |

*Notes*: Significance levels: *p < 0.1, **p < 0.05, ***p < 0.01. Standard errors in parentheses. Inequalities (4) and (5) are tested starting from the estimates of Coefficients $\beta_1$, $\beta_2$ and $\beta_3$ shown in Tables 1 and 2. Average values of climate change awareness and of the energy initiatives are employed.

to the level of climate change awareness.[29] Assume now to introduce a new energy initiative. In this context, an increase of 1 percent in the level of awareness generates a percentage increase in investment in sustainable energies equal to the value of the Coefficient $\beta_2$.

According to the estimates in Tables 1 and 2, this implies that an increase in 1 percent in climate change awareness generates an impact on the effectiveness of a new energy initiative ranging from a minimum of 0.0135 percent (the increase in the effectiveness of energy legislation on investments in renewable energies) to a maximum of 1.1368 percent (the increase in the effectiveness of market-based energy policies on investments in solar energy). In general, the impact on effectiveness of all types of new energy initiatives on investments in renewable energy is smaller, whereas a stronger impact is obtained for the effectiveness on specific types of energy, i.e. solar and wind energies.

Lastly, it is must be emphasized that the effects described are cross-effects, in the sense that we are examining a scenario in which a new

[29] Since both variables $Y$ and $Z$ are expressed in logarithm, Eq. (3) is a logarithmic derivative.

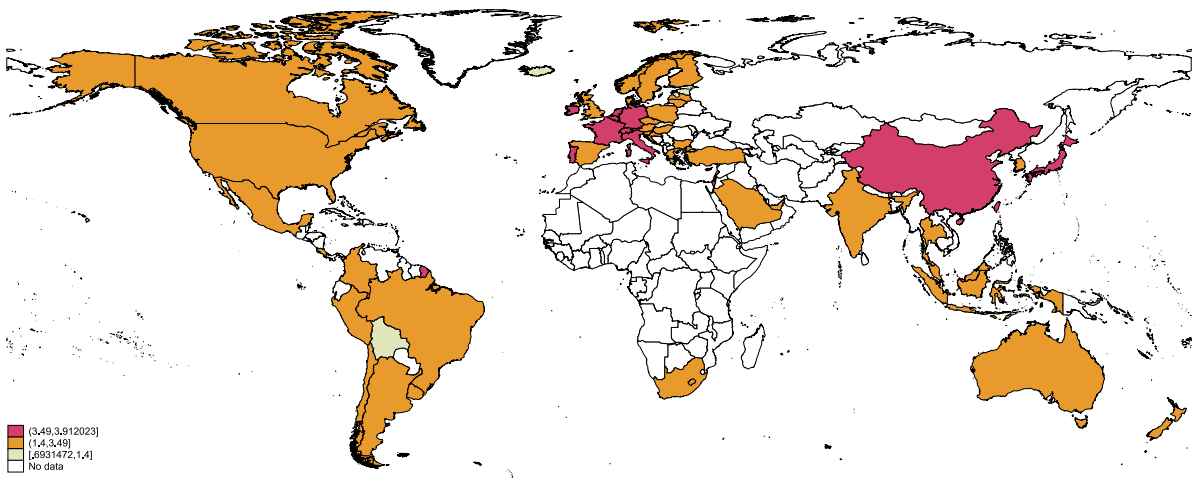



**Fig. 10.** The effectiveness of solar energy legislation according to climate change awareness level in 2022.
*Notes:* Authors' elaborations on data retrieved from International Renewable Energy Agency and Google Trend. Solar energy legislation is effective (purple), potentially not effective (orange) and counterproductive (light green). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

energy initiative is introduced contemporaneously with a 1 percent increase in climate change awareness. More generally, the fact that $\beta_2$ is positive implies that the effects of awareness and energy initiatives reinforce each other.[30] Thus, an efficient strategy should act on both these dimensions contemporaneously.

## 7. Conclusions and policy implications

The transition from fossil to clean energy sources is crucial in fighting climate change, and various actions are currently being taken to accelerate it. The empirical analysis presented in this paper studies how the marginal effects of two distinct types of energy initiatives acting in this direction are affected by the level of climate change awareness.

Empirical evidence indicates that greater climate change awareness increases the effectiveness of market-based energy policies and energy legislation. This conclusion holds for renewable, solar and wind energies and it is robust to the use of different lags of the level of climate change awareness, as well as to additional alternative specifications.

However, some differences emerge according to the type of energy initiatives when more complex effects of climate change awareness are tested. In fact, in the case of market-based energy policies, our empirical evidence shows that renewable and solar policies are potentially ineffective and even counterproductive for low levels of awareness and effective for high levels. These conclusions hold, in the case of energy legislation, only for solar energy.

These findings also provide a possible explanation for the puzzling evidence on the null or even negative effect of energy initiatives on investments in sustainable energies often found in the literature.

Moreover, our results have important implications for policymakers and investors. Cross-country policy coordination and cooperation are necessary to enhance knowledge and, hence, awareness of climate change. This is especially important given our findings on the number of countries having a sufficiently high level of awareness to ensure policy effectiveness, because in the most recent years considered in our analysis, this group of countries is small. Thus, strong efforts are urgently needed to increase awareness of climate change to prevent energy initiatives from being ineffective in many economies.

Our results also show that policymakers should take into account the fact that the impact of climate change awareness on the effectiveness of energy initiatives varies according to the type of energy source. This could also have important repercussions not only in terms of the type of policy intervention that is most appropriate, but also in terms of the timing and sequence of these interventions.

More specifically, we emphasize that our estimates indicate that the most important impact of climate change awareness is on the effectiveness of market-based solar energy policies. However, more generally, our results indicate a kind of complementarity between policies stimulating the energy transition and policies enhancing climate change awareness which should thus be developed together.

In this respect, our findings suggest not only that increasing climate change awareness makes energy initiatives more productive, but also that it is often a preliminary condition for their effectiveness. It is thus important that policy interventions towards the transition to sustainable energy are accompanied (or even preceded) by energy conservation education, targeted advertising and publicity campaigns, as well as a rapid and accurate dissemination of scientific findings on climate change.

Our results also complement those of Charfeddine and Rahman (2025), who show that the perception of policy effectiveness strongly predicts people's support for a policy. Policymakers aiming to foster the transition to sustainable energy should carefully choose the timing of energy initiatives to avoid being caught in self-reinforcing cycles of low environmental awareness and weak policy effectiveness.

To conclude, we examine the possible limitations of the present work which also open space for new future research lines.

First, our paper separately considers market-based energy policy and energy legislation, distinguishing the interventions according to the type of energy involved. Although this classification is, in our opinion, exhaustive, availability of more disaggregated data would allow us to further refine it. Similarly, a different refinement could be possible if data on financial resources allocated to policies (instead of the number of them) were available. Finally, based on recent evidence that monetary policy affects investments in sustainable energies (Chen and Lin, 2024; Akan, 2024), a further development could be the study of the effect of awareness on this linkage.

Second, an additional issue is how measuring climate change awareness. Google Trend Data used in the present work is an appropriate proxy for this purpose. However, other proxies may be used to capture

[30] In a sense, these results also complements those by Charfeddine and Rahman (2025). In fact, Charfeddine and Rahman (2025) show that energy policies are effective only beyond a certain threshold. Our results show that an increase in the number of policies is effective only if there is a sufficient level of climate change awareness and that an increase in climate change awareness is effective only if there is a sufficient number of policies.

other psychological aspects of awareness or the level of awareness of specific groups of people. An example in this regard is media and social media sentiment on climate change problems (Ye et al., 2024; Rogmann et al., 2024).

Lastly, a recent literature emphasized the role of spatial spillovers in the investments in sustainable energies (Pronti and Zoboli, 2024; García-Riazuelo et al., 2025) and the effect of cross-border energy policies (Bergantino et al., 2025). All these aspects are neglected in our analysis, mainly because our data are at the country level. Spatial spillovers can, however, represent the basis for interesting future research lines if more geographically disaggregated data became available.

## CRediT authorship contribution statement

**Donatella Baiardi:** Writing – original draft, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Enrico Cristofoletti:** Writing – original draft, Software, Investigation, Data curation. **Mario Menegatti:** Writing – original draft, Methodology, Investigation, Formal analysis, Conceptualization.

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## Appendix A. Data description

### A.1. Data information

This subsection provides information about the stage of development of the countries analyzed (Table A.1) and the sources of the variables used in the empirical estimates (Table A.2 and Appendix A.2).

### A.2. Climate change awareness - technical details

In line with Siliverstovs and Wochner (2018), data are defined as follows: be $n(q,l,t)$ the absolute number of Google searches for query $q \in Q(l,t)$ in a given location $l \in \{1,\dots,L\}$ at time $t \in \{1,\dots,T\}$. The query popularity is defined as:

$$RP(q,l,t) = \frac{n(q,l,t)}{\sum_{q \in Q(l,t)} n(q,l,t)} \cdot \mathbf{I}_{n(q,l,t)>\pi}$$

where $\mathbf{I}_{n(q,l,t)>\pi}$ is an indicator function equal to 1 when the number of searches is above a certain threshold $\pi$.[31] Google SVI is then computed as the normalized value:

$$SVI(q,l,t) = \frac{RP(q,l,t)}{max(RP(q,l,t)_{t\in 1,\dots,T})} \cdot 100$$

The derived index is rounded to integer which ranges from 0 (i.e., the period with the lowest popularity) to 100 (i.e., the period with the highest popularity). When $RP(q,l,t)$ is less than 1/100th of the period with the highest popularity, the record appears as '< 1' (Cebrián and Domenech, 2023). This occurs in the case of Indonesia in the month of June, 2018, where a value equal to 0.05 is ascribed instead of the observation reporting '< 1'.

[31] The threshold $\pi$ is set by Google and it is unknown (Bleher and Dimpfl, 2022).

## Appendix B. Estimation strategy - Additional details

This appendix provides additional information on the strategy used to estimate Eq. (1). Appendix B.1 presents the panel unit roots tests, whose results are at the basis of data transformations. Appendix B.2 reports the country and time fixed effects included in the estimates, while Appendix B.3 discusses the specific sources of endogeneity of the explanatory variables.

### B.1. Panel unit root tests

Table B.1 shows Fisher-type Augmented Dickey–Fuller and Breitung unit root tests for panel data (for further details see Baltagi, 2008, chap. 12). Regarding the Fisher-type Augmented Dickey–Fuller panel unit root test, the inverse normal Z statistic results are reported, because it has the best trade-off between size and power according to Choi's simulations (Choi, 2001).

In all tests, not rejecting the null hypothesis implies that the panels contain unit roots. The two tests are performed with the inclusion of panel-specific means. They are computed twice, by considering variables in levels and in their first differences (indicated with the expression 'D.').

Table B.1 shows that the three dependent variables are integrated of order 1, while climate change awareness and all the policy variables are integrated of order 0. With reference to the remaining control variables, per capita GDP, the crop production index and electricity net imports are integrated of order 1, while the access to electricity is integrated of order 0. Population density is the only variable for which results are mixed. Given that the Fisher-type Augmented Dickey–Fuller panel unit root test provides strong evidence in favor of an order of integration equal to 1, while the evidence of the Breitung test is mild, we decide to treat this series as not stationary in levels.

### B.2. Country and time fixed effects

This subsection provides additional information on the country and time fixed effects included in the estimation of Eq. (1).

With regard to country fixed effects, a dummy for the high-income economies of the sample is included in all estimates (Table A.1). This is in line with the Environmental Kuznets Curve literature, which underlines that these countries are the most aware of environmental problems (Dinda, 2004; Leiserowitz et al., 2017; Baiardi, 2023).

At the same time, when renewable energy legislation is considered, a dummy for China is also included. As noted in Cao et al. (2024) and Zhang et al. (2025b), the time period 2004–2021 represents a pivotal phase in China's *legal and institutional efforts* to promote green growth and fight climate change.

With regard to time fixed effects, instead, a set of time dummies has been selected not only on the base of their statistical significance but also on the presence of relevant energy-related or economic events. Based on these criteria, the selected years are:

- 2009, capturing the effects of the global financial and economic crisis;
- 2010, 2011, and 2012, capturing the initial stages of the global transition towards a cleaner energy era. Specifically, IEA (2013, p. 60) reports that '*From 2000 to 2010, the amount of energy used to produce a unit of gross domestic product (GDP) decreased by 0. 4% per year on average. However, there has been a significant improvement since 2010 and, in 2012, the amount of energy used to produce a unit of GDP declined by 1.5%*'. Lastly, IEA (2024c, p. 135) also highlights that: '*Fossil fuels met just under 80% of global energy demand in 2023, a share that has fallen very gradually since 2011, when it stood at 83%*', and on page 53, it indicates the 2010s as a '*potential golden age for gas*', which is a cleaner energy resource than coal and oil, which were predominant in the last century;

**Table A.1**
Sample countries and their stage of development.

| Country | Income level |
|---|---|
| Argentina | Lower middle income/Upper middle income |
| Australia | High income |
| Austria | High income |
| Belgium | High income |
| Bolivia (Plurinational State of) | Lower middle income/Upper middle income |
| Brazil | Lower middle income/Upper middle income |
| Bulgaria | Lower middle income/Upper middle income |
| Canada | High income |
| Chile | High income |
| China | Lower middle income/Upper middle income |
| Colombia | Lower middle income/Upper middle income |
| Costa Rica | Lower middle income/Upper middle income |
| Croatia | High income |
| Czechia | High income |
| Denmark | High income |
| Estonia | High income |
| Finland | High income |
| France | High income |
| Germany | High income |
| Greece | High income |
| Hungary | High income |
| Iceland | High income |
| India | Lower middle income/Upper middle income |
| Indonesia | Lower middle income/Upper middle income |
| Ireland | High income |
| Israel | High income |
| Italy | High income |
| Japan | High income |
| Korea (the Republic of) | High income |
| Latvia | High income |
| Lithuania | High income |
| Luxembourg | High income |
| Malaysia | Lower middle income/Upper middle income |
| Mexico | Lower middle income/Upper middle income |
| Netherlands (the) | High income |
| New Zealand | High income |
| Norway | High income |
| Peru | Lower middle income/Upper middle income |
| Poland | High income |
| Portugal | High income |
| Saudi Arabia | High income |
| Slovakia | High income |
| Slovenia | High income |
| South Africa | Lower middle income/Upper middle income |
| Spain | High income |
| Sweden | High income |
| Switzerland | High income |
| Thailand | Lower middle income/Upper middle income |
| Turkey | Lower middle income/Upper middle income |
| United Arab Emirates (the) | High income |
| United Kingdom of Great Britain and Northern Ireland (the) | High income |
| United States of America (the) | High income |
| Uruguay | High income |

*Notes*: Authors' elaborations on World Bank data (2024 Edition).

- 2016, capturing the adoption of the Paris Agreement, which marked a turning point in international efforts to address climate change;
- 2019, capturing the adoption of the European Green Deal, which consists of a package of policy initiatives, with the ultimate goal of reaching climate neutrality by 2050 in the European countries. It is also a pivotal year for the energy transition in the electricity sector. In fact, as highlighted by the IEA (2024c, p. 132), '*Total power sector investment averaged over USD 1 trillion per year from 2019 to 2023 – including to build or refurbish all types of power plants, to expand and refurbish electricity grids and to deploy energy storage – and overtook investment in fossil fuel supply in 2020*';
- 2020, capturing the effects of the COVID-19 pandemic and related economic crisis.

The case of market-based renewable energy policies (Tables 1 and C.1, Column 1) requires particular attention, as the number of cross-sectional units (i.e., countries) is only 31. Thus, the reduced set of instruments selected above remains too large, and their inclusion would violate the rule of thumb that the number of instruments should be lower than the number of cross-sectional units (Roodman, 2009). On the one hand, if we applied this rule too strictly, only the inclusion of a single-time dummy would ensure that this constraint is satisfied. On the other hand, the inclusion of a single time dummy may not be, in turn, an efficient choice '*to remove universal time-related shocks from the errors*' (Roodman, 2009, p.121).

In an effort to partially address these recommendations, the estimates have been calculated by selecting a subset of time dummies from those previously identified, to reasonably control the potential contemporaneous correlation. These dummies are for the years 2010, 2012 and 2016.

**Table A.2**
Variables, description and data sources.

| | Description | Source |
|---|---|---|
| Dependent variables | | |
| Investments in renewable energies | Installed Renewable Electricity capacity; Renewable energy; (MW) | IRENA (2023): https://pxweb.irena.org/pxweb/en/IRENASTAT |
| Investments in solar energies | Installed Renewable Electricity capacity; Solar; (MW) | IRENA (2023): https://pxweb.irena.org/pxweb/en/IRENASTAT |
| Investments in wind energies | Installed Renewable Electricity capacity; Wind; (MW) | IRENA (2023): https://pxweb.irena.org/pxweb/en/IRENASTAT |
| Market-based energy policies | | |
| Renewable energy policy | Policy: market-based instruments | OECD: https://stats.oecd.org/Index.aspx?DataSetCode=EPS |
| Solar energy policy | Solar energy support : Auctions and FITs | OECD: https://stats.oecd.org/Index.aspx?DataSetCode=EPS |
| Wind energy policy | Wind energy support : Auctions and FITs | OECD: https://stats.oecd.org/Index.aspx?DataSetCode=EPS |
| Energy legislation | | |
| Renewable energy legislation | Number of policies retrieved making the following query: "Renewable" | Climate policy database: https://climatepolicydatabase.org/ |
| Solar energy legislation | Number of policies retrieved making the following query: "Solar" | Climate policy database: https://climatepolicydatabase.org/ |
| Wind energy legislation | Number of policies retrieved making the following query: "Wind" | Climate policy database: https://climatepolicydatabase.org/ |
| Climate change awareness | | |
| Climate change awareness | Google SVI. topic: climate change (Code: 0d063v) | Google trends: https://trends.google.com/trends/ |
| Control variables | | |
| Per capita GDP | GDP per capita (current US$) | World Bank: https://data.worldbank.org/ |
| Population density | Population density (people per sq. km of land area) | World Bank: https://data.worldbank.org/ |
| Crop production index | Crop production index: agricultural production (all crops but fodder crops) for each year (measured in international dollars) relative to the base period 2014–2016 | World Bank: https://data.worldbank.org/ |
| Access to clean fuels and technologies for cooking | Access to clean fuels and technologies for cooking (% of population) | World Bank: https://data.worldbank.org/ |
| Electricity net imports | Net electricity import (billion kWh) | EIA : https://www.eia.gov/international/data/world |

**Table B.1**
Panel unit root tests.

| Variable | Fisher-type augmented Dickey–Fuller panel unit root test | | | | | Breitung panel unit root test | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Test | p-value | Time trend | Demean | Lags | Test | p-value | Time trend | Demean | Lags |
| Investments in renewable energies | 9.3409 | 1.0000 | 0 | 0 | 1 | 3.5808 | 0.9998 | 0 | 0 | 2 |
| D. Investments in renewable energies | −5.6295 | 0.0000*** | 0 | 0 | 1 | −4.0684 | 0.0000*** | 0 | 0 | 2 |
| Investments in solar energies | −1.4786 | 0.0696* | 0 | 0 | 1 | 2.5971 | 0.9953 | 0 | 0 | 2 |
| D. Investments in solar energies | −5.6305 | 0.0000*** | 0 | 0 | 1 | −1.9210 | 0.0274** | 0 | 0 | 2 |
| Investments in wind energies | 1.7851 | 0.9629 | 0 | 0 | 8 | 2.0604 | 0.9803 | 0 | 0 | 1 |
| D. Investments in wind energies | −7.5640 | 0.0000*** | 0 | 0 | 2 | −2.8110 | 0.0025*** | 0 | 0 | 1 |
| Market-based renewable energy policies | −2.6145 | 0.0045*** | 0 | 0 | 0 | −2.5925 | 0.0048*** | 0 | 0 | 6 |
| D. Market-based renewable energy policies | −14.7133 | 0.0000*** | 0 | 0 | 1 | −2.7124 | 0.0033*** | 0 | 0 | 6 |
| Market-based solar energy policies | −1.7301 | 0.0418** | 0 | 0 | 5 | −2.3992 | 0.0082*** | 0 | 0 | 1 |
| D. Market-based solar energy policies | −2.4100 | 0.0080*** | 0 | 0 | 5 | −3.7934 | 0.0001*** | 0 | 0 | 1 |
| Market-based wind energy policies | −4.8599 | 0.0000*** | 0 | 1 | 4 | −3.2550 | 0.0006*** | 0 | 0 | 1 |
| D. Market-based wind energy policies | −1.7339 | 0.0415** | 0 | 1 | 4 | −5.8295 | 0.0000*** | 0 | 0 | 1 |
| Renewable energy legislation | −11.8788 | 0.0000*** | 0 | 0 | 1 | −5.6826 | 0.0000*** | 0 | 0 | 1 |
| D. Renewable energy legislation | −19.7278 | 0.0000*** | 0 | 0 | 1 | −3.6094 | 0.0002*** | 0 | 0 | 1 |
| Solar energy legislation | −10.4528 | 0.0000*** | 0 | 0 | 1 | −15.7601 | 0.0000*** | 0 | 0 | 0 |
| D. Solar energy legislation | −35.0695 | 0.0000*** | 0 | 0 | 1 | −15.5246 | 0.0000*** | 0 | 0 | 0 |
| Wind energy legislation | −9.0851 | 0.0000*** | 0 | 0 | 1 | −13.2173 | 0.0000*** | 0 | 0 | 0 |
| D. Wind energy legislation | −36.0818 | 0.0000*** | 0 | 0 | 1 | −15.2422 | 0.0000*** | 0 | 0 | 0 |
| Climate change awareness | −1.9472 | 0.0258** | 0 | 0 | 1 | −6.0409 | 0.0000*** | 0 | 0 | 1 |
| D. Climate change awareness | −12.3852 | 0.0000*** | 0 | 0 | 1 | −5.6633 | 0.0000*** | 0 | 0 | 1 |
| Per capita GDP | 4.4297 | 1.0000 | 0 | 0 | 4 | 1.3394 | 0.9098 | 0 | 0 | 2 |
| D. Per capita GDP | −6.7689 | 0.0000*** | 0 | 0 | 2 | −2.6459 | 0.0041*** | 0 | 0 | 2 |
| Population density | 4.6720 | 1.0000 | 0 | 0 | 3 | −1.4630 | 0.0717* | 0 | 0 | 8 |
| D. Population density | −3.6223 | 0.0001*** | 0 | 0 | 1 | −2.8143 | 0.0024*** | 0 | 0 | 8 |
| Crop production index | 0.2769 | 0.6091 | 0 | 0 | 2 | 2.2157 | 0.9866 | 0 | 0 | 1 |
| D. Crop production index | −13.2291 | 0.0000*** | 0 | 0 | 2 | −9.8732 | 0.0000*** | 0 | 0 | 1 |
| Access to clean fuels and technologies for cooking | −18.4913 | 0.0000*** | 0 | 0 | 0 | −1.6465 | 0.0498** | 0 | 0 | 2 |
| D. Access to clean fuels and technologies for cooking | −1.9783 | 0.0239** | 0 | 0 | 0 | −1.4894 | 0.0682* | 0 | 0 | 9 |
| Electricity net imports | −0.9828 | 0.1628 | 0 | 0 | 2 | −0.1829 | 0.4275 | 0 | 0 | 2 |
| D. Electricity net imports | −9.7649 | 0.0000*** | 0 | 0 | 2 | −3.0085 | 0.0013*** | 0 | 0 | 2 |

*Notes*: Fisher-type Augmented Dickey–Fuller panel unit root test inverse normal Z statistic. 'D.' indicates first difference. Authors' elaboration. The expression 'D.' indicates that the variable has been transformed in first differences.

### B.3. Endogeneity

This subsection provides additional information on the specific sources of endogeneity for each explanatory variable in Eq. (1).

The two-step version of the system GMM estimator proposed by Blundell and Bond (1998) is based on the original equation in levels and its transformation in first differences (Roodman, 2009). By construction, the autoregressive term $Y_{t-1}$ correlates with the error term in the level and first difference equations.

The two types of energy initiatives (market-based energy policy and energy legislation) are designed to promote investments in sustainable energies and are therefore planned and implemented in response to the existing level of installed electricity capacity. As a result, the relationship between these variables may be subject to reverse causality. The same applies for the interaction term between each energy initiative and climate change awareness ($X_{it}Z_{it-j}$).

Per capita GDP growth and investment in sustainable energies are also subject to reverse causality, as the latter influence aggregate demand and, in turn, aggregate production. Moreover, simultaneity bias may arise due to the potential expansion of the energy infrastructure, which can positively affect productivity and energy security, and thus foster economic growth.

Higher population density may be influenced by the presence of sustainable energy plants, as they can affect electricity prices and, consequently, electricity demand. This, in turn, may stimulate further investments in sustainable energy and improve access to electricity and related infrastructure, potentially driving migration and urbanization patterns. In contrast, new investments in sustainable energy can alter the landscape, as in the case of wind farms, generating a disincentive to live in that area. For all these reasons, a problem of reverse causality may arise.

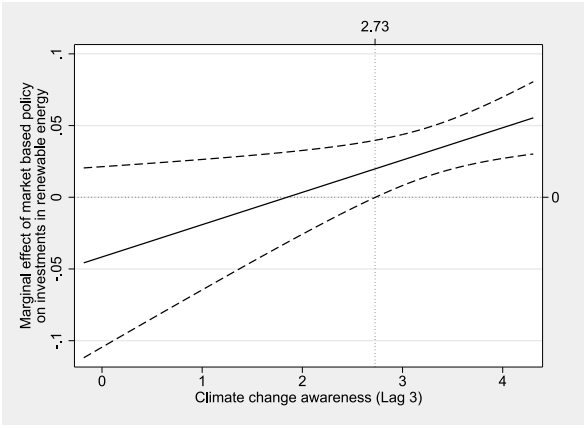
Agricultural activity is a driver of energy demand. Given the strong negative impact of agriculture on climate change, the connection between agricultural production (proxied by the crop production index) and energy demand also has relevant effects on investment decisions for cleaner energy sources. However, at the same time, the increased availability of cleaner electricity can support agricultural productivity through improved irrigation and the adoption of new techniques that require specialized knowledge and higher levels of awareness of climate change. This introduces the possibility of two-way causation.

Improved access to clean energy technologies for cooking may increase the demand for sustainable energies, increasing investments. However, access to these technologies strictly depends on prior infrastructure, which in turn is linked to energy investments. This implies a potential reverse causality issue.

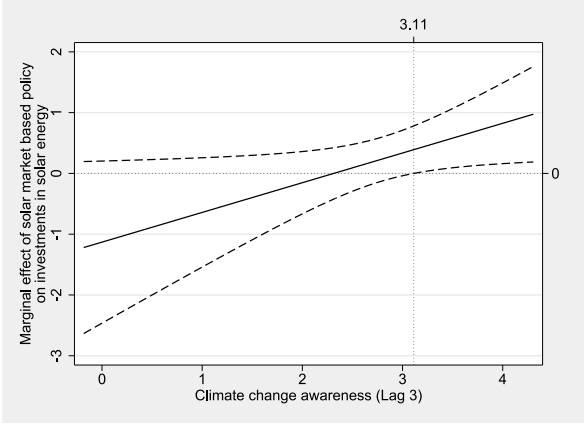
Net imports of electricity are necessarily influenced by domestic energy production. An increase in investments in sustainable energies may, in turn, affect this domestic production if it generates capacity additional to traditional energy sources, according to recent trends in energy transition patterns.

## Appendix C. Robustness analyses

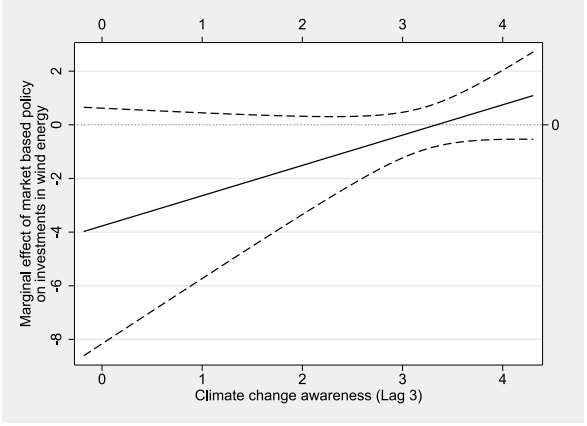
This appendix provides different robustness checks of our main results presented in Tables 1 and 2. Specifically, Tables C.1 and C.2 show alternative estimates of Eq. (1) when climate change awareness is lagged for three years, instead of the five-year delay used in Tables 1 and 2. An additional robustness check has been performed by removing geothermal power from investments in renewable energies (Table C.3). In this context, climate change awareness is lagged for three and five years. Furthermore, Tables C.4 and C.5 provide alternative estimates of Eq. (1) using as instruments all available lags of the endogenous variables starting from the second.




**(a)** Renewable energy




**(b)** Solar energy




**(c)** Wind energy

**Fig. C.1.** Marginal effects of market-based energy policies for different levels of climate change awareness.
*Notes*: The solid line represents the estimates of the function in Eq. (2), while the two dotted lines correspond to the upper and lower bounds of the 95 percent confidence interval. These estimates are computed starting from the results reported in Table C.1.

## Appendix D. Supplementary data

Supplementary material related to this article can be found online at https://doi.org/10.1016/j.eneco.2025.108912.

**Table C.1**
Estimates of Eq. (1) for market-based energy policies when climate change awareness is lagged for three years.

| | (1) Investments in renewable energies | (2) Investments in solar energies | (3) Investments in wind energies |
|---|---|---|---|
| *Coefficient* $\beta_0$ | | | |
| Investments in renewable energies (t−1) | 0.4774*** | – | – |
| | (0.1186) | | |
| Investments in solar energies (t−1) | – | 0.4769*** | – |
| | | (0.0451) | |
| Investments in wind energies (t−1) | – | – | −0.0461 |
| | | | (0.0322) |
| *Coefficient* $\beta_1$ | | | |
| Market-based renewable energy policies | −0.0416 | – | – |
| | (0.0321) | | |
| Market-based solar energy policies | – | −1.1303* | – |
| | | (0.6805) | |
| Market-based wind energy policies | – | – | −3.7716* |
| | | | (2.2408) |
| *Coefficient* $\beta_2$ | | | |
| Market-based renewable energy policies × Climate change awareness $(t-3)$ | 0.0225** | – | – |
| | (0.0094) | | |
| Market-based solar energy policies × Climate change awareness $(t-3)$ | – | 0.4887** | – |
| | | (0.2348) | |
| Market-based wind energy policies × Climate change awareness $(t-3)$ | – | – | 1.1293* |
| | | | (0.6809) |
| *Coefficient* $\beta_3$ | | | |
| Climate change awareness $(t-3)$ | 0.0067 | −0.0517 | −0.0329 |
| | (0.0133) | (0.0564) | (0.0615) |
| *Control variables* | | | |
| Per capita GDP | −0.0625** | 0.0553 | −0.3857*** |
| | (0.0316) | (0.1695) | (0.1475) |
| Population density | −5.1900*** | −32.3358** | −35.3741* |
| | (1.9870) | (14.0894) | (18.2712) |
| Access to clean fuels and technologies for cooking | −0.1658*** | −0.7382 | −3.6421*** |
| | (0.0629) | (1.8288) | (0.8122) |
| Crop production index | −0.0004 | 0.3416** | 0.0675 |
| | (0.0172) | (0.1609) | (0.0902) |
| Electricity net imports | −0.0005*** | −0.0036** | −0.0024 |
| | (0.0002) | (0.0017) | (0.0015) |
| Constant | 0.7740*** | 3.9659 | 15.2707*** |
| | (0.2772) | (7.6759) | (3.4834) |
| Observations | 434 | 491 | 516 |
| Number of cross-sections | 31 | 43 | 42 |
| Number of instruments | 34 | 36 | 37 |
| *Diagnostic statistics* | | | |
| Arellano-Bond test for first-order autocorrelation (z-statistics) | −2.3623 | −3.4880 | −1.9824 |
| Arellano-Bond test for first-order autocorrelation (p-value) | 0.0182 | 0.0005 | 0.0474 |
| Arellano-Bond test for second-order autocorrelation (z-statistics) | −1.8259 | 0.7537 | 0.5073 |
| Arellano-Bond test for second-order autocorrelation (p-value) | 0.0679 | 0.4510 | 0.6120 |
| Sargan test ($\chi^2$) | 9.8796 | 4.1966 | 2.5943 |
| Sargan test (p-value) | 0.9705 | 0.9998 | 1.0000 |
| Hansen test ($\chi^2$) | 22.4616 | 17.9221 | 10.6718 |
| Hansen test (p-value) | 0.3160 | 0.5276 | 0.9543 |
| Extracted principal components from GMM-style instruments | 28 | 25 | 28 |
| Portion of variance explained by the components | 0.7993 | 0.7516 | 0.7475 |
| Kaiser-Meyer-Olkin measure of sampling adequacy | 0.9027 | 0.8490 | 0.8391 |

*Notes*: Significance levels: *p < 0.1, **p < 0.05, ***p < 0.01. Standard errors in parentheses. Dependent variables are in computed as the first differences of each series (transformed in natural logarithms). The same transformation is applied for per capita GDP, population density and the crop production index. Market-based energy policies, climate change awareness (proxied by means of Google Trend data and lagged for three years) and the access to clean fuels and technologies for cooking are in levels (transformed in natural logarithms, with the exception of market-based energy policies). The electricity net imports are used in first differences. Time dummies for the years 2010, 2012 and 2016 are included in Column 1, while time dummies related to the years 2009, 2010, 2011, 2012, 2016, 2019 and 2020 are included in Columns 2 and 3. A dummy for high-income countries is included in all the estimates. The instruments are used by the first-difference and level equations when renewable and solar energies are considered; only by the first-difference equation when wind energy is analyzed.

**Table C.2**
Estimates of Eq. (1) for energy legislation when climate change awareness is lagged for three years.

| | (1) Investments in renewable energies | (2) Investments in solar energies | (3) Investments in wind energies |
|---|---|---|---|
| *Coefficient* $\beta_0$ | | | |
| Investments in renewable energies $(t-1)$ | −0.2443*** | – | – |
| | (0.0375) | | |
| Investments in solar energies $(t-1)$ | – | 0.3903*** | – |
| | | (0.0335) | |
| Investments in wind energies $(t-1)$ | – | – | −0.0502*** |
| | | | (0.0146) |
| *Coefficient* $\beta_1$ | | | |
| Renewable energy legislation | −0.0555** | – | – |
| | (0.0273) | | |
| Solar energy legislation | – | −1.7659*** | – |
| | | (0.2526) | |
| Wind energy legislation | – | – | 0.6031*** |
| | | | (0.1856) |
| *Coefficient* $\beta_2$ | | | |
| Renewable energy legislation × Climate change awareness $(t-3)$ | 0.0151* | – | – |
| | (0.0082) | | |
| Solar energy legislation × Climate change awareness $(t-3)$ | – | 0.6006*** | – |
| | | (0.0850) | |
| Wind energy legislation × Climate change awareness $(t-3)$ | – | – | −0.2241*** |
| | | | (0.0601) |
| *Coefficient* $\beta_3$ | | | |
| Climate change awareness $(t-3)$ | 0.0159 | −0.1002** | −0.0598*** |
| | (0.0120) | (0.0423) | (0.0219) |
| *Control variables* | | | |
| Per capita GDP | 0.1505*** | 0.5609*** | −0.2340*** |
| | (0.0539) | (0.1500) | (0.0875) |
| Population density | −5.7984** | −20.8213*** | −29.5141*** |
| | (2.5185) | (7.3571) | (10.6453) |
| Access to clean fuels and technologies for cooking | 0.0562 | −1.0669*** | −4.6849*** |
| | (0.135) | (0.3421) | (0.7665) |
| Crop production index | −0.0769*** | −0.2549** | 0.2083*** |
| | (0.0285) | (0.1011) | (0.0438) |
| Electricity net imports | −0.0005 | −0.0016 | −0.0017 |
| | (0.0003) | (0.0014) | (0.0011) |
| Constant | −0.2113 | 5.1306*** | 21.1390*** |
| | (0.5555) | (1.4150) | (3.2569) |
| Observations | 710 | 644 | 652 |
| Number of cross-sections | 51 | 51 | 50 |
| Number of instruments | 40 | 47 | 48 |
| *Diagnostic statistics* | | | |
| Arellano-Bond test for first-order autocorrelation (z-statistics) | −1.3216 | −3.9657 | −2.6757 |
| Arellano-Bond test for first-order autocorrelation (p-value) | 0.1863 | 0.0001 | 0.0075 |
| Arellano-Bond test for second-order autocorrelation (z-statistics) | −0.1351 | 1.2828 | 0.2103 |
| Arellano-Bond test for second-order autocorrelation (p-value) | 0.8925 | 0.1996 | 0.8335 |
| Sargan test ($\chi^2$) | 20.4500 | 17.3805 | 14.3710 |
| Sargan test (p-value) | 0.4929 | 0.9559 | 0.9928 |
| Hansen test ($\chi^2$) | 21.4581 | 25.9447 | 29.7669 |
| Hansen test (p-value) | 0.4313 | 0.6284 | 0.4776 |
| Extracted principal components from GMM-style instruments | 27 | 38 | 39 |
| Portion of variance explained by the components | 0.7370 | 0.7766 | 0.7629 |
| Kaiser-Meyer-Olkin measure of sampling adequacy | 0.8119 | 0.7820 | 0.7998 |

*Notes*: Significance levels: *p < 0.1, **p < 0.05, ***p < 0.01. Standard errors in parentheses. Dependent variables are in computed as the first differences of each series (transformed in natural logarithms). The same transformation is applied for per capita GDP, population density and the crop production index. Energy legislation variables, climate change awareness (proxied by means of Google Trend data and lagged for three years) and the access to clean fuels and technologies for cooking are in levels (transformed in natural logarithms, with the exception of energy legislation variables). The electricity net imports are used in first differences. Time dummies related to the years 2009, 2010, 2011, 2012, 2016, 2019 and 2020 are included. A dummy for high-income countries is included in all the estimates. Following Cao et al. (2024) and Zhang et al. (2025b), a dummy for China is included in Column 1.
The instruments are used by the first-difference and level equations when renewable energy is considered; only by the first-difference equation when solar and wind energies are analyzed.

**Table C.3**
Estimates of Eq. (1) when geothermal power is withdrawn from investments in renewable energies.

| | (1) | (2) | (3) | (4) |
|---|---|---|---|---|
| ***Coefficient*** $\beta_0$ | | | | |
| Investments in renewable (excluding geothermal) energies (t−1) | 0.2511*** | 0.4745*** | 0.1210*** | −0.2503*** |
| | (0.0749) | (0.1153) | (0.0306) | (0.0375) |
| ***Coefficient*** $\beta_1$ | | | | |
| Market-based renewable energy policies | −0.0982** | −0.0445 | – | – |
| | (0.0450) | (0.0314) | | |
| Renewable energy legislation | – | – | −0.0352 | −0.0603** |
| | | | (0.0254) | (0.0273) |
| ***Coefficient*** $\beta_2$ | | | | |
| Market-based renewable energy policies × climate change awareness ($t-5$) | 0.0329** | – | – | – |
| | (0.0136) | | | |
| Market-based renewable energy policies × climate change awareness ($t-3$) | | 0.0232** | – | – |
| | | (0.0092) | | |
| Renewable energy legislation × climate change awareness ($t-5$) | – | – | 0.0105* | – |
| | | | (0.0060) | |
| Renewable energy legislation × climate change awareness ($t-3$) | – | – | – | 0.0166** |
| | | | | (0.0081) |
| ***Coefficient*** $\beta_3$ | | | | |
| Climate change awareness ($t-5$) | −0.0202 | – | 0.0254*** | – |
| | (0.0145) | | (0.0071) | |
| Climate change awareness ($t-3$) | – | 0.0059 | – | 0.0164 |
| | | (0.0134) | | (0.0124) |
| ***Control variables*** | | | | |
| Per capita GDP | 0.0568 | −0.0641** | 0.2229*** | 0.1482*** |
| | (0.0388) | (0.0315) | (0.0635) | (0.0537) |
| Population density | 3.1461 | −5.0336** | −1.6333 | −5.8901** |
| | (2.0278) | (1.9944) | (2.0254) | (2.6881) |
| Access to clean fuels and technologies for cooking | 0.0375 | −0.1616** | 0.0799 | 0.0543 |
| | (0.1477) | (0.0644) | (0.0545) | (0.1316) |
| Crop production index | 0.0173 | −0.0047 | −0.0890*** | −0.0750*** |
| | (0.0161) | (0.0166) | (0.0261) | (0.0283) |
| Electricity net imports | −0.0002 | −0.0005*** | −0.0002 | −0.0005 |
| | (0.0002) | (0.0002) | (0.0003) | (0.0003) |
| Constant | −0.0550 | 0.7572*** | −0.3628 | −0.2050 |
| | (0.6188) | (0.2845) | (0.2369) | (0.5475) |
| Observations | 372 | 434 | 610 | 710 |
| Number of cross-sections | 31 | 31 | 51 | 51 |
| Number of instruments | 34 | 34 | 41 | 40 |
| *Diagnostic statistics* | | | | |
| Arellano-Bond test for first-order autocorrelation (z-statistics) | −2.1415 | −2.3891 | −1.5943 | −1.3143 |
| Arellano-Bond test for first-order autocorrelation (p-value) | 0.0322 | 0.0169 | 0.1109 | 0.1887 |
| Arellano-Bond test for second-order autocorrelation (z-statistics) | −1.5322 | −1.8237 | 1.3769 | −0.1742 |
| Arellano-Bond test for second-order autocorrelation (p-value) | 0.1255 | 0.0682 | 0.1686 | 0.8617 |
| Sargan test ($\chi^2$) | 8.6808 | 9.8824 | 29.1713 | 19.75 |
| Sargan test (p-value) | 0.9863 | 0.9703 | 0.1400 | 0.5371 |
| Hansen test ($\chi^2$) | 17.1897 | 22.8556 | 25.8685 | 21.0668 |
| Hansen test (p-value) | 0.6406 | 0.2959 | 0.2574 | 0.4549 |
| Extracted principal components from GMM-style instruments | 28 | 28 | 28 | 27 |
| Portion of variance explained by the components | 0.8035 | 0.7992 | 0.7531 | 0.7365 |
| Kaiser-Meyer-Olkin measure of sampling adequacy | 0.9019 | 0.9028 | 0.8148 | 0.8120 |

*Notes*: Significance levels: *p < 0.1, **p < 0.05, ***p < 0.01. Standard errors in parentheses. Dependent variables are in computed as the first differences of each series (transformed in natural logarithms). The same transformation is applied for per capita GDP, population density and the crop production index. Energy legislation variables, climate change awareness (proxied by means of Google Trend data and lagged for three and five years) and the access to clean fuels and technologies for cooking are in levels (transformed in natural logarithms, with the exception of energy legislation variables). The electricity net imports are used in first differences. Time dummies for the years 2010, 2012 and 2016 are included in Columns 1 and 2, while time dummies related to the years 2009, 2010, 2011, 2012, 2016, 2019 and 2020 are included in Columns 3 and 4. A dummy for high-income countries is included in all the estimates. Following Cao et al. (2024) and Zhang et al. (2025b), a dummy for China is also included in Columns 3 and 4. The instruments are used by the first-difference and level equations.

**Table C.4**
Estimates of Eq. (1) for market-based energy policies by using as instruments all available lags of the endogenous variables starting from the second.

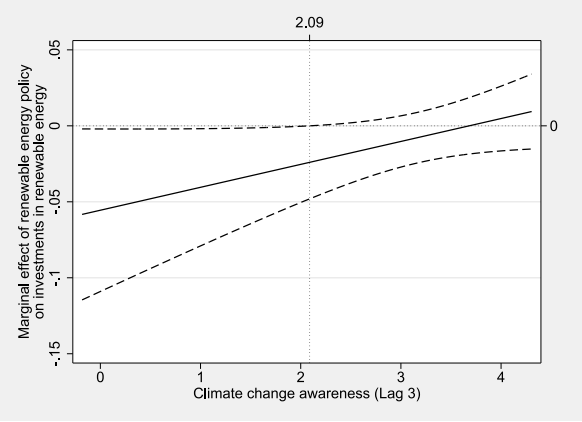
| | (1) Investments in renewable energies | (2) Investments in solar energies | (3) Investments in wind energies |
|---|---|---|---|
| *Coefficient* $\beta_0$ | | | |
| Investments in renewable energies (t−1) | 0.2660** | – | – |
| | (0.1111) | | |
| Investments in solar energies (t−1) | – | 0.5334*** | – |
| | | (0.0750) | |
| Investments in wind energies (t−1) | – | – | −0.7444*** |
| | | | (0.0853) |
| *Coefficient* $\beta_1$ | | | |
| Market-based renewable energy policies | −0.0737** | – | – |
| | (0.0371) | | |
| Market-based solar energy policies | – | −2.7735*** | – |
| | | (0.6776) | |
| Market-based wind energy policies | – | – | −1.9726*** |
| | | | (0.5909) |
| *Coefficient* $\beta_2$ | | | |
| Market-based renewable energy policies × Climate change awareness $(t-5)$ | 0.0253** | – | – |
| | (0.0127) | | |
| Market-based solar energy policies × Climate change awareness $(t-5)$ | – | 0.9669*** | – |
| | | (0.2210) | |
| Market-based wind energy policies × Climate change awareness $(t-5)$ | – | – | 0.6682*** |
| | | | (0.1786) |
| *Coefficient* $\beta_3$ | | | |
| Climate change awareness $(t-5)$ | −0.0157 | −0.0156 | −0.0727 |
| | (0.0117) | (0.0509) | (0.0460) |
| *Control variables* | | | |
| Per capita GDP | 0.0838** | 0.3075 | −0.3376** |
| | (0.0371) | (0.2292) | (0.1656) |
| Population density | 4.0463* | −54.1090*** | −43.3744*** |
| | (2.1616) | (13.5653) | (15.1379) |
| Access to clean fuels and technologies for cooking | −0.1018 | 0.3399 | −3.8676*** |
| | (0.0916) | (1.6682) | (1.3950) |
| Crop production index | 0.0787*** | 0.1342 | 0.0223 |
| | (0.0208) | (0.2818) | (0.0867) |
| Electricity net imports | 0.0001 | 0.0036 | −0.0025 |
| | (0.0005) | (0.0028) | (0.0016) |
| Constant | 0.5167 | −0.6231 | 17.5634*** |
| | (0.4014) | (7.0817) | (6.4528) |
| Observations | 372 | 431 | 440 |
| Number of cross-sections | 31 | 43 | 42 |
| Number of instruments | 32 | 36 | 33 |
| *Diagnostic statistics* | | | |
| Arellano-Bond test for first-order autocorrelation (z-statistics) | −1.9798 | −2.8720 | −1.8602 |
| Arellano-Bond test for first-order autocorrelation (p-value) | 0.0477 | 0.0041 | 0.0629 |
| Arellano-Bond test for second-order autocorrelation (z-statistics) | −1.4212 | 0.3386 | −1.8204 |
| Arellano-Bond test for second-order autocorrelation (p-value) | 0.1557 | 0.7349 | 0.0687 |
| Sargan test ($\chi^2$) | 11.5188 | 4.2019 | 2.4606 |
| Sargan test (p-value) | 0.8711 | 0.9998 | 1.0000 |
| Hansen test ($\chi^2$) | 17.1709 | 18.0756 | 17.1687 |
| Hansen test (p-value) | 0.5114 | 0.5174 | 0.3748 |
| Extracted principal components from GMM-style instruments | 26 | 25 | 23 |
| Portion of variance explained by the components | 0.7930 | 0.7700 | 0.7344 |
| Kaiser-Meyer-Olkin measure of sampling adequacy | 0.8965 | 0.8436 | 0.8114 |

*Notes*: Significance levels: *p < 0.1, **p < 0.05, ***p < 0.01. Standard errors in parentheses. Dependent variables are in computed as the first differences of each series (transformed in natural logarithms). The same transformation is applied for per capita GDP, population density and the crop production index. Market-based energy policies, climate change awareness (proxied by means of Google Trend data and lagged for five years) and the access to clean fuels and technologies for cooking are in levels (transformed in natural logarithms, with the exception of market-based energy policies). The electricity net imports are used in first differences. Time dummies for the years 2010, 2012 and 2016 are included in Column 1, while time dummies related to the years 2009, 2010, 2011, 2012, 2016, 2019 and 2020 are included in Columns 2 and 3. A dummy for high-income countries is included in all the estimates. The instruments are used by the first-difference and level equations when renewable and solar energies are considered; only by the first-difference equation when wind energy is analyzed.

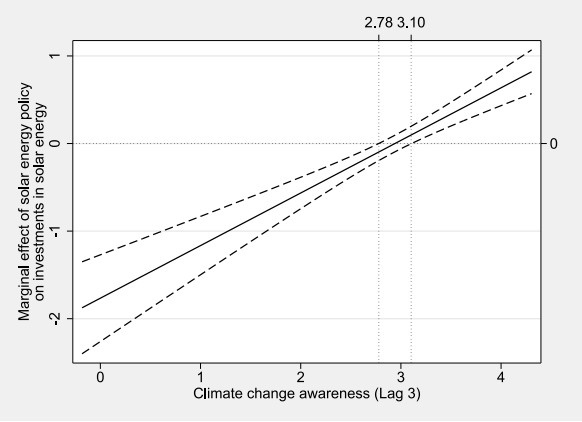
**Table C.5**
Estimates of Eq. (1) for energy legislation by using as instruments all available lags of the endogenous variables starting from the second.

| | (1) Investments in renewable energies | (2) Investments in solar energies | (3) Investments in wind energies |
|---|---|---|---|
| *Coefficient* $\beta_0$ | | | |
| Investments in renewable energies (t−1) | −0.9453*** | – | – |
| | (0.0414) | | |
| Investments in solar energies (t−1) | – | 0.3941*** | – |
| | | (0.0532) | |
| Investments in wind energies (t−1) | – | – | −0.1874*** |
| | | | (0.0470) |
| *Coefficient* $\beta_1$ | | | |
| Renewable energy legislation | −0.0357* | – | – |
| | (0.0193) | | |
| Solar energy legislation | – | −0.6424* | – |
| | | (0.3472) | |
| Wind energy legislation | – | – | 0.0517 |
| | | | (0.4981) |
| *Coefficient* $\beta_2$ | | | |
| Renewable energy legislation × Climate change awareness $(t-5)$ | 0.0113** | – | – |
| | (0.0055) | | |
| Solar energy legislation × Climate change awareness $(t-5)$ | – | 0.1830* | – |
| | | (0.1036) | |
| Wind energy legislation × Climate change awareness $(t-5)$ | – | – | −0.0481 |
| | | | (0.1428) |
| *Coefficient* $\beta_3$ | | | |
| Climate change awareness $(t-5)$ | 0.0135 | 0.0745*** | 0.0671** |
| | (0.0098) | (0.0278) | (0.0317) |
| *Control variables* | | | |
| Per capita GDP | 0.1842** | 1.2523*** | 0.0646 |
| | (0.0873) | (0.2018) | (0.1413) |
| Population density | −0.8300 | 1.6181 | −21.8269*** |
| | (4.4186) | (8.8368) | (6.5785) |
| Access to clean fuels and technologies for cooking | −0.5850 | −1.4406** | −0.0941 |
| | (0.5850) | (0.5833) | (0.5930) |
| Crop production index | −0.1209* | −1.0130*** | −0.1395*** |
| | (0.0629) | (0.2283) | (0.0518) |
| Electricity net imports | −0.0006 | −0.0104*** | −0.0048*** |
| | (0.0007) | (0.0026) | (0.0018) |
| Constant | 2.1262 | 6.4444** | 0.7936 |
| | (2.7117) | (2.6195) | (2.6492) |
| Observations | 610 | 573 | 565 |
| Number of cross-sections | 51 | 51 | 50 |
| Number of instruments | 36 | 45 | 43 |
| *Diagnostic statistics* | | | |
| Arellano-Bond test for first-order autocorrelation (z-statistics) | 2.3571 | −3.7908 | −2.2815 |
| Arellano-Bond test for first-order autocorrelation (p-value) | 0.0184 | 0.0002 | 0.0225 |
| Arellano-Bond test for second-order autocorrelation (z-statistics) | −1.3706 | 0.6505 | −0.9133 |
| Arellano-Bond test for second-order autocorrelation (p-value) | 0.1705 | 0.5154 | 0.3611 |
| Sargan test ($\chi^2$) | 0.2722 | 17.0794 | 6.9092 |
| Sargan test (p-value) | 1.0000 | 0.9291 | 0.9999 |
| Hansen test ($\chi^2$) | 22.7289 | 24.3067 | 24.6431 |
| Hansen test (p-value) | 0.1583 | 0.6133 | 0.4825 |
| Extracted principal components from GMM-style instruments | 25 | 35 | 33 |
| Portion of variance explained by the components | 0.7339 | 0.7675 | 0.7304 |
| Kaiser-Meyer-Olkin measure of sampling adequacy | 0.8074 | 0.8031 | 0.8094 |

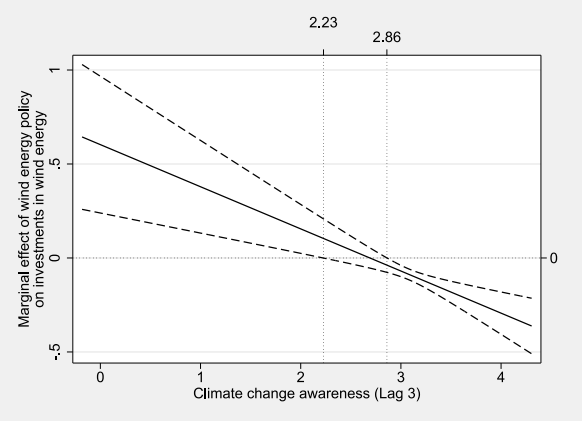
*Notes*: Significance levels: *p < 0.1, **p < 0.05, ***p < 0.01. Standard errors in parentheses. Dependent variables are in computed as the first differences of each series (transformed in natural logarithms). The same transformation is applied for per capita GDP, population density and the crop production index. Market-based energy policies, climate change awareness (proxied by means of Google Trend data and lagged for five years) and the access to clean fuels and technologies for cooking are in levels (transformed in natural logarithms, with the exception of market-based energy policies). The electricity net imports are used in first differences. Time dummies for the years 2010, 2012 and 2016 are included in Column 1, while time dummies related to the years 2009, 2010, 2011, 2012, 2016, 2019 and 2020 are included in Columns 2 and 3. A dummy for high-income countries is included in all the estimates. Following Cao et al. (2024) and Zhang et al. (2025b), a dummy for China is included in Column 1. The instruments are used by the first-difference equation in Column 1, the level equation in Column 2, and the first-difference equation in Column 3.




**(a)** Renewable energy




**(b)** Solar energy




**(c)** Wind energy

**Fig. C.2.** Marginal effects of energy legislation for different levels of climate change awareness.
*Notes*: The solid line represents the estimates of the function in Eq. (2), while the two dotted lines correspond to the upper and lower bounds of the 95 percent confidence interval. These estimates are computed starting from the results reported in Table C.2.

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