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Achieving energy resilience: The joint role of environmental policy stringency and environmental awareness

Amal Dabbous[a,1], Alexandre Croutzet[b,2,*], Matthias Horn[c,3]

[a] *Saint-Joseph University of Beirut, Lebanon*
[b] *TELUQ University, Canada*
[c] *Department of Finance, Bamberg University, Bamberg, Germany*

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A B S T R A C T

This paper examines the critical interplay between environmental policy stringency, public environmental awareness, and energy resilience, leveraging a dataset for 32 OECD countries between 2004 and 2020. Further, it explores the channels through which these variables influence energy resilience. Principal component analysis (pca) is adopted to derive the multidimensional index of energy resilience based on three pillars, renewable energy, energy access, and energy efficiency. The findings underscore a significant positive relationship between stringent environmental policies, environmental awareness, and energy resilience. Additionally, environmental awareness and environmental policy stringency are shown to exert a positive effect on renewable energy and enhance energy access. Environmental policy stringency is found to have a significant negative impact on energy intensity, i.e. a positive impact on energy efficiency. The results demonstrate that by increasing public environmental awareness and implementing more stringent environmental policies policymakers can improve energy resilience, energy efficiency, and the share of renewable energy. The latter are considered essential elements for the environmental transition emerging as a prominent solution when addressing climate change challenges.

1. Introduction

Over the past decade, several international institutions, such as the United Nations (UN) and the International Energy Agency (IEA), have been highly engaged in addressing the challenges posed by global warming and climate change. In addition, policymakers and governments in the Organization for Economic Cooperation and Development (OECD) countries have been extremely concerned about environmental degradation and have adopted several policies that rely on pricing mechanisms to raise the cost of pollution and finance environmental transition (Hassan and Rousselière, 2022).

In this context, a large number of countries have actively promoted major shifts towards low-carbon and green economies (Khan et al., 2021; Zhao et al., 2021). At the same time, energy is seen as a key component for achieving growth and higher levels of

* Corresponding author.
E-mail addresses: amal.dabbous@usj.edu.lb (A. Dabbous), alexandre.croutzet@teluq.ca (A. Croutzet), matthias.horn@uni-bamberg.de (M. Horn).
[1] https://orcid.org/0000–0001-6122–5674
[2] https://orcid.org/0000–0003-2238–3236
[3] https://orcid.org/0000–0002-0032–908X

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industrialization, as energy is an essential driver of economic development and social stability (Dong et al., 2021; Zhao et al., 2020a). Furthermore, in the face of the ongoing energy crisis, renewable energy sources can contribute to reducing energy dependence on traditional energy sources, as renewable energy sources are not affected by fluctuations in fossil fuel prices (Ioannidis et al., 2023). Therefore, proposing strategies to enhance energy security while realizing green energy transition and ensuring energy resilience has become crucial and one of the major concerns of governments (Dong et al., 2021).

Thus, the concept of resilience in the energy sector has emerged and attracted the attention of a growing number of academics. Improving the resilience of energy infrastructure contributes to the stability and efficient operation of both the economy and societal functions while facilitating a shift to a sustainable, low-emission energy framework. This shift is essential to mitigate the effects of global climate change and represents a step forward in improving the well-being and quality of life of individuals, particularly in developing countries (Gatto and Drago, 2020a). According to Gatto and Drago (2020b), energy resilience is a multi-dimensional concept and is defined as "the ability of an energy system to retain, react, overcome and overpass perturbations caused by a shock in economic, social, environmental and institutional terms, coming from the learning capacity to adapt to change." It is a multi-dimensional index based on three pillars: renewable energy, energy access, and energy efficiency (Gatto and Drago, 2020b).

However, despite all the efforts to ensure energy resilience, Iturriza et al. (2020) show that current strategies for building energy resilience are not very effective in addressing climate change concerns in urban areas due to the passive behavior of the stakeholders involved. Therefore, the authors argue that the development of climate change awareness is the key component needed to ensure energy resilience, as it leads to behavioral changes and fosters partnerships aimed at increasing resilience. Further, Egert et al. (2021) argue that a continuous process of citizen awareness is needed to ensure people's participation in activities that support the resilience of energy networks. They claim that achieving awareness is a major challenge but will actively contribute to a more resilient energy system. Thus, it appears that environmental awareness is a critical requirement for achieving energy resilience.

However, the relationship between individual environmental awareness and energy resilience has not been empirically investigated. Moreover, the complex relationship between environmental awareness and the adoption of renewable energy forms a complex puzzle that has not been fully solved despite the attention it has received since the 1980s (Al Masud, 2023). Additionally, Chatzistamoulou and Koundouri (2022) state that there is a void in the literature to be filled concerning the effect of environmental awareness on environmental efficiency. Further, Meo et al. (2024) state that there is a lack of research examining how climate attention, needed to raise awareness of climate change, influences renewable energy. It is therefore evident that there is a void in the literature regarding the impact of environmental awareness on energy resilience. Therefore, this study aims to fill this gap and investigate the potential of environmental awareness in increasing energy resilience.

Additionally, in response to the urgent danger that climate change presents to the global economy, social well-being, and the environment, several initiatives have been realized to facilitate the shift towards low-carbon economies and to promote energy transition. Environmental policies have notably gained traction, emerging as essential focal points in the strategic agendas of governments, aiming to address the challenges of climate change (Ma et al., 2023), successfully reduce pollution, mitigate carbon emissions, decrease the depletion of resources (Espoir et al., 2022) and efficiently drive the transition to cleaner energy sources (Ao et al., 2023). Several OECD countries have advanced sustainable development by endorsing green industries, investing in renewable energy, and enhancing resource efficiency (Ahmad and Satrovic, 2023). However, despite these efforts, challenges persist throughout OECD countries, encompassing resistance from industries relying on fossil fuels and financial obligations linked to the adoption of sustainable technologies (Clémençon, 2023). It therefore appears that environmental regulation can play a specific role in improving the environment and establishing a sustainable energy structure.

However, the predominant focus in the literature revolves around exploring the impact of environmental regulation on energy efficiency and energy intensity (Zhao et al., 2023). Further, Ma et al. (2023) state that one notable gap observed in the literature is the fact that most studies focus on the organizational level analysis and do not investigate the broader aspect by exploring the efficiency of environmental policies in fostering energy transition across OECD countries. A link between environmental regulation and energy resilience has not yet been established. Finally, the literature reveals two opposing results regarding the influence of environmental regulations on CO2 emissions and environmental quality. These conflicting findings are explained by two theories, namely the Porter (1991) Hypothesis and the Pollution Haven Hypothesis. This motivates this analysis aiming to explore the effect of environmental policies on energy efficiency in OECD countries. This study therefore aims to fill these gaps observed in the literature and explore whether environmental policy stringency affects energy resilience.

In light of the above, the main objective of this study is to examine the impact of environmental policy stringency and environmental awareness on energy resilience. It also examines the channels through which environmental awareness and policy stringency affect energy resilience, namely whether and how these two variables affect renewable energy generation and consumption, energy access, and energy efficiency.

To do so, the analysis makes use of panel data for 32 OECD countries between 2004 and 2020. The main focus is to examine OECD countries given that they are heavily reliant on non-renewable energy sources which yield a large increase in CO2 emissions (Ma et al., 2023). OECD countries account for about one-third of global emissions from non-renewable energy sources (OECD, 2023). Principal component analysis (pca) is adopted to derive the multi-dimensional index of energy resilience based on three pillars, renewable energy, energy access, and energy efficiency. As a measure of environmental awareness, this study employs the environmental awareness index (EAI) developed by Dabbous et al. (2023a) and employed by Horn et al. (2023) to explain the returns of environmentally friendly stocks. The Hausman test is conducted to choose the appropriate estimation technique. The results indicate that the fixed effects model is the appropriate one to use. Furthermore, to address these characteristics of the dataset, this study relies on panel regressions with Driscoll-Kraay standard errors that are robust to cross-sectional and temporal dependence (Hoechle, 2007). Moreover, to account for possible endogeneity and as a robustness check this study uses instrumental variables 2SLS-regressions and 2-step GMM estimations with three lags of the Stringency-variable as instruments. Additional robustness check adds two lags of the variable RuleOfLaw as further instruments.

This study makes several contributions to the literature. First, it is considered among the few studies (Gatto and Drago, 2020b; Dong et al., 2021) to comprehensively incorporate the concept of energy resilience as a multi-dimensional index based on three pillars, renewable energy, energy access, and energy efficiency, rather than just focusing on renewable energy. However, these 2 studies use cross-sectional data for one year only while the index developed in this paper covers a longer period between the years 2014 and 2020. Second, treating the environmental policy stringency and environmental awareness as continuous treatment parameters, i.e., including them as non-binary variables to shed light on their crucial role in shaping and influencing the course of energy resilience highly contributes and provides valuable insights to the literature on, environmental economics, energy, and policy. By doing so, this work also advances prior works in the literature that often investigate individuals' environmental awareness using the results of surveys as an indicator for this variable (Beiser-McGrath and Huber, 2018; Iosifidi, 2016). Third, this study contributes to the stream of literature exploring the connection between environmental regulations and the use of clean energy sources. However, the findings advance prior works by establishing that by increasing public environmental awareness and implementing more stringent environmental policies policymakers can improve energy resilience, energy efficiency, and the share of renewable energy considered essential components for energy transition. These results also contribute to the literature by providing additional evidence to support the strand of theory advocating that environmental policies and laws foster the use of green energy because they urge both companies and the general population to transition to it as a power source (Bai et al., 2020; Du et al., 2021). Fourth, this study contributes to the salience literature. Salience pertains to the phenomenon where directing an individual's attention to a particular aspect of the environment leads information related to that aspect to carry disproportionate weight in subsequent judgments (Taylor and Thompson, 1982). In this study, the environment refers to a change in environmental awareness which is considered a factor that can change individuals' attitudes toward the choice of clean energy, influence energy intensity and efficiency, and consequently impact energy resilience. Fifth, the study results highlight the channels through which environmental awareness and environmental policy stringency impact energy resilience by deriving the influence of those two variables on each component of the resilience index separately. By doing so, this study contributes to the environmental management strand of the literature (Doğan et al., 2020; Nasir et al., 2021) by revealing how OECD countries considered as heavily dependent on non-renewable energy sources can leverage environmental awareness and environmental regulations to manage energy efficiency and ensure better environmental management.

The remainder of this study is organized as follows. Sections 2 and 3 present the theoretical framework and the literature review. Section 4 details the data used and demonstrates the methodology adopted. Section 5 explains the results and summarizes the results discussions. Section 6 concludes and presents the policy implications, limitations, and future directions.

2. Theoretical framework

To address pressing environmental issues, several countries, particularly OECD countries, have begun to implement stringent environmental policies such as imposing carbon taxes (Meo et al., 2024). However, the carbon intensity remains constantly on a positive trajectory (Sohag et al., 2024). Moreover, these policies give rise to debates about their impact on key environmental attributes, such as ecological footprints, carbon emissions, clean energy adoption, and eco-innovation (Liao et al., 2023). Two main theories, Porter's (1991) hypothesis, and the Pollution Haven Hypothesis explain the impact of environmental regulations on clean energy adoption, energy transition, and environmental quality, however, the literature shows mixed support for both theories (Gill et al., 2018).

The first theory is Porter's (1991) hypothesis that environmental regulation will stimulate technological innovation within industries. This will lead to productivity gains in the long run and make firms more competitive. Strong and well-designed environmental policies implemented by the government will trigger technological innovation within firms and promote the use of more environmentally friendly technologies and sustainable and renewable energy sources (Porter and Linde, 1995). Previous studies show that environmental innovation can improve energy efficiency and lead to a reduction in energy consumption (Fisher-Vanden et al., 2006; Tang and Tan, 2013). Therefore, the Porter hypothesis supports the idea that environmental regulations help to address the challenges of climate change (Ma et al., 2023), reduce pollution, mitigate carbon emissions, and efficiently drive the transition to cleaner energy sources (Ao et al., 2023).

The second theory is the Pollution Haven Hypothesis, which argues that countries with more stringent environmental policies will experience a decline in their economic competitiveness as highly polluting industries in these countries relocate to countries with less stringent or no environmental regulations. This could lead to higher levels of pollution overall (Chen et al., 2023; Liu et al., 2023). For example, Jiang et al. (2022) show that environmental innovation reduced CO2 emissions for high-income countries, but not for low- and middle-income countries. The authors state that these results show that the impact of a pollution haven has influenced the effect of environmental innovation on reducing carbon emissions. As Zhao et al. (2020b) argue, the impact of environmental regulation on CO2 emissions includes both the direct overall impact of reducing carbon emissions and the indirect impact of increasing these emissions through the relocation of carbon-dependent industrial investment. Therefore, the Pollution Haven Hypothesis supports the idea that it is not feasible to achieve both economic growth and a healthy, clean environment at the same time, as environmental policies impose burdens on firms and consumers, most likely leading to income sacrifices (Gallagher, 2004; Van Den Bergh, 2017).

In the OECD context, Cole (2004) showed that pollution-intensive industries developed rapidly in developing countries during periods characterized by highly stringent environmental regulations across OECD nations. However, Xu (2000) explored the influence of stringent environmental policies on the competitiveness of goods that are environmentally sensitive in 25 OECD nations and they rejected the Pollution Haven Hypothesis since their results did not show changes in trade patterns for the countries investigated.

Hashmi and Alam (2019) revealed that an increase in environmental patent applications decreased carbon emissions in 29 OECD countries for the period 1999–2014. These opposing results regarding the influence of environmental regulations on CO2 emissions and environmental quality indicate that this topic warrants further investigation. As such this study explores the effect of environmental policies on energy efficiency in OECD countries.

Regarding the relationship between environmental awareness and energy efficiency, this study uses Ajzen's (1991) Theory of Planned Behavior (TPB) to explain the association between these factors. Based on TPB, individuals‘ attitudes towards a particular behavior act as a predictor of their intention to perform this behavior (Ajzen, 1991). Intention is associated with real behavior (Ajzen, 2002). Conradie et al. (2021) relied on this theory to explain people's attitudes and intentions to perform a particular behavior, in their case individual's intention to join renewable energy consumption. Prior works established that environmental concerns, education, and awareness act as predictors of individuals' willingness to participate in renewable energy projects (Broughel and Hampl, 2018; Koirala et al., 2018). Proudlove et al. (2020) also reveal that attitude toward investing in renewable energy projects is a significant predictor of the real intention to invest. Further, Tavitiyaman et al. (2024) applied the TPB and showed that environmental awareness has a positive effect on peoples‘ habits environmental knowledge affects pro-environmental behavior and this relationship is mediated by environmental intention. Therefore, based on TPB and previous studies' results there is a good reason to propose that environmental awareness will generate a positive attitude towards energy efficiency which in turn will promote a pro-environmental behavior that will increase energy efficiency.

3. Literature review

The present paper extends upon three distinct threads within the field of economic research. The first studies the factors affecting energy resilience. The second focuses on the relationship between environmental awareness and energy resilience. The third investigates the impact of environmental policy stringency on energy resilience.

3.1. Energy resilience

Energy resilience holds a prominent position in the global development agenda and aligns closely with the UN's Sustainable Development Goals. It is assumed to play a major role in policymaking. Several studies underscore the multifaceted approaches to measuring energy system resilience, highlighting a gap in considering economic aspects and the social and economic outcomes of energy resilience, which have yet to gain ample focus.

Shandiz et al. (2020) proposed specific indicators for assessing energy resilience, considering both the immediate and prolonged effects of disruptions on the energy system. From a microeconomic viewpoint, Gupta et al. (2019) explored energy resilience in poor communities in Oxford by implementing solar photovoltaic systems and intelligent battery solutions across 82 households. He et al. (2019) developed a model using input-output linear programming to assess the resilience of energy systems of multi-regional economies, finding that the efficiency of specific energy-intensive sectors influences China's energy resilience. Additionally, Gatto and Drago (2020b) developed a composite indicator for energy resilience based on the Sustainable Energy for All (SEforAll) initiative by the World Bank, incorporating three main facets: energy access, renewable sources, and effectiveness, across 27 indicators. Dong et al. (2021) developed a comprehensive index of energy resilience utilizing data from 107 countries in 2016. This index incorporates three key aspects: access to energy, the use of renewable sources, and the efficiency of energy consumption.

However, the clarification of the concepts surrounding energy resilience, vulnerability, and sustainability remains elusive (Gatto and Drago, 2023; Stirling, 2013). Certain researchers maintain that the definition of energy vulnerability should encompass attributes of energy resilience while also acknowledging the critical nature of sustainability in the context of the impacts of energy vulnerability (Gatto and Busato, 2020). This study follows Gatto and Drago (2020b) and considers that energy resilience is a multi-dimensional index based on three pillars, renewable energy, energy access, and energy efficiency.

3.2. Environmental awareness and energy resilience

The literature establishes strong relationships between sustainable energy adoption and awareness campaigns, market traits, and legislative contexts (Lerman et al., 2021). Nie et al. (2016) advocate that to develop efficient strategies for mitigating environmental concerns, an assessment of public knowledge about energy topics is needed. Aldieri et al. (2022) stress that firms' and individuals' behavior are key factors to consider to increase knowledge and awareness of energy use and to raise energy security. Nonetheless, Ergun and Rivas (2019) reveal that studies exploring the links between awareness, acceptance, and attitudes remain scarce specifically in developing countries. Few studies (Al Masud, 2023; Ioannidis et al., 2023) examined the impact of knowledge and education or public awareness on renewable energy or environmentally friendly lifestyles but non-directly investigated the influence of environmental awareness on energy resilience as a multi-dimensional construct. For instance, Ioannidis et al., (2023) show that higher levels of education raise the willingness to pay more for renewable energy sources as well as increase their acceptance from the public in Greece. Casaló et al. (2019) and Casaló and Escario (2018) established that environmental knowledge affects individuals' environmental attitudes which in turn fosters pro-environmental behavior. Egert et al. (2021) reveal that ensuring the resilience of operations of energy grids highly relies on increasing consumers' active behavior i.e., prosumers (i.e. a consumer and a producer) that can have local electricity production. The authors argue that increasing energy-related knowledge and climate change awareness will make informed citizens capable of contributing to a more resilient energy system, particularly during the energy transition process aiming to achieve SDGs. Further, several authors also indicate that integrating environmental education in schools using smart applications and devices and social media can increase environmental awareness and lead to a more environmentally conscious lifestyle (Mallick and Bajpai, 2019) driving individuals to create solutions to face the climate change problems and risks. Al Masud (2023) shows that an increase in the awareness level of students leads to an increase in renewable energy consumption. Almulhim (2022) indicates that to achieve the Saudi government's 2030 vision, it is imperative to implement outstanding and intelligent measures aiming to promote awareness of renewable energy among citizens across all societal classes. It appears that ensuring higher environmental awareness is crucial to ensure better environmental quality and can increase energy resilience particularly since Li et al. (2024) confirm that human activities specifically energy consumption are considered the major cause of the degradation of the environment. This study therefore examines the influence of environmental awareness on energy resilience and tests the following hypothesis:

H1: Environmental awareness has a positive influence on energy resilience.

3.3. Environmental policy stringency and energy resilience

Climate change is widely acknowledged as a primary challenge to economic growth, due to its potential for devastation and the accompanying economic burdens (Gilson, 2023). Human actions are essentially the cause of climate change problems (Köpsel et al., 2017). Transition to sustainable energy plays an essential role in establishing cleaner consumption and production lifestyles within households and industries as well as enhancing energy security (Gatto and Drago, 2021). According to Wolde-Rufael and Mulat-Weldemeskel (2021), environmental policy stringency has emerged as a vital tool in addressing and mitigating environmental degradation. Environmental policies and regulations are considered top-tier elements in shaping energy futures (Sadik-Zada and Gatto, 2023). Environmental policy stringency frequently encompasses initiatives that encourage the use of renewable energy, such as financial incentives, regulatory frameworks, and providing the appropriate infrastructure for renewables (Yu et al., 2023). Policy stringency implemented by governments and international institutions influences the interaction between environmental elements and the progress of sustainable and renewable energies (Feng et al., 2023). Stringent environmental policies also impact consumer behavior by promoting sustainable practices, education, and incentive programs, as a result, this will encourage the use of energy-efficient technologies, minimize waste, and contribute to lowering CO_2 emissions and ecological footprints (Sohag et al., 2024).

Top of Form Hassan and Rousselière (2022) examine the impact of more stringent environmental policies on the advancement of green technology innovations across 27 OECD countries from 1990 to 2015. They find that stricter environmental regulations significantly boost the rate of green innovation. Moreover, it was observed that non-market environmental policy tools encourage more innovation in green technology compared to market-based tools, suggesting that command and control policy instruments are more efficient than pricing strategies in promoting eco-friendly innovation.

Li and Shao (2023) investigate how the advancement of financial markets and the rigor of environmental regulations affect innovation in renewable energy. Findings indicate that with the progression of financial development, its positive impact on innovation decreases, whereas the impact of stricter environmental regulations on innovation intensifies. Hassan et al. (2024) examine the influence of the updated Environmental Policy Stringency Index and its elements on the consumption of renewable energy. They find that more stringent environmental policies enhance the adoption of renewable energy. Both types of environmental policies, market, and non-market, along with policies supporting technological advancements, are found to have beneficial impacts on the adoption of sustainable energy.

Further, Mandal and Madheswaran (2010) demonstrate the advantages of regulations for energy efficiency in the Indian cement industry, yet noticeable spatial heterogeneity is apparent. Guo and Yuan (2020) show that mandatory environmental regulations positively influence energy efficiency, but the impact exhibits a non-linear relationship. According to Yang et al. (2022) strengthening environmental regulation substantially restricts the consumption of fossil energy. Liu et al. (2020) show that environmental regulations alleviated China's energy concerns. Finally, several scholars advocate that environmental regulations can drive a reduction in energy intensity, and the indirect mechanism behind this is that it compels enterprises to enhance innovation (Xu et al., 2022).

Based on the theoretical framework and the literature review presented this study proposes to test the following hypothesis:

H2: Environmental policy stringency has a positive effect on energy resilience

H2 is in line with the Porter hypothesis: environmental regulations foster the use of more eco-friendly technologies and sustainable and renewable energy sources (Porter and Linde, 1995). Conversely, H2 contradicts the Pollution Haven Hypothesis, which suggests that firms relocate to countries with lax environmental regulations to avoid stringent policies leading to higher levels of pollution overall and lower use of sustainable energy sources.

4. Data and methodology

The first step consists of creating the Energy Resilience Index (ERI) and environmental awareness index (EAI). We use data from different sources. According to Gatto and Drago (2020b) and Dong et al. (2021), energy resilience is a multi-dimensional index built on three pillars: renewable energy, energy access, and energy efficiency. The authors used 27 indicators retrieved from the Sustainable Energy for All (SEforAll) initiative by the World Bank to build an index for the year 2019 incorporating the three main facets: energy access, renewable sources, and efficiency. We follow this framework to create an ERI for a more prolonged period since data for all 27 indicators is not available for the 32 OECD countries included in this study for the period 2004–2020. The choice of the period of study is driven by the availability of data on the Environmental Policy Stringency Index for which the latest available data is for the year 2020. More specifically, we derive the ERI from a principal component analysis using four main variables representing the three pillars of the multi-dimensional index proposed by Gatto and Drago (2020b), renewable energy, energy access, and energy efficiency. Energy access is proxied by electricity access as a percentage of the population (Access). Energy intensity (Intens) is used as a proxy for energy efficiency following Payne et al. (2023). Energy intensity represents the ratio between energy supply and gross domestic product measured at purchasing power parity. Renewable energy is proxied by two indicators. First, renewable energy consumption as a percent of total final energy consumption (ConsumptionWB). Second, renewable energy generation in Terawatt-hour (TWh) (Generation) was retrieved from our world in data. Data for energy access, energy intensity, and renewable energy consumption are retrieved from the World Bank.

The principal component analysis (pca) is based on the eigenvalue decomposition of the covariance matrix. This method will create the ERI by combining several variables into a smaller set using the variance analysis (Latif et al., 2018). This technique is widely used in the literature to create multi-dimensional composite indices (Dabbous et al., 2023b, Dutta et al., 2019, Zhu et al., 2022). Particularly, Gatto and Busato (2020) performed pca to evaluate the energy vulnerability of 146 nations.

For capturing environmental awareness, we rely on the EAI of Dabbous et al. (2023a) (see also Horn et al., 2023 and Pelster et al., 2024). The EAI is based on more than 300 keywords that are first translated into each country's official language and then used to gather the search volume of these keywords on Google via Google Trends. The search volume is available for all OECD countries. Hence, we can compute an individual EAI for each country. Our conjecture is that increases (decreases) in the environmental awareness of a country's population will have a positive (negative) effect on the country's energy resilience. Hence, we compute the change in EAI as described in model (1).

$$ChangeEAI_{i,t} = \frac{EAI_{i,t}}{EAI_{i,t-1}} - 1 \quad (1)$$

The Environmental Policy Stringency Index (EPS) is retrieved from the OECD library. It is a country-specific composite index of the stringency of environmental policy. It is defined "as the degree to which environmental policies put an explicit or implicit price on polluting or environmentally harmful behavior." (OECD, 2016). The index uses 13 environmental policy instruments related to climate and air pollution to measure the degree of stringency. It ranges from 0 (not stringent) to 6 (highest degree of stringency). The latest available data on EPS are for the year 2020.

For the remaining control variables, this study uses Gross Domestic Product per capita (GDP), Carbon Dioxide Emissions (CO_2), and Foreign Direct Investment (FDI). According to Alsagr (2023), CO_2 emissions can positively influence renewable energy investments. Yang et al. (2019) and Alsagr (2023) state that an increase in economic development (GDP) tends to raise the level of investment in renewable energy. GDP can also influence climate change (Ma et al., 2023). FDI is also included as a control variable that can impact climate change (Ma et al., 2023) and affect energy security (Zhao et al., 2023).

Gross Domestic Product per capita (GDP) is in constant 2015 US$. Carbon Dioxide Emissions (CO_2) are measured in kiloton (kt). Finally, Foreign Direct Investment (FDI) represents the net inflows of investment as a percentage of GDP. Data for the three indicators are retrieved from the World Bank. The logarithm of all the variables except FDI which has negative values is used to facilitate the

Table 1
Variables and data sources.

Abbreviation	Full name	Definition	Source
Access	Energy access	Electricity access as a percentage of the population	World Bank https://data.worldbank.org/indicator/EG.ELC.ACCS.ZS
CO2	Carbon Dioxide Emissions in kiloton (kt)	Carbon Dioxide Emissions in kiloton (kt)	World Bank https://data.worldbank.org/indicator/EN.ATM.CO2E.KT
ConsumptionWB	Renewable energy consumption	Renewable energy consumption as a percent of total final energy consumption	World Bank https://data.worldbank.org/indicator/EG.FEC.RNEW.ZS
EAI	Environmental Awareness Index	Measures Google search volume of more than 300 keywords per country to proxy environmental awareness of the population	Google trends and authors' own calculations
EPS	Environmental Policy Stringency Index	A country-specific composite index of the stringency of environmental policy	OECD https://stats.oecd.org/Index.aspx?DataSetCode=EPS
ERI	Energy Resilience Index	Multi-dimensional index derived by principal component analysis built on three pillars: renewable energy, energy access, and energy efficiency	Own calculations
FDI	Foreign Direct Investment	Net inflows of investment as a percentage of GDP	World Bank https://data.worldbank.org/indicator/BX.KLT.DINV.WD.GD.ZS
GDP	Gross Domestic Product per capita	Gross Domestic Product per capita in constant 2015 US$	World Bank https://data.worldbank.org/indicator/NY.GDP.PCAP.KD
Generation	Renewable energy generation in Terawatt-hour	Renewable energy generation in Terawatt-hour	Ourworldindata.org https://ourworldindata.org/renewable-energy
Intens	Energy intensity	Energy intensity is used as a proxy for energy efficiency and represents the ratio between energy supply and gross domestic product measured at purchasing power parity	World Bank https://databank.worldbank.org/metadataglossary/world-development-indicators/series/EG.EGY.PRIM.PP.KD
RuleOfLaw	Rule of Law: Percentile Rank	Perceptions of the extent to which agents have confidence in and abide by the rules of society, and in particular the quality of contract enforcement, property rights, the police, and the courts, as well as the likelihood of crime and violence	World Bank https://databank.worldbank.org/source/worldwide-governance-indicators

interpretation of the results and to decrease heteroskedasticity and nonnormality (Charfeddine and Khediri, 2016).

An overview of all variables and data sources is presented in Table 1. Descriptive statistics of all variables are provided in Table 2.

Correlations between the four variables used to compute the ERI and correlations between the ERI and the independent variables are provided in Table 3. Overall, we only observe weak correlations with coefficients smaller than.30. The energy access in the different countries is not correlated to their energy intensity, consumption, and generation of renewable energy. This can be explained by the small variation of Access over time and among countries. The two measures of renewable energy are positively correlated with each other with a coefficient of.18 and statistical significance at the 1 %-level. The ERI is positively correlated with the Change in EAI and the GDP per capita. A negative correlation is observed between ERI and CO_2 emissions, environmental policy stringency, and foreign direct investments.

To elicit the appropriate regression models for our analysis, we run Hausman tests, tests of multicollinearity, heteroscedasticity, and cross-sectional independence with ERI as dependent and EAI, stringency, FDI, CO_2, and GDP (as well as their lagged values) as independent variables. The Hausman test results suggest using country-fixed-effects models. The two tested regression models (2) and (3) differ only regarding the time lags of the independent variables.

$$ERI_{i,t} = \beta_{1i} * EAI_{i,t} + \beta_{2i} * Stringency_{i,t} + \beta_{3i} * CO2_{i,t} + \beta_{4i} * FDI_{i,t} + \beta_{5i} * GDP_{i,t} + \alpha_i + u_{i,t} \tag{2}$$

$$ERI_{i,t} = \beta_{1i} * EAI_{i,t} + \beta_{2i} * Stringency_{i,t\ 1} + \beta_{3i} * CO2_{i,t\ 1} + \beta_{4i} * FDI_{i,t\ 1} + \beta_{5i} * GDP_{i,t\ 1} + \alpha_i + u_{i,t} \tag{3}$$

Where $ERI_{i,t}$ is the energy resilience index in country i in year t, $EAI_{i,t}$ is the relative change of the Environmental Awareness Index for country i from year t-1 to year t, and $Stringency_{i,t}$ is the environmental policy stringency in country i in year t, $CO2_{i,t}$ are the CO_2 emissions, $FDI_{i,t}$ are the foreign direct investments, and $GDP_{i,t}$ is the GDP per capita.

The Hausman (1978) test results confirm that the fixed effects model is the appropriate one to use (chi^2 (5) = 168.24 with p value= 0.00 < 0.05 for model 2 and chi^2 (5) = 173.06 with p value= 0.00 < 0.05 for model 3). Further, as the correlation coefficients indicate, multicollinearity is not a problem among the independent variables. Additionally, the respective VIFs of the independent variables in both models are calculated as none exceeds the value of 1.22. However, modified Wald tests for groupwise heteroscedasticity clearly show that the errors exhibit groupwise heteroscedasticity ($chi^2(32)$= 16134.59 with Prob>chi^2 = 0.00 for model 2 and $chi^2(32)$= 1593.7 with Prob>chi^2 = 0.00 for model 3). Pesaran's test of cross-sectional independence (Hoechle, 2007) clearly indicates cross-sectional dependence in the errors (PR=0.00; Average absolute value of the off-diagonal elements >= 0.42 for both models). To address these characteristics of our dataset, this study relies on panel regressions with Driscoll-Kraay standard errors and fixed effects that are robust to cross-sectional and temporal dependence (Hoechle, 2007). However, the fixed effects model does not account for possible endogeneity. Therefore, as a robustness check and to consider endogeneity concerns this study uses instrumental variables 2SLS-regressions and 2-step GMM estimations with three lags of the *Stringency*-variable as instruments.

An additional robustness check adds two lags of the variable *RuleOfLaw* as further instruments. According to the World Bank, *RuleOfLaw* "captures perceptions of the extent to which agents have confidence in and abide by the rules of society, and in particular the quality of contract enforcement, property rights, the police, and the courts, as well as the likelihood of crime and violence".[4]. The idea behind this robustness check is that more stringent environmental policy only will have an effect when firms and private persons follow the established laws. As such this variable is highly correlated with environmental policy stringency and is considered an adequate instrument.

5. Results and discussion

The results of panel regressions with country-fixed effects on ERI are presented in Table 4. The results support the existence of a positive relation between changes in environmental awareness and energy resilience. Hypothesis H1 is therefore validated. A 1% change (increase or decrease) in environmental awareness generates a change of magnitude between 2.4% and 3.4% in energy resilience. These results match the view of Edsand and Broich (2020) who advocate that environmental awareness is of major importance not only just for driving renewable energy transition but also for enabling individuals to make conscious choices to address the sustainability challenges in this case awareness is shown to influence energy resilience as a multi-dimensional index. The findings also present the empirical evidence needed to highlight the major relevance of developing environmental awareness to improve energy resilience. These results are in line with and advance the results of Al Masud (2023) who established that higher awareness of climate change is associated with a strong willingness among individuals to provide financial support for renewable energy initiatives. Specifically, a person possessing a heightened awareness of climate issues is shown to be 9.38% more willing to pay additional costs for renewable energy. The findings also align with Casaló et al. (2019) and Casaló and Escario (2018) who showed that environmental knowledge affects individuals' environmental attitudes which in turn fosters pro-environmental behavior. However, they advance prior works by showing that environmental awareness does not only shape peoples' attitudes or willingness to perform a certain behavior but it actually impacts energy resilience therefore presenting evidence for the importance of this factor as an essential element for energy transition and sustainable development.

Higher energy resilience is also observed in countries with more stringent environmental policies and higher GDP. Carbon emissions are negatively related to energy resilience. Specifically, a 1 % percent increase in environmental policy stringency drives an

[4] https://databank.worldbank.org/source/worldwide-governance-indicators

Table 2
Descriptive statistics.

	Mean	Std. Dev.	Min	Max	N
Panel A: Energy resilience variables					
Energy resilience index (ERI)	0	1	3.41	2.06	544
Electricity access (Access)	4.60	.00	4.58	4.61	544
Energy intensity (Intens)	1.37	.39	.20	2.76	544
Renewable energy generation (Generation)	3.28	1.49	2.81	6.71	544
Renewable energy consumption world bank (Consumption WB)	2.66	.86	.26	4.42	544
Panel B: Independent Variables					
CO_2 emissions (CO_2)	11.67	1.54	7.28	15.57	544
Change in environmental awareness index (EAI) * 10^2	.33	1.06	6.71	3.19	512
Environmental policy stringency (Stringency)	1.27	.31	0	1.77	544
Foreign direct investments (FDI)	4.65	11.15	40.08	106.59	544
GDP (GDP)	10.31	.61	8.87	11.38	544

Table 3
Pearson correlations.

Panel A: Energy resilience index variables						
	Access	Intens	Generation	ConsumptionWB		
Access	1					
Intens	0.03	1				
Generation	0.03	0.12 * **	1			
Consumption WB	0.01	0.11 * *	0.18 * **	1		
Panel B: Energy resilience index and independent variables						
	ERI	CO_2	EAI	Stringency	FDI	GDP
ERI	1					
CO_2	0.61 * **	1				
Change EAI	0.10 * *	0.09 * *	1			
Stringency	0.14 * **	0.23 * **	0.27 * **	1		
FDI	0.15 * **	0.10 * *	0.10 * *	0.04	1	
GDP	0.16 * **	0.04	0.12 * **	0.25 * **	0.01	1

Notes: We provide Pearson correlation coefficients. The symbols * ** and * * indicate statistical significance at the 1 % and 5 % levels, respectively. Coefficients that have p-values > =.10 are not considered statistically significant.

increase of magnitude between 0.18 % and 0.34 % in energy resilience. Therefore hypothesis H2 is supported and more stringent environmental policy is shown to positively influence energy resilience. This indicates that environmentally friendly ways of energy generation and consumption are associated with higher energy resilience. This result aligns with Li and Shao (2023) and Hassan et al. (2024) who show that environmental policy stringency can increase renewable energy consumption and innovation. The result aligns with Ma et al. (2023) who reveal that environmental regulations are essential to address climate change challenges, and with Ao et al. (2023) who show that environmental regulations reduce pollution, decrease CO2 emissions, and foster energy transition. It also matches Mandal and Madheswaran (2010) and Guo and Yuan (2020) who show that environmental regulations positively influence energy efficiency and are in line with the strand of literature advocating that environmental regulations can drive a reduction in energy intensity (Xu et al., 2022). However, this finding advances prior works by establishing that environmental policy stringency does not only influence renewable energy or energy efficiency separately but also has a significant positive impact on energy resilience considered a multi-dimensional index based on three pillars, renewable energy, energy access, and energy efficiency. As such this result highlights the crucial role that environmental regulations play in addressing energy crises, mitigating environmental degradation, and ensuring energy security. This matches the viewpoint of Sadik-Zada and Gatto (2023) who advocate that environmental policies and regulations are considered top-tier elements in shaping energy futures.

Finally, the result obtained shows the prevalence of the Porter Hypothesis across OECD countries and contradicts the Pollution Haven Hypothesis by showing that more stringent environmental regulations can eventually lead to higher energy resilience. This finding matches Hashmi and Alam (2019) who showed that an increase in environmental patent applications decreased carbon emissions in 29 OECD countries for the period 1999–2014. It also aligns with Xu (2000) who rejected the Pollution Haven Hypothesis by revealing that stringent environmental policies did not change competitiveness or trade patterns across 25 OECD countries. Further, this result complements Porter's Hypothesis (Porter and Linde, 1995), by revealing that environmental regulations will not only trigger technological innovation within firms and promote renewable energy sources use but will foster energy resilience a broader concept that encompasses energy access, and energy efficiency in addition to renewable energy.

These relations are robust and statistically significant (at least at the 5 %-level) among fixed-effect panel regressions with Driscoll-Kraay standard errors, 2SLS-regressions, and 2-step GMM estimations and when we use lagged variables as shown in Table 4. Further, the Kleibergen-Paap Wald F statistic that is adopted to check for the use of weak instruments is significant at the 5 % significance level, which reveals that the instruments used are considered valid. Therefore, the results of the instrumental variables regression are most likely considered to be reliable. The Kleibergen-Paap LM under-identification test results all have a p-value= 0.00, they are significant,

Table 4
Panel regressions with country-fixed effects on ERI.

	(1)	(2)	(3)	(4)	(5)	(6)
Change $EAI_{i,t}$	2.73 * * (1.24)	3.21 * * (1.52)	3.16 * * (1.51)	2.41 * * (1.11)	3.47 * * (1.47)	3.41 * * (1.47)
$Stringency_{i,t}$	.18 * ** (.04)	.27 * * (.12)	.34 * * (.14)			
$CO_{2i,t}$	1.56 * ** (.24)	1.35 * ** (.17)	1.35 * ** (.17)			
$FDI_{i,t}$* 10^2	.26 * * (.10)	.26 * ** (.09)	.26 * ** (.09)			
$GDP_{i,t}$	1.31 * ** (.22)	1.12 * ** (.16)	1.07 * ** (.16)			
$Stringency_{i,t\ 1}$				.21 * ** (.06)	.24 * * (.10)	.25 * * (.10)
$CO_{2\ i,t\ 1}$				1.66 * ** (.19)	1.43 * ** (.12)	1.44 * ** (.12)
$FDI_{\ i,t\ 1}$* 10^2				.16 (.12)	.23 * * (.11)	.25 * * (.11)
$GDP_{\ i,t\ 1}$				1.44 * ** (.21)	1.29 * ** (.16)	1.27 * ** (.16)
α	4.57 * * (1.89)			4.33 * * (1.85)		
Model	Driscoll-Kraay	2SLS with instruments	2-Step GMM with instruments	Driscoll-Kraay	2SLS with instruments	2-Step GMM with instruments
R^2	0.58	.56	.55	0.57	.54	.54
Kleibergen-Paap Chi^2 P-value		0.00	0.00		0.00	0.00
Kleibergen-Paap Wald F statistic		55.27	55.01		101.47	101.48
Hansen J statistic Chi^2 P-value		0.28	0.15		0.22	0.22
Endogeneity test Chi^2 P-value		0.20	0.18		0.26	0.26
N	512	448	448	512	448	448

Notes: The Table presents the estimated coefficients, and robust standard errors figuring in parentheses and R^2 for panel regression analysis with model (2) in columns (1)-(3) and with model (3) in columns (4)-(5). The symbols * ** and * * indicate statistical significance at the 1 % and 5 % levels, respectively. Example: Regressing $ERI_{i,t}$ on model (2) with panel regressions and Driscoll-Kraay standard errors (see column (1)) generates a coefficient of 2.73 with a p-value $<$ .05 for relative changes in $EAI_{i,t}$ as an independent variable.

and this shows that a strong relationship exists between the instrument used and the endogenous variable considered. The Hansen J statistic that is used to test for overidentification fails to reject the null hypothesis that the overidentification restrictions are valid. Hence, the instrumental variables models used are all considered valid.

In the following, and as a robustness check, we dig deeper into the individual components of energy resilience. Instead of the ERI, we use Generation, Consumption WB, Access, and Intens as dependent variables in 2SLS-regressions and 2-step GMM estimations. The respective results are presented in Table 5 and Table 6. According to the results in Table 5, increases in environmental awareness are followed by higher levels of renewable energy consumption and generation. Hence, our findings further support that an increase in the awareness level leads to an increase in renewable energy consumption (see Al Masud, 2023) and contributes to a smoother energy transition process (Egert et al., 2021). Furthermore, the generation and consumption of renewable energy are higher in countries with more stringent environmental policies and higher GDP. This is a further indication that environmental policy stringency has the desired effect of fostering the ramp-up of sustainable and renewable energies (Feng et al., 2023) and their consumption by the population (Hassan et al., 2024).

If at all, foreign direct investments are negatively related to renewable energy generation and consumption. Of course, renewable energy production and consumption and carbon emissions have a mutual relationship. We control this mutual relationship by using 2SLS and 2-step GMM models. The negative relation between these two variables may be interpreted as a sign of a steady decarbonization of the countries' energy systems in which hardly a country overtakes another, i.e. the countries that already have high renewable energy capacities and, therefore, lower carbon emissions, also have higher renewable energy capacities in the following year. Moreover, our results would support that the countries with already lower carbon emissions are more ambitious in expanding their renewable energy production than countries with higher carbon emissions.where $Y_{i,t}$ is the renewable energy generation (Generation) or the renewable energy consumption according to the World Bank (Consumption WB) in country i in year t, $EAI_{i,t}$ is the relative change of the Environmental Awareness Index for country i from year t-1 to year t, and $Stringency_{i,t}$ is the environmental policy stringency in country i in year t, $CO2_{i,t}$ are the CO_2 emissions, $FDI_{i,t}$ are the foreign direct investments, and $GDP_{i,t}$ is the GDP per capita. The symbols * ** and * * indicate statistical significance at the 1 % and 5 % levels, respectively. Example: Regressing $Generation_{i,t}$ on a model with panel regressions and Driscoll-Kraay standard errors (see column (1)) produces a coefficient of 4.85 with a p-value $<$ .05 for relative changes in $EAI_{i,t}$ as an independent variable.

The results for energy access as a dependent variable in Table 6 are statistically significant. The signs of the coefficients are as expected. However, the magnitude of the coefficients does not support the economic significance of the relations. The reason for the

Table 5
Panel regressions with country-fixed effects on Generation and Consumption WB.

	Generation				Consumption WB			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Change $EAI_{i,t}$	4.85 * * (2.25)	4.91 * * (2.25)	4.48 * * (2.08)	4.99 * * (2.04)	2.75 * * (1.30)	2.97 * * (1.26)	2.71 * * (1.29)	2.92 * * (1.26)
$Stringency_{i,t}$	1.10 * ** (.30)	1.05 * ** (.30)			.23 * * (.11)	.21 * * (1.26)		
$CO_{2i,t}$	1.01 * ** (.13)	1.00 * ** (.13)			1.16 * ** (.14)	1.22 * ** (.11)		
$FDI_{i,t}$* 10^2	.10 (.13)	.09 (.13)			.22 * ** (.08)	.20 * ** (.10)		
$GDP_{i,t}$	1.96 * ** (.21)	1.93 * ** (.21)			.96 * ** (.14)	1.10 * ** (.13)		
$Stringency_{i,t\ 1}$			1.08 * ** (.29)	1.05 * ** (.28)			.29 * * (.12)	.21 * * (.09)
$CO_{2\ i,t\ 1}$			.87 * ** (.14)	.88 * ** (.14)			1.15 * ** (.14)	1.23 * ** (.11)
$FDI_{i,t\ 1}$* 10^2			.21 (.13)	.21 (13)			.22 * ** (.08)	.21 * * (.10)
$GDP_{i,t\ 1}$			1.89 * ** (.19)	1.85 * ** (.19)			.91 * ** (.14)	1.09 * ** (.13)
Model	2SLS with instruments	2-Step GMM with instruments	2SLS with instruments	2-Step GMM with instruments	2SLS with instruments	2-Step GMM with instruments	2SLS with instruments	2-Step GMM with instruments
R^2	.46	.47	.46	.46	.56	.54	0.55	0.54
Kleibergen-Paap Chi^2 P-value	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Kleibergen-Paap Wald F statistic	23.43	23.43	21.65	21.65	55.27	55.01	101.48	101.47
Hansen J statistic Chi^2 P-value	0.11	0.11	0.18	0.18	0.28	0.22	0.15	0.22
Endogeneity test Chi^2 P-value	0.00	0.00	0.00	0.00	0.20	0.26	0.18	0.26
N	448	448	448	448	448	448	448	448

Notes: The Table presents the estimated coefficients, and robust standard errors figuring in parentheses and R^2 for panel regression analysis with the model

$$Y_{i,t} = \beta_{1i} * EAI_{i,t} + \beta_{2i} * Stringency_{i,t} + \beta_{3i} * CO2_{i,t} + \beta_{4i} * FDI_{i,t} + \beta_{5i} * GDP_{i,t} + \alpha_i + u_{i,t},$$

small magnitude is likely the very high rate of energy access in the analyzed countries with little variation. Therefore, we turn to the results for energy intensity as a dependent variable. Surprisingly at first glance is the absence of a significant relationship between energy intensity and changes in environmental awareness.

However, we observe a significant negative relation between environmental policy stringency and energy intensity. Our interpretation is that companies stick to energy-intensive processes until more stringent policies make the processes unprofitable and investments in less energy-intensive processes more profitable. This would be in line with the findings of Xu et al. (2022), stating that stricter environmental policy compels enterprises to enhance innovation. Changes in environmental awareness may only have an indirect influence through the positive correlation between changes in environmental awareness and environmental policy stringency (Pearson correlation coefficient of 0.27 with p-value<0.01). Higher GDP is related to lower levels of energy intensity. This relation may be explained by the higher importance of the service sector in countries with higher GDP. The mutuality of carbon emissions and energy intensity is considered in the 2SLS and 2-step GMM models. Nevertheless, the relation between both variables is positive and significant at the 1 %-level, indicating that countries with high carbon emissions lower their energy intensity less (increase it stronger) than countries with lower carbon emissions.where $Y_{i,t}$ is the access to electricity (Access) or the energy intensity (Intens) in country i in year t, $EAI_{i,t}$ is the relative change of the Environmental Awareness Index for country i from year t-1 to year t, and $Stringency_{i,t}$ is the environmental policy stringency in country i in year t, $CO2_{i,t}$ are the CO_2 emissions, $FDI_{i,t}$ are the foreign direct investments, and $GDP_{i,t}$ is the GDP per capita. The symbols * ** and * * indicate statistical significance at the 1 % and 5 % levels, respectively. Example: Regressing $Intens_{i,t}$ on a model with panel regressions and Driscoll-Kraay standard errors (see column (5)) produces a coefficient of.52 with a p-value > .10 for relative changes in $EAI_{i,t}$ as an independent variable.

The results explain how awareness can help in increasing the consumption and generation of renewable energy and also enhance energy access. As such, environmental awareness is shown to endorse renewable energy sources use and to stay aware of the existing energy infrastructure that contributes to environmental pollution. Environmentally aware individuals will exhibit a positive attitude

Table 6
Panel regressions with country-fixed effects on Access and Intens.

	Access				Intens			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Change $EAI_{i,t}$	.015 * * (.006)	.022 * * (.010)	.016 * * (.007)	.025 * * (.011)	.52 (.34)	.27 (.31)	.25 (.42)	.16 (.41)
$Stringency_{i,t}$	.006 * ** (.002)	.006 * ** (.002)			.15 * ** (.05)	.18 * ** (.04)		
$CO_{2i,t}$	.002 * * (.000)	.003 * ** (.001)			.50 * ** (.04)	.49 * ** (.04)		
$FDI_{i,t}* 10^2$	.000 * (.000)	.001 * * (.000)			.00 (.02)	.02 (.02)		
$GDP_{i,t}$	.001 * ** (.000)	.001 * * (.001)			.89 * ** (.04)	.87 * ** (.04)		
$Stringency_{i,t-1}$			.005 * ** (.002)	.005 * ** (.001)			.13 * ** (.04)	.14 * ** (.04)
$CO_{2\ i,t-1}$			.003 * ** (.001)	.004 * ** (.001)			.48 * ** (.03)	.48 * ** (.03)
$FDI_{\ i,t-1}* 10^2$			.001 * (.000)	.001 * * (.000)			.02 (.03)	.01 (.03)
$GDP_{\ i,t-1}$			.001 (.001)	.001 (.001)			.91 * ** (.05)	.91 * ** (.05)
Model	2SLS with instruments	2-Step GMM with instruments	2SLS with instruments	2-Step GMM with instruments	2SLS with instruments	2-Step GMM with instruments	2SLS with instruments	2-Step GMM with instruments
R^2	0.25	.27	0.19	0.24	0.82	0.81	0.73	0.73
Kleibergen-Paap Chi^2 P-value	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Kleibergen-Paap Wald F statistic	32.69	55.27	57.1	101.47	55.01	55.02	101.47	101.48
Hansen J statistic Chi^2 P-value	0.06	0.15	0.21	0.54	0.07	0.07	0.31	0.31
Endogeneity test Chi^2 P-value	0.52	0.52	0.03	0.02	0.01	0.01	0.00	0.00
N	448	448	448	448	448	448	448	448

Notes: The Table presents the estimated coefficients, and robust standard errors figuring in parentheses and R^2 for panel regression analysis with the model

$$Y_{i,t} = \beta_{1i} * EAI_{i,t} + \beta_{2i} * Stringency_{i,t} + \beta_{3i} * CO2_{i,t} + \beta_{4i} * FDI_{i,t} + \beta_{5i} * GDP_{i,t} + \alpha_i + u_{i,t},$$

toward the environment and acknowledge the imperative for a shift towards sustainable energy and this will help increase energy access since this will facilitate the process of integrating privately owned sources of energy. These results align with Chatzistamoulou and Koundouri (2022) who show that awareness is essential to ensure the transition to sustainability. They advance prior studies by revealing the channel through which this transition occurs, specifically environmental awareness drives renewable energy consumption and generation and increases energy access therefore yielding higher energy resilience. As such the obtained results take a step forward and help present a framework that seeks to elucidate the process through which changes in individuals' environmental awareness can lead to behavioral changes affecting energy resilience and sustainable transition. The findings also reveal that this awareness is not sufficient to push stakeholders and firms to decrease their energy intensity but might need to be supported by stronger mandatory measures. By implementing stringent policy measures, governments provide incentives for both businesses and individuals to increase energy resilience and this is realized through the increase in renewable energy generation and consumption, lower energy intensity, and better energy access.

Taken together the results provide indications that increases in environmental awareness increase energy resilience by leading to higher renewable energy consumption and generation. This makes sense since the population, by itself, can contribute to higher renewable energy production and consumption by e.g. installing solar panels. More stringent energy policies lead companies to decrease the energy intensity of their processes and can stimulate investments in renewable energy generation and consumption. Both avenues, individually and combined, lead to higher energy resilience.

Overall the results dictate that by actively promoting and implementing environmental regulations OECD countries can significantly increase energy efficiency, increase renewable energy and energy access as well as decrease energy intensity, therefore, contributing to the global efforts to foster energy transition and reduce CO2 emissions. This matches Ma et al. (2023) who established the role of regulations in reducing CO2 emissions and promoting sustainable development. These findings show that by implementing environmental strategies, countries can effectively enhance energy resilience therefore complementing the results of Chen et al. (2022) who advocate that environmental policies increase energy efficiency and foster resilience.

The obtained results take a step forward and show that the Pollution Haven Hypothesis does not hold for OECD countries. The findings support the Porter Hypothesis since environmental regulations are shown to enhance energy resilience, increase renewable energy, and energy access, and decrease energy intensity therefore fostering the use of more eco-friendly technologies and sustainable and renewable energy sources (Porter and Linde, 1995).

The relationship between environmental policy stringency on the one hand and energy intensity, renewable energy generation, and consumption on the other, however, could be influenced by the perception of the companies regarding the quality of contracts and law enforcement. We, therefore, provide an additional robustness check for which we add two lags of the World Bank's *RuleOfLaw* indicator as a further instrument. The results are presented in Tables 7, 8, and 9. The coefficients stay similar in magnitude and their statistical significance levels stay the same. Hence, we consider our results robust to further governance aspects.where $Y_{i,t}$ is the renewable energy generation (Generation) or the renewable energy consumption according to the World Bank (Consumption WB) in country i in year t, $EAI_{i,t}$ is the relative change of the Environmental Awareness Index for country i from year t-1 to year t, and $Stringency_{i,t}$ is the environmental policy stringency in country i in year t, $CO2_{i,t}$ are the CO_2 emissions, $FDI_{i,t}$ are the foreign direct investments, and $GDP_{i,t}$ is the GDP per capita. The symbols * ** and * * indicate statistical significance at the 1 % and 5 % levels, respectively. Example: Regressing $Generation_{i,t}$ on a model with panel regressions and Driscoll-Kraay standard errors (see column (1)) produces a coefficient of 4.85 with a p-value $< .05$ for relative changes in $EAI_{i,t}$ as an independent variable.where $Y_{i,t}$ is the access to electricity (Access) or the energy intensity (Intens) in country i in year t, $EAI_{i,t}$ is the relative change of the Environmental Awareness Index for country i from year t-1 to year t, and $Stringency_{i,t}$ is the environmental policy stringency in country i in year t, $CO2_{i,t}$ are the CO_2 emissions, $FDI_{i,t}$ are the foreign direct investments, and $GDP_{i,t}$ is the GDP per capita. The symbols * ** and * * indicate statistical significance at the 1 % and 5 % levels, respectively. Example: Regressing $Intens_{i,t}$ on a model with panel regressions and Driscoll-Kraay standard errors (see column (5)) produces a coefficient of.52 with a p-value $> .10$ for relative changes in $EAI_{i,t}$ as an independent variable.

6. Conclusion, implications, and future directions

This study aims to explore the influence of both environmental policy stringency and environmental awareness on energy resilience. It focuses on increasing the understanding of the importance of these two variables in increasing energy resilience, a multidimensional concept needed to efficiently address climate change concerns. Moreover, it investigates the pathways by which environmental awareness and environmental policy stringency impact energy resilience. Specifically, it examines whether and how these variables influence renewable energy, energy access, and energy efficiency. The findings show that both environmental policy stringency and environmental awareness have a significant positive influence on energy resilience. Additionally, they exert a positive effect on renewable energy consumption and generation and contribute to enhancing energy access. Regarding energy efficiency, only environmental policy stringency demonstrates a significant negative impact on energy intensity, i.e. a positive impact on energy efficiency while environmental awareness is shown not to have a direct influence on this variable.

The study results have several policy implications for policymakers, governments, and firms. They first shed the lead on the importance of increasing individuals' environmental awareness as it has the potential to enhance energy resilience and increase renewable energy use and energy access. The government is encouraged to adopt participatory measures aiming to increase environmental public awareness and affect lifestyles. Based on our findings, private institutions, and national authorities should focus on

Table 7
Panel regressions with country-fixed effects on ERI.

	(1)	(2)	(3)	(4)
Change $EAI_{i,t}$	3.22 * * (1.53)	3.26 * * (1.44)	3.47 * * (1.47)	3.65 * * (1.42)
$Stringency_{i,t}$	.27 * * (.12)	.32 * * (.14)		
$CO_{2i,t}$	1.35 * ** (.17)	1.34 * ** (.17)		
$FDI_{i,t}$* 10^2	.26 * ** (.09)	.26 * ** (.09)		
$GDP_{i,t}$	1.12 * ** (.16)	1.12 * ** (.15)		
$Stringency_{i,t\ 1}$			.24 * * (.10)	.23 * * (.10)
$CO_{2\ i,t\ 1}$			1.43 * ** (.12)	1.42 * ** (.12)
$FDI_{\ i,t\ 1}$* 10^2			.23 * * (.11)	.25 * * (.11)
$GDP_{\ i,t\ 1}$			1.29 * ** (.16)	1.31 * ** (.14)
α				
Model	2SLS with instruments	2-Step GMM with instruments	2SLS with instruments	2-Step GMM with instruments
R^2	.56	.56	.54	.54
Kleibergen-Paap Chi^2 P-value	0.00	0.00	0.00	0.00
Kleibergen-Paap Wald F statistic	33.52	27.40	67.75	67.75
Hansen J statistic Chi^2 P-value	0.53	0.43	0.39	0.39
Endogeneity test Chi^2 P-value	0.26	0.22	0.27	0.27
N	448	448	448	448

Notes: The Table presents the estimated coefficients, and robust standard errors figuring in parentheses and R^2 for panel regression analysis with model (2) in columns (1)-(3) and with model (3) in columns (4)-(5). The symbols * ** and * * indicate statistical significance at the 1 % and 5 % levels, respectively. Example: Regressing $ERI_{i,t}$ on model (2) with panel regressions and Driscoll-Kraay standard errors (see column (1)) generates a coefficient of 2.73 with a p-value $< .05$ for relative changes in $EAI_{i,t}$ as an independent variable.

Table 8
Panel regressions with country-fixed effects on Generation and Consumption WB.

	Generation				Consumption WB			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Change $EAI_{i,t}$	6.77 * ** (2.48)	7.55 * ** (2.42)	7.17 * ** (2.72)	7.43 * ** (2.66)	2.76 * * (1.31)	2.97 * * (1.26)	2.82 * * (1.23)	3.13 * * (1.21)
$Stringency_{i,t}$	.62 * ** (.15)	.59 * ** (.15)			.23 * * (.11)	.21 * * (.09)		
$CO_{2i,t}$	1.16 * ** (.13)	1.19 * ** (.13)			1.16 * ** (.14)	1.22 * ** (.11)		
$FDI_{i,t}* 10^2$	.19 (.12)	.23 * (.12)			.22 * ** (.08)	.20 * ** (.10)		
$GDP_{i,t}$	2.05 * ** (.20)	2.13 * ** (.19)			.96 * ** (.14)	1.10 * ** (.13)		
$Stringency_{i,t\ \ 1}$			.61 * ** (.15)	.59 * ** (.14)			.24 * * (.10)	.20 * * (.09)
$CO_{2\ i,t\ \ 1}$			1.09 * ** (.14)	1.11 * ** (.14)			1.16 * ** (.14)	1.22 * ** (.11)
$FDI_{\ i,t\ \ 1}* 10^2$			.24 * (.12)	.27 * * (12)			.24 * ** (.08)	.21 * * (.10)
$GDP_{\ i,t\ \ 1}$			1.89 * ** (.19)	2.15 * ** (.19)			.98 * ** (.12)	1.12 * ** (.12)
Model	2SLS with instruments	2-Step GMM with instruments	2SLS with instruments	2-Step GMM with instruments	2SLS with instruments	2-Step GMM with instruments	2SLS with instruments	2-Step GMM with instruments
R^2	.51	.51	.48	.48	.56	.54	0.56	0.54
Kleibergen-Paap Chi^2 P-value	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Kleibergen-Paap Wald F statistic	33.52	33.52	67.75	67.75	33.52	67.75	120.76	67.75
Hansen J statistic Chi^2 P-value	0.09	0.09	0.13	0.13	0.53	0.39	0.53	0.39
Endogeneity test Chi^2 P-value	0.04	0.04	0.03	0.03	0.26	0.27	0.26	0.27
N	448	448	448	448	448	448	448	448

Notes: The Table presents the estimated coefficients, and robust standard errors figuring in parentheses and R^2 for panel regression analysis with the model

$$Y_{i,t} = \beta_{1i} * EAI_{i,t} + \beta_{2i} * Stringency_{i,t} + \beta_{3i} * CO2_{i,t} + \beta_{4i} * FDI_{i,t} + \beta_{5i} * GDP_{i,t} + \alpha_i + u_{i,t},$$

educating citizens about the risks of climate change and increase their environmental awareness through proposing specific programs, certificates, and free seminars for example. Increasing environmental awareness should be considered as one of the top priorities aiming to inform citizens about the ways, possibilities, and benefits of using renewable energy sources, lowering energy intensity, and achieving higher energy efficiency which consequently leads to higher energy resilience. OECD countries are urged to increase knowledge sharing about renewable energy sources and capacity building (Ma et al., 2023), this in turn will increase environmental awareness shown to foster the transition toward renewable energy and to increase energy resilience. One way to do so would be by integrating specific educational programs and workshops in the educational systems, particularly since environmental knowledge and environmental awareness are shown to increase pro-environmental behavior and raise investment in renewable energy (Casaló et al., 2019; Ioannidis et al., 2023). Further, to achieve higher levels of awareness towards greener solutions, officials and policymakers need to reinforce education related to renewable energy sources in schools. Education is highly effective in increasing awareness and changing people's attitudes toward more pro-environmental behavior (Broughel and Hampl, 2018; Koirala et al., 2018). National authorities are encouraged to evaluate individuals' and firms' behavioral-oriented approaches aiming to collect valuable information needed to increase environmental awareness and knowledge. This is considered essentially important to foster environmental transition and complement green technology-oriented innovation efforts (Aldieri et al., 2022). Finally, the use of social media channels could play an important role in increasing environmental awareness particularly since the literature established that the use of social media can raise environmental awareness which in turn promotes a beneficial behavioral conduct on environmental sustainability (Hamid et al., 2017).

Second, the findings revealing the importance of environmental policy stringency for energy resilience shed light on the pivotal role of environmental policies in ensuring higher energy resilience. As such governments and policymakers are urged to set appropriate regulations and institutional frameworks needed for the development and adoption of sustainable energy sources that are essential to decrease energy intensity. As argued by Omri and Boubaker (2024) and Omri and Jabeur, (2024) the creation of a strong regulatory framework to efficiently enforce environmental policies is a necessary condition for the successful implementation of environmental regulations. Additionally, since environmental regulations can promote energy resilience, renewable energy, and energy efficiency considered essential to fostering environmental transition, OECD countries are urged to adopt stringent environmental policies. This

Table 9
Panel regressions with country-fixed effects on Access and Intens.

	Access				Intens			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Change $EAI_{i,t}$	.020 * * (.010)	.019 * * (.009)	.016 * * (.007)	.022 * * (.011)	.34 (.34)	.28 (.31)	.25 (.42)	.15 (.41)
$Stringency_{i,t}$	.007 * ** (.002)	.006 * ** (.002)			.10 * * (.04)	.18 * ** (.04)		
$CO_{2i,t}$	.003 * ** (.001)	.003 * ** (.001)			.50 * ** (.04)	.49 * ** (.04)		
$FDI_{i,t}$* 10^2	.000 * * (.000)	.000 * * (.000)			.01 (.02)	.02 (.02)		
$GDP_{i,t}$	.002 * ** (.001)	.001 * * (.001)			.90 * ** (.04)	.88 * ** (.04)		
$Stringency_{i,t\ 1}$			.006 * ** (.002)	.005 * ** (.001)			.13 * ** (.04)	.14 * ** (.04)
$CO_{2\ i,t\ 1}$			.004 * ** (.001)	.004 * ** (.001)			.48 * ** (.03)	.48 * ** (.03)
$FDI_{\ i,t\ 1}$* 10^2			.001 * * (.000)	.000 * * (.000)			.02 (.03)	.01 (.03)
$GDP_{\ i,t\ 1}$			.001 (.001)	.001 (.001)			.91 * ** (.05)	.91 * ** (.05)
Model	2SLS with instruments	2-Step GMM with instruments	2SLS with instruments	2-Step GMM with instruments	2SLS with instruments	2-Step GMM with instruments	2SLS with instruments	2-Step GMM with instruments
R^2	.27	.27	.24	.24	.83	.81	.73	0.73
Kleibergen-Paap Chi^2 P-value	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Kleibergen-Paap Wald F statistic	33.52	33.52	67.75	67.75	33.52	27.40	67.75	67.75
Hansen J statistic Chi^2 P-value	0.07	0.07	0.58	0.58	0.07	0.31	0.60	0.60
Endogeneity test Chi^2 P-value	0.66	0.66	0.01	0.01	0.16	0.01	0.00	0.00
N	448	448	448	448	448	448	448	448

Notes: The Table presents the estimated coefficients, and robust standard errors figuring in parentheses and R^2 for panel regression analysis with the model

$$Y_{i,t} = \beta_{1i} * EAI_{i,t} + \beta_{2i} * Stringency_{i,t} + \beta_{3i} * CO2_{i,t} + \beta_{4i} * FDI_{i,t} + \beta_{5i} * GDP_{i,t} + \alpha_i + u_{i,t},$$

joins the view of Usman et al. (2024) who argue that the design and implementation of more stringent and successful environmental regulations must be considered by policymakers. However, as stated by Ma et al. (2023) they will also need to offer guidance on best practices to improve energy resilience and its components. Further regulations can be issued to enhance the infrastructure required to ensure higher energy access across the population particularly since energy access represents an essential component for energy resilience. Moreover, to foster renewable energy which represents the major driver of energy resilience, OECD countries are urged to set regulations aiming to realize renewable energy goals. They can provide economic incentives, and establish emission restrictions, therefore encouraging renewable investments from both businesses and individuals. Further regulations can be used to make clean energy more competitive with conventional fossil fuels.

This study might suffer from some limitations. First, it uses four variables to compute the energy resilience index. Future works can extend this method by using a bigger number of variables once data becomes available. However, the results remain valid, particularly since the empirical exercise conducted confirms that the obtained results are consistent when using the computed energy resilience index and when analyzing the impact of environmental awareness and environmental policy stringency on each of the considered four variables separately. Second, the study considers OECD countries only, this limits the generalization of results particularly since other regions could be characterized by other levels of environmental awareness, different socioeconomic contexts, and distinct energy profiles (see e.g. the high level of energy access among OECD countries that should be lower in many countries around the world), and diverse policy frameworks, which may yield altered outcomes. Future studies can consider a larger set of countries once data for the environmental policy stringency index becomes available for these nations and compare the findings across developing and developed countries. Third by focusing on environmental policy and environmental awareness this study might not offer a comprehensive framework to depict all the factors contributing to energy resilience. Future works can explore a wider range of factors related to climate change and energy crises. Finally, future research should prioritize the analysis of emerging economies that have witnessed substantial economic growth while maintaining comparatively lenient environmental regulations.

CRediT authorship contribution statement

Amal Dabbous: Writing – original draft, Validation, Methodology, Formal analysis, Data curation, Conceptualization. **Alexandre Croutzet:** Writing – review & editing, Writing – original draft, Validation, Investigation, Conceptualization. **Matthias Horn:** Writing – original draft, Validation, Methodology, Formal analysis, Data curation, Conceptualization.

Declaration of Competing Interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: Alexandre Croutzet reports article publishing charges was provided by TELUQ University. If there are other authors, they declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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