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Renewables, taxes and competitive markets: the role of energy policies on the EU's sustainable energy consumption

María Teresa García-Álvarez[1] · Gustavo Pineiro-Villaverde[2] · Isabel Soares[3]

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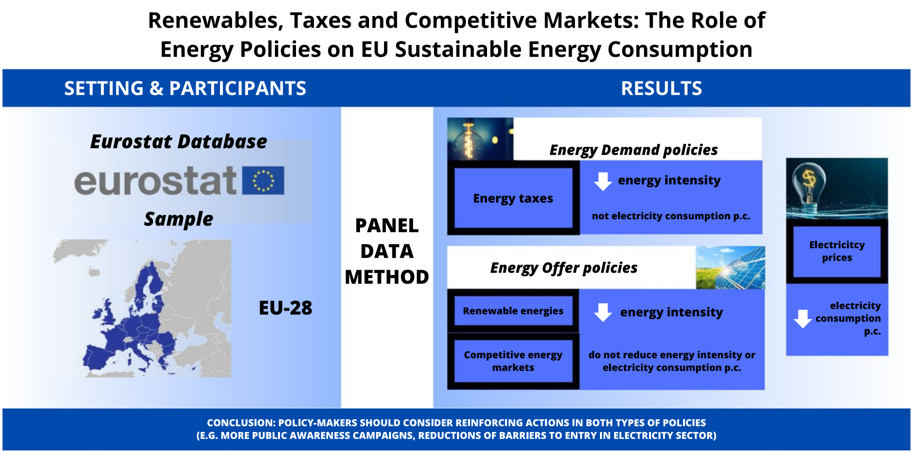
Abstract

In recent years, the European Union has made sustainable consumption and production a political priority, to address economic and social development within the capacity of the ecosystem. To this end, it has put in place several actions related to resource efficiency, energy taxation and the promotion of renewable energies. This has been positive in terms of production, but less progress has been achieved in consumption. Greater understanding of the factors that influence sustainable energy consumption is particularly important. This paper investigates the effects of energy demand policies (energy taxes) and energy supply policies (renewable energies development, competitive energy markets and eco-innovation) on sustainable energy consumption in the EU-28 from 2008 to 2019. This research employs a panel data model to investigate the study's hypotheses. Our results show that energy tax policies and clean energy have reduced energy intensity. However, electricity prices have been the greatest determinant in reducing total energy consumption. In light of its findings, this paper makes recommendations for several crucial measures for sustainable energy consumption to policymakers.

Graphical abstract



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Keywords Sustainable energy policies · Resource efficiency · Climate change · Panel data method

1 Introduction

Sustainable development has been a key strategy in the European Union (EU) in recent decades, with its concomitant challenges: climate change and clean energy, sustainable transport, sustainable production and consumption, conservation and management of natural resources, public health, social inclusion, demography and migration, and global poverty. Concrete actions must be developed in these areas that enable society to satisfy its needs without eroding living standards (Li et al., 2022; Micah et al., 2023; Zhang et al., 2022).

The traditional model of economic development based on increasing resource use and harmful emissions is not sustainable in the long-term. The second objective of the European Union's 7th Environment Action Programme established the need to "*turn the European Union into a resource-efficient, green and competitive low-carbon economy*" (European Commission, 2013, p. 7).

Moreover, the European Environment Agency highlighted that "*new governance approaches that transcend national boundaries and engage businesses and society more fully are necessary*" (European Environment Agency, 2015, p.3). Integrated production-consumption systems that fulfil societal functions should be developed, rather than seeking isolated efficiency improvements. This perspective entails focusing on economic, social and environmental systems that organise society's resource use and do not focus merely on material flows.

The EU has made resource efficiency and climate change political priorities. The EU sustainable development strategy (Council of the European Union, 2006) sets the goal of promoting sustainable consumption and production patterns. Economic and social development must be addressed within the capacity of the ecosystem and economic growth decoupled from environmental degradation.

Energy is an essential component for achieving sustainable development as it is highly correlated with social, economic, and environmental development. The EU has rolled out several action plans to achieve sustainable energy production, a secure energy supply and a competitive environment. These reference Directive 2009/72/EC and Directive 2009/73/EC on common rules for the internal energy market in the EU (European Commission, 2009a; b), Directive 2009/28/EC (European Commission, 2009c), Resource-Efficient Europe (Council of the European Union, 2011a) and the European Energy Security Strategy (Council of the European Union, 2014a). Likewise, the European Efficiency Plan (Council of the European Union, 2011b) and the European Energy Security Strategy (Council of the European Union, 2014a) seek to promote sustainable energy consumption in the EU.

More recently, the European Green Deal sets zero net emissions by 2050 as its goal (Council of the European Union, 2019). Sustainability in both production and consumption are essential, among other factors, if that aim is to be achieved. The Fit for 55 package (Fig. 1), part of the European Green Deal, is a preliminary approach to achieving the target of zero net emissions by 2050. Likewise, it sets an intermediate goal of reducing emissions by at least 55% from 1990 levels by 2030.

The package is based on eight proposals to revise existing laws and five new proposals (Council of the European Union, 2021). Those to revise EU legislation are based on:

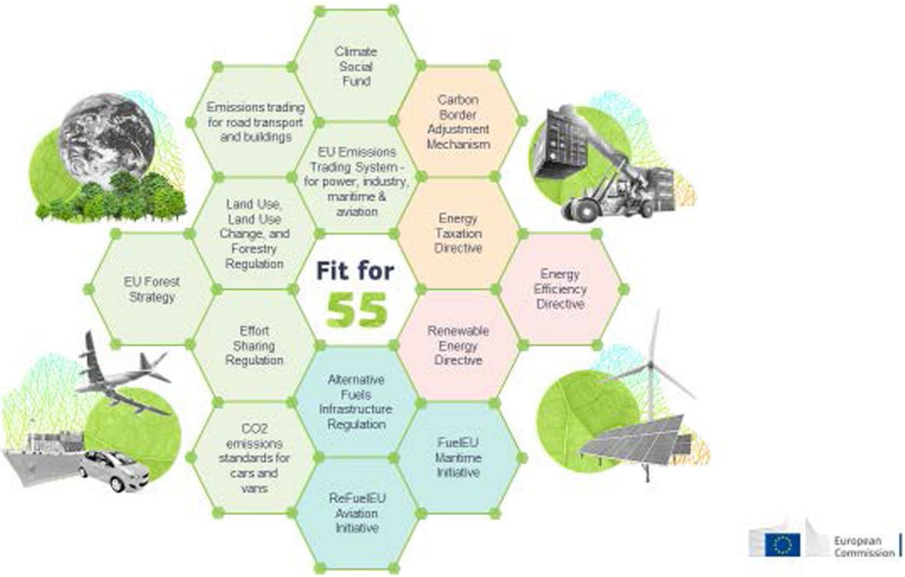

Fig. 1 "Fit for 55 package" scheme. Source: European Commission, 2021

(1) tougher reduction targets in the construction, road, domestic maritime transport, agriculture, waste and small industry sectors; (2) a more ambitious RES-E target in energy use by 2030 (40% of energy use from these clean production technologies); (3) a more demanding energy efficiency target (from 32.5 to 36%); (4) lower CO_2 emissions by new cars (55% reduction between 2021 and 2030 and zero emissions by 2035); (5) an emission trading system, with the aim of reducing the overall emissions cap per sector; (6) clean energy fuels in infrastructure (ports and airports); (7) an energy taxation directive, in order to align energy products taxation with climate change policies. The new proposals, meanwhile, include quality/quantity upgrades, as well as the resilience of the forests in the EU, by means of an EU Forest Strategy, as well as promoting citizens' investments in energy efficiency, clean mobility and RES-E by creating a social climate fund.

The EU can report a positive trend from a production perspective, which is more sustainable, but it has made less progress in consumption (European Environment Agency, 2015; Hale, 2018; Pineiro-Villaverde & García-Álvarez, 2022).

Therefore, it is particularly important to advance research in the field of sustainable energy consumption to obtain a better comprehension of its determinants. Moreover, previous studies have been mainly based on the analysis of a specific sustainable energy consumption policy: energy taxes (Wolde-Rufael & Mulda-Weldemeskel, 2022), clean production technologies (Da Silva & Cerqueira, 2017) or competitive energy markets (Szulecki et al., 2015). Nevertheless, there is no comprehensive framework that studies sustainable energy consumption from different perspectives (both demand- and supply-side polices). This approach is essential if policymakers are to understand the main strengths and/or weaknesses of different policies and thus if required, suggest improvements.

This paper seeks to contribute to the empirical evidence by analysing the effects of both types of policies (demand- and supply-side) on sustainable energy consumption. This paper's principal contribution is to provide a comprehensive approach to both supply and demand energy policies in the EU and their impact on sustainable energy consumption.

The findings enable policymakers to understand the strengths and weaknesses of several responsible consumption-related energy sector policies. It will be especially relevant for future sustainable development policymaking to achieve the EU targets. The structure of the paper is as follows: Section 1 presents the theoretical framework. The variables are then discussed, and the methodology is proposed. Then, the main results are shown. Finally, the results are discussed, and the principal conclusions that may be drawn are presented.

2 Theoretical framework

2.1 Literature review

Extensive research on sustainable development and carbon dioxide emissions is ongoing, globally, within existing economic and social realities (Chen, 2021; Gani, 2023; Honegger et al., 2021). Likewise, various studies have been developed at industry level. Abbasi et al. (2021a) developed a mathematical model of the green closed-loop supply chain network during the COVID-19 pandemic. They explained the trade-offs between environmental and economic factors in the first study and incorporated social factors in the second. Their results showed an increase in the total costs (economic factors) and social costs related to the number of job opportunities created and the number of lost days (social factors), although there was a positive impact, with the reduction of carbon dioxide emissions (environmental factors) during the pandemic. Similar results were obtained by Khan et al. (2018) by means of a generalised method of moments panel. Due to these economic, social, and environmental impacts, Taghikhah et al. (2019) highlighted the importance of encouraging consumers towards green consumption patterns, which should motivate suppliers to change their operations. More specifically, by means of a case study, Abassi et al. (2021) proposed a recovery network using a design focused on sustainability and hygiene, which was subsequently analysed with a sustainable supply chain applied mathematics model (Abbasi et al., 2023b). Meanwhile, Marinagi et al. (2023) and Abbasi et al., (2022a, 2022b) showed the importance of developing sustainable supply chain indicators, especially during the COVID pandemic, to reduce the environmental impact in different industries. Besides, these indicators enable composite indexes to be developed, which could provide much information by means of case study in each specific industry.

With the aim of reducing CO_2 emissions, Di Filippo et al. (2019) identified the main carbon policies (carbon tax, strict carbon caps and carbon cap-and-trade) and analysed them by the supply chain's total cost and carbon dioxide emissions. Their results showed that carbon market price and cap allocation had a significant effect on the cap-and-trade system, while carbon taxes exert great financial pressure to achieve CO_2 reduction targets. Similar results were obtained by Abbasi and Choukolaei (2023) and Abbasi and Erdebilli (2023).

Nevertheless, sustainable energy consumption is still a recent field of research, which is being analysed from different perspectives. The true relevance of this research topic lies in the current reality of limited resources, increasing energy demand and climate change, in which consumers' energy needs must be adjusted to achieve sustainability (Bilgen, 2014; Pineiro-Villaverde & García-Álvarez, 2022).

The study of sustainable energy consumption has been used different approaches in various sectors. Balsalobre-Lorente et al. (2023) analysed, among other factors, the effect of natural resources (where energy consumption and production patterns from tourism are incorporated) on environmental sustainability in 36 Organisation for Economic Co-operation and Development (OECD) economies from 2000 to 2018. Using the Augmented Mean Group method, they obtained the outcome that, from an energy consumption approach, tourism increases environmental sustainability, hence the importance of promoting eco-tourism, among other policies. Similar results were obtained by Abbas et al. (2022) from tourism, pointing to the importance of developing CSR strategies in this sector. Shah et al. (2023a) applied the same method to the energy industry, studying the impact of natural gas supply on energy consumption and environmental degradation, among other factors. Their results, in 15 gas natural supplier economies, showed that natural gas supply (as green energy) increases energy consumption but not environmental degradation.

The literature is nearly unanimous about the importance of considering energy intensity variables and energy consumption patterns as proxy indicators of sustainable energy consumption (Abbasi et al., 2021b; Cohen, 2010; Yahoo & Othman, 2017). An economy's energy intensity refers to the ratio between the gross domestic consumption of energy and gross domestic product for a specific year (Eurostat). In order to preserve sources of domestic energy and to reduce the need for imported hydrocarbons, it is vital to promote sustainable energy consumption patterns (with the consequent reduction in energy intensity), with the consequent positive impact on climate change.

Table 1 shows an overview of the literature analysing the effectiveness of sustainable energy policies as part of broader energy policies. Here, energy demand policies are likely to be effective tools to promote sustainable energy consumption, emphasising energy taxes and energy saving measures (Wolde-Rufael & Mula-Weldemeskel, 2022; Martin & Saikawa, 2017).

Energy taxes on conventional energy sources seek to modify levels of energy consumption by penalising the use of fossil combustibles and, thus, stimulating sustainable consumption patterns in the economy. Moreover, these instruments enable total generation costs to be moved away from fossil or non-fossil sources. Thus, an optimum energy tax should lead to fair competition between power generation technologies (Dogan et al., 2023; Martin & Saikawa, 2017; Menanteau et al., 2003). Finally, energy taxes act indirectly through recycling as these are partly offset to support RES-E and other environmental projects (Abbas et al., 2023). Abdmouleh et al. (2015) took a case study to emphasise the success of Finland, the first member state to implement energy taxes, in the design of this instrument that converted that country into one of the leaders in developing RES-E in the EU. Yahoo and Othman (2017) developed a computable general equilibrium model to assess the impact of energy and carbon taxes in Malaysia. Their results showed that the implementation of these instruments would shift people towards more sustainable energy consumption patterns. The explanation was given by the changes in relative prices that resulted in a reduction in fuel demand. Likewise, because of the implementation of energy and carbon taxes, green energy was promoted for their recycling revenue scenario. On the other hand, Wolde-Rufael and Mula-Weldemeskel (2022) analysed the effectiveness of environmental, energy and transport taxes in reducing CO_2 emissions in 20 European countries, over the period 1995–2012, using a panel data method. The results showed how these policies involved lower consumption (included energy consumption) with the consequent reduction of CO_2 emissions. More specifically, they indicated that the higher the environmental stringency, the lower the CO_2 emissions, because of the reduction in consumption.

Turning to energy saving measures, ecolabel licences are important in the European Union as they can influence consumers' purchasing decisions (Courtat et al., 2023; Iraldo & Barberio, 2017; Peattie & Crane, 2005; Testa et al., 2015). The EU Ecolabel Regulation

Table 1 Overview of effectiveness of energy policies in sustainable energy consumption

Analysis	Authors (year)	Approach	Results
Energy demand policy. Energy taxes	Dogan et al. (2023) Martin and Saikawa (2017)	Empirical assessment	An optimal energy tax can entail more energy efficiency
	Menanteau et al. (2003)	Qualitative and theoretical	
	Abbas et al. (2023)	Empirical assessment	Energy taxes are partly recycled to support RES-E, entailing more efficient energy use
	Abdmouleh et al. (2015)	Qualitative and theoretical	
	Wolde-Ruafel and Mula-Weldesmekel (2022) Yahoo andOthman (2017)	Empirical assessment	Energy taxes resulted in lower energy consumption
Energy demand policy. Ecolabel licenses	Courtat et al. (2023) Testa et al., (2015, 2021))	Qualitative and theoretical	Ecolabels resulted in consumers' eco-friendly behaviour. For this to work, ecolabelling must be credible and have clear messaging
	Iraldo and Barberio (2017) Zaccaï (2008)	Qualitative and theoretical	Barriers in EU ecolabels
Energy supply policies. Development of RES-E	Shah et al., (2023a, 2023b) Voigt et al. (2014) Shafiei and Salim (2014)	Empirical assessment	RES-E reduces energy intensity and entails energy efficiency improvements
Energy supply. Eco-innovation	Khurshid et al. (2022)	Empirical assessment	Eco-innovation helps to achieve sustainability targets in the EU
	Tsai and Liao (2017) Polzin et al. (2016)	Qualitative and theoretical	Eco-innovation needs appropriate regulation to be effective
Energy supply. Competitive energy markets	Wolgast et al. (2022) Liu et al. (2022) Da Silva and Cerqueira (2017)	Empirical assessment	Importance of avoiding market dominance in energy markets to promote investment in more sustainable energy
	Szulecki et al. (2015)	Qualitative and theoretical	

Conclusion:
There is no comprehensive framework that studies sustainable energy consumption from different perspectives (both demand- and supply-side polices)

This research:
To provide a comprehensive approach to both the supply and demand energy policies in the EU and their impact on sustainable energy consumption

66/2010 (European Commission, 2010) recognises products/services with reduced environmental impact that use the latest scientific and technological advancements and provide information to consumers about their environmental impact. This includes appliance/equipment efficiency standards, which have an impact on energy consumption. Several studies show that consumers may remain sceptical about companies' environmental claims due to the lack of credibility and unclear messaging (Courtat et al., 2023; Eurobarometer, 2022; Peattie & Crane, 2005). Nevertheless, the implementation of recognised certification schemes could eliminate these misleading claims, as shown by Testa et al. (2015). Through a quantitative analysis applied to Italian consumers, this study found that ecolabels play a significant role in guiding consumers' purchasing choices. They found that the knowledge, awareness, and information obtained by consumers about the environmental impact of a product from an ecolabel stimulated eco-friendly behaviour. From the corporate perspective, Iraldo and Barberio (2017) and Zaccaï (2008) showed that barriers still exist to the uptake of the EU ecolabel and the perception of both a lack of consumer awareness about ecolabelling and insufficient recognition of the same on the part of public authorities. On the other hand, Testa et al. (2021), after analysing 113 major peer-reviewed articles published between 2000 and 2018, identified the following principal green behaviour drivers: behavioural factors, socio-demographic factors, intrapersonal values, personal capabilities, products and producer-related factors and contextual factors. In terms of products and producer-related factors, ecolabelling is significant. Courtat et al. (2023) proposed a framework to improve current EU ecolabel licence schemes, based on four key principles: relevance, trust and transparency, scientific robustness and feasibility. These characteristics may win consumers' trust, with the consequent positive impact on their purchasing decisions. On the other hand, energy supply policies can be also considered likely to be effective in encouraging sustainable energy production, and here the development of clean production technologies and competitive energy markets is important (Fatras et al., 2022; Da Silva & Cerqueira, 2017; Bilgen, 2014; Shafiei & Salim, 2014).

With regard to clean production technologies, they must be developed to produce energy without greenhouse gas emissions. Besides, RES-E makes it possible to increase energy self-sufficiency with the consequent vulnerability reduction in terms of resource availability and fuel prices (Bleischwitz et al., 2009; Shah et al., 2023b).

Shafiei and Slime (2014) highlighted the importance of designing and implementing effective support policies to promote investment in RES-E technologies. Their results showed that, by applying the STIRPAT model to OECD countries over the 1980 to 2011 period, the consumption of RES-E had a negative and significant impact on carbon dioxide emissions, while the consumption of non-RES-E had a positive and significant impact on CO_2 emissions. Similarly, Voigt et al. (2014) demonstrated, by using the Divisia Index decomposition method of 40 major economies, the key importance of technology in reducing energy intensity and improving energy efficiency. Kriegler et al. (2014) analysed global technology strategies to mitigate climate change in 18 cases from Europe, Asia and North America. Their results suggested that RES-E technologies are the key factor in achieving ambitious climate policy objectives, in which versatile technologies are especially important for their ability to produce negative emissions. Similar results were obtained by Bilgen (2014) from a macro-analysis of energy consumption. Their results showed the need to substitute the more polluting traditional energy sources, as they are finite in the long term, by RES-E, to obtain a sustainable energy supply. Similarly, Shah et al. (2023b) studied 15 waste-recycling economies, using an advanced set of unit root tests and long-term cointegration, from 2000 to 2020, whose results showed the positive contribution made by environmental policy in green electricity generation. Therefore, eco-innovation is particularly significant here, that is, *"any innovation that makes progress towards the goal of sustainable development by reducing impacts on the environment, increasing resilience to environmental pressures or using natural resources more efficiently and responsibly"* (European Commission, 2006).

Hojnik and Ruzzier (2016) and Cohen (2010) showed the importance of implementing resource-saving innovations to the energy supply to achieve environmental policy aims. Tsai and Liao (2017) pointed to regulations as the dominant driving force to achieve these eco-innovations. Therefore, it is important to remove the regulatory barriers that persist in several economies, such as in the EU, in order to reach better resource-efficient solutions (Polzin et al., 2016). On the other hand, Khurshid et al. (2022) analysed the effects of different instruments on achieving sustainable development targets in the EU using a panel data method. They found that sustainability depends on green innovation and the stringency of the environmental policy.

In the case of energy market structures, the promotion of fair competition is essential to develop a sustainable supply (Liu et al., 2022; Szulecki et al., 2015). Easy access by different agents to energy markets is necessary to overcome incumbents' market power with its consequent negative implications on energy prices (Egging & Gabriel, 2006; Wolgast et al., 2022).

Nevertheless, despite the liberalisation process in this sector, research has shown there have been limited benefits in this area due to the extensive regulations still present in this industry (Da Silva & Cerqueira, 2017). It revealed the persistence of the largest generator in electricity markets holding on to an important market share, together with the scarce number of large generating companies and natural gas retailers in several energy markets across the EU (Eurostat).

In conclusion, previous literature has mainly centred on the study of a specific policy/action related to sustainable energy consumption: energy taxes (e.g. Martin & Saikawa, 2017; Wolde-Rufael & Mula-Weldemeskel, 2022), clean production technologies (e.g. Bilgen, 2014; Da Silva & Cerqueira, 2017; Fatras et al., 2022), or competitive energy markets (e.g. Egging & Gabriel, 2006; Szulecki et al., 2015). However, there is no comprehensive framework that analyses sustainable energy consumption from different perspectives (policies/instruments). The aim of this paper is to go further in the study of sustainable energy supply and demand instruments/policies in the EU, analysing their effects on sustainable energy consumption, as also shown in Table 1. The results of this analysis will allow policymakers to have a better understanding of the effectiveness of different policies on sustainable energy consumption in order to take direct action on these policies. This issue is especially important at the moment, given that the consumption perspective has progressed more slowly than that of production (Hale, 2018; Pineiro-Villaverde & García-Álvarez, 2022).

2.2 Statement of hypotheses

Governments can set energy taxation from the demand side to incentivise sustainable energy consumption patterns. Energy taxes have had a key role in the EU. They are based on the introduction of electricity consumption surcharges with the aim of promoting consumers' energy savings (Martin & Saikawa, 2017). Wolde-Rufael and Mula-Weldemeskel (2022) and Abdmouleh et al. (2015) emphasise the importance of energy taxes in the EU to nudge energy consumption towards more sustainable consumption patterns.

In view of the above-mentioned arguments, our first hypothesis is as follows:

H1a Energy taxes will result in lower energy intensity.

H1b Energy taxes will negatively affect energy consumption.

Likewise, supply-side policies can also impact sustainable energy consumption. Thus, the use of RES-E in the energy generation process should involve energy consumption using clean production technologies, which will not result in environmental impact (Shah et al., 2023b; Yi, 2015). Similarly, eco-innovation seeks to reduce environmental impact, by means of resource-saving energy supply innovations, with the consequent expected positive impact on sustainable energy consumption (Khurshid et al., 2022; Polzin et al., 2016).

At this juncture, taking into consideration that RES-E and eco-innovations entail a more efficient and productive use of energy, we propose our second hypothesis.

H2 Supply-side policies, based on RES-E and eco-innovation, will negatively influence energy intensity.

Finally, the development of competitive energy markets is an essential prerequisite of achieving a sustainable energy supply, which can be expected to derive in sustainable energy consumption. However, despite the liberalisation process, it is not clear whether the market share held by the major energy companies makes it possible to obtain competitive energy prices due to the extensive regulations in the sector (Da Silva & Cerqueira, 2017; Egging & Gabriel, 2006; Fatras et al., 2022).

Taking into account the above-mentioned arguments and the aims of the European Commission (2023), related to re-designing the EU electricity market to incentivise the RES-E transition, within a framework of energy transition and affordability, we propose our final hypothesis.

H3 Competitive energy markets, by virtue of the development of a sustainable energy offering, will negatively influence energy intensity.

3 Variables, data and methodology

3.1 Variables

The dependent and independent variables have been chosen from the literature review outlined in the theoretical framework section. The information about these variables is shown in Table 2.

Finally, the control variables refer to socio-economic factors linked to sustainable energy consumption. For this reason, gross domestic product (GDP) and electricity prices variables have been introduced into the model.

GDP per capita is used as a proxy variable of economic situation. GDP per capita is expected to be negatively correlated to sustainable energy consumption as it entails more electricity consumption (Ahmad & Zhang, 2020).

On the other hand, electricity prices refer to average domestic prices for medium size household consumers (consumption band Dc with annual consumption between 2500 and 5000 kWh) (EL-PR). This variable may have a positive impact on more sustainable

Table 2 Model's dependent and independent variables Source: Own elaboration

Sustainable energy consumption		
Dependent variables	*Definition*	*Units*
Energy intensity (EN-INT)	This variable measures energy consumption of an economy and its overall energy efficiency. It is calculated as the ratio between the gross inland consumption of energy and the gross domestic product (Eurostat)	Kilogram of oil equivalent per 1 000 EUR
Electricity consumption per capita (p.c.) (EL-CONS)	Quantity of electricity consumed by households divided by population	1 000 tonnes of oil equivalent p.c
Incentives for sustainable energy consumption*		
Independent variables	*Definition*	*Units*
Implicit tax rate on energy ((EN-TAX)	Ratio between energy tax revenues and final energy consumption	EUR per tonne of oil equivalent
Clean production technologies		
Independent variables	*Definition*	*Units*
Share of RES-E in total installed electricity generation capacity (RES-CAP)	Ration between RES-E installed capacity (small hydro, thermal solar, photovoltaic solar, tide, wave and ocean) and total electricity installed capacity	%
Electricity generation from RES-E (RES-GEN)	Ratio between the electricity produced from RES-E and the gross national electricity consumption. It measures the contribution of electricity produced from RES-E (hydro-plants, wind, solar, geothermal and electricity from biomass/wastes) to the national electricity consumption	%
Eco-innovation index (ECO-INN)	This variable shows how well individual member states perform in eco-innovation compared to the EU average, which is equated with 100. It is based on the EU average of 16 indicators from five areas (eco-innovation inputs, eco-innovation activities, eco-innovation outputs, environmental outcomes and socio-economic outcomes) (Eurostat)	Dimensionless
Competitive energy markets		
Independent variables	*Definition*	*Units*

Table 2 (continued)

Sustainable energy consumption		
Market share of main electricity generator (MARK-SH)	Market share of the largest generator in the electricity market	%
Number of main electricity generating companies p.c. (NUM-COM)	Number generating companies that represents, at least, 95% of the national net divided by population	Number per 100,000 inhabitants

*ECO-L was discarded due to the number of missing values in the period consumption patterns, as it promotes lower energy consumption (Abbasi et al., 2021a; Yi, 2015).

3.2 Data and methodology

To test the proposed hypotheses, the 2000–2019 period of the Eurostat database (28 countries, 560 observations) was used at the outset. 2000 was to be the starting date for analysis as sustainable energy policies, both supply- and demand side, became significant from this period. Most of the technologies promoting clean production, as well as the implementation of surcharges on energy consumption, were introduced from the early 2000s. The analysis ends in 2019 as much of the data were published by the Statistical Office of the European Commission until that year. Nevertheless, due to the high amount of data missing in some of the variables before 2008, in the end, the analysis covers the 2008–2019 period, to give us a more consistent data set. Where there was no available information on any of the variables, the study did not consider them. The result was an unbalanced panel of 26 countries and 237 observations.

A panel data model was used in the research with the STATA®13 programme (26 member states, period: 2008–2019). The main objective of this methodology is to capture unobservable heterogeneity, whether between countries or over time, since such heterogeneity cannot be detected with time series or cross-sectional studies (Baronio and Vianco, 2014). Thus, this technique makes the analysis more dynamic by incorporating the data's temporal dimension.

Likewise, the panel data methodology allows us to analyse two particularly relevant issues when operating with this type of information and which are part of the unobservable heterogeneity: (1) specific individual effects and (2) time effects (Arellano & Bond, 1991). The former refer to those effects that unequally affect each of the agents that make up the sample, which are invariant over time and directly affect the decisions made by these units. Time effects, meanwhile, are those that affect all the individual units in the study equally.

Individual endogeneity can be controlled either by fixed effects models or assumed to be random in random effects models. Here, Hausman tests were performed to find the most appropriate type of model (random or fixed effect). Two models were chosen from the results to study the influence of energy taxes, clean production technologies and competitive energy markets on energy intensity and/or electricity consumption per capita. The hypotheses were tested by means of a fixed effect model (model 1) and a random effects model (model 2). This type of model generates consistent estimation in those cases of correlation between unobserved country-level variables and the error term. The model is formulated as follows:

$$Y_{it} = a_i + \beta X_{it} + \varepsilon_{it},$$

Y_{it} is the dependent variable—energy intensity in model 1; electricity consumption in model 2. X_{it} denotes the explanatory and control variables. ε_{it} is the error term. a_i is a country-specific intercept (assumed to be uncorrelated with X in the random effects model). "i" is the country, and "t" is the year of the observation.

In the two models analysed, the three types of explanatory variables were used—energy taxes, clean production technologies and competitive energy markets.

Table 3 Descriptive statistics

Variable	Obs[1]	Mean	Std. Dev.	Min	Max
EN-INT	336	182.635	87.83523	51.04	517.15
EL-CONS	336	5.990165	2.905019	2.087299	15.84549
EN-TAX	336	208.304	78.46232	77.53	454.67
RES-CAP	336	0.1514651	0.103697	0.0010322	0.4424882
RES-GEN	336	18.41649	11.56513	0.195	56.391
ECO-INN	277	89.95668	30.46782	20	165
MARK-SH	293	52.65618	25.85604	10.66	100
NUM-COM	324	15.62322	43.48955	0	287.7373
EL-PR	333	0.122278	0.0304617	0.0639	0.2376
GDP	308	27,027.89	17,807.49	4930	102,200

[1]Observation after discarding missing values: 237

Table 4 Shapiro–Wilk test results[1]

Variables	Obs	W	V	z	p
EN-TAX	336	0.93889	14.398	6.295	0.0000
RES-CAP	336	0.90531	22.309	7.328	0.0000
RES-GEN	336	0.93488	15.344	6.445	0.0000
ECO-INN	277	0.98089	3.795	3.118	0.0009
MARK-SH	293	0.95708	8.955	5.140	0.0000
NUM-COM	324	0.34244	149.997	11.805	0.0000
EL-PR	333	0.96592	7.965	4.895	0.0000
GDP	308	0.85679	31.230	8.088	0.0000

[1]H_o: variable normality. H_o is rejected if $p<0.05$

4 Results

The complete list of descriptive statistics is shown in Table 3. A Shapiro–Wilk test was carried out to analyse the normality of the explanatory and control variables. This analysis confirms the non-normality of the variables involved in the study, as shown in Table 4.

Considering that Pearson's correlation coefficient does not work well for discrete variables as it is very sensitive to violations of normality assumptions, Spearman's rank correlations were calculated, as shown in Table 5. The estimates for a regression model cannot be uniquely computed when there is a perfect linear relationship between the predictors. For this reason, Spearman's rank correlations were analysed to detect the presence of multicollinearity and to rule out, where necessary, some of the predictors. As a result, none of the variables were discarded.

As mentioned above, Hausman tests were conducted to choose between fixed effects and random effects models. The null hypothesis establishes that there is no systematic difference between the coefficients estimated using the two methods. According to the results (X^2 (7d.f.) = 105.20 Prob > X^2 = 0.000 for model 1; X^2 (7d.f.) = 7.34 Prob > X^2 = 0.394 for model 2), in model 1, this hypothesis is rejected, indicating the suitability of a fixed effects model. In model 2, on the other hand, the p value greater than 0.05 indicates that it is more appropriate to use a random effects model. To control

Table 5 Spearman's rank correlation matrix[1]

Variables	1	2	3	4	5	6	7	8
1 EN-TAX	1							
2 RES-CAP	− 0.1350* (0.0378)	1						
3 RES-GEN	−0.1813* (0.0051)	0.9765* (0.0000)	1					
4 ECO-INN	0.3981* (0.0000)	0.2637* (0.0000)	0.2138* (0.0009)	1				
5 MARK-SH	0.1508* (0.0202)	−0.2173* (0.0008)	−0.1370* (0.0350)	−0.3293* (0.0000)	1			
6 NUM-COM	−0.1147 (0.0780)	0.2900* (0.0000)	0.2539* (0.0001)	0.1196 (0.0661)	−0.0918 (0.1588)	1		
7 EL-PR	0.4976* (0.0000)	−0.4459* (0.0000)	−0.5061* (0.0000)	0.3021* (0.0000)	0.0628 (0.3359)	−0.1792* (0.0057)	1	
8 GDP	0.6496* (0.0000)	−0.0560 (0.3907)	−0.0966 (0.1382)	0.7914* (0.0000)	−0.1285* (0.0482)	0.1196 (0.0660)	0.5369* (0.0000)	1

[1]Observation after discarding missing values: 237

*(p value) $p < 0.05$

possible heteroscedasticity, the proposed models use heteroscedasticity-robust standard errors. Tables 6 and 7 summarise the results of the two panel regression models.

Turning to demand incentives for sustainable energy consumption (energy taxes) and their impact on energy intensity in the electricity sector, the results of model 1 support hypothesis H1a, as EN-TAX ($\beta = -0.269$ $p = 0.007$) has a negative and statistically significant influence on energy intensity. This means that a reduction in energy intensity might be expected through the introduction of incentives for sustainable energy consumption, such

Table 6 Results of the panel regression analysis for model 1 (fixed effects)

EN-INT	Coef.	St. Err.	*t* value	*p* value	[95% Conf.	Interval]	Sig
EN-TAX	−0.269	0.092	−2.92	0.007	−0.459	−0.080	***
RES-CAP	−334.363	189.105	−1.77	0.089	−723.833	55.106	*
RES-GEN	1.202	1.768	0.68	0.503	−2.438	4.843	
ECO-INN	−0.177	0.114	−1.56	0.132	−0.411	0.057	
MARK-SH	−0.129	0.147	−0.88	0.388	−0.432	0.174	
NUM-COM	−0.134	0.195	−0.68	0.500	−0.536	0.269	
EL-PR	121.921	148.953	0.82	0.421	−184.853	428.696	
GDP	−0.002	0.001	−2.36	0.026	−0.003	0.000	**
Constant	317.771	38.446	8.27	0.000	238.59	396.953	***
Mean dependent var	177.013	SD dependent var 73.496					
R-squared	0.514	Number of obs 237					
F test	5.449	Prob > *F* 0.001					
Akaike crit. (AIC)	1874.056	Bayesian crit. (BIC) 1901.801					

***$p < 0.01$, **$p < 0.05$, *$p < 0.1$

Table 7 Results of the panel regression analysis for model 2 (random effects)

EL_CONS	Coef.	St. Err.	*t* value	*p* value	[95% Conf	Interval]	Sig
EN-TAX	0.002	0.002	0.83	0.406	−0.002	0.006	
RES-CAP	−1.088	1.357	−0.80	0.423	−3.747	1.571	
RES-GEN	−0.013	0.013	−0.99	0.321	−0.038	0.012	
ECO-INN	0.007	0.003	1.99	0.047	0.000	0.013	**
MARK-SH	0.011	0.009	1.24	0.214	−0.006	0.028	
NUM-COM	0.000	0.002	0.17	0.862	−0.004	0.005	
EL-PR	−4.447	1.263	−3.52	0.000	−6.922	−1.972	***
GDP	0.000	0.000	2.26	0.024	0.000	0.000	**
Constant	4.944	0.811	6.10	0.000	3.355	6.532	***
Mean dependent var	6.047	SD dependent var	3.057				
Overall *r*-squared	0.158	Number of obs	237				
Chi-square	34.104	Prob > chi2	0.000				
R-squared within	0.161	*R*-squared between	0.174				

***$p<0.01$, ** $p<0.05$, * $p<0.1$

as energy taxes. In the case of electricity consumption per capita, the results of model 2 indicate that although the sign of the coefficient goes in the expected direction, the analysis shows that hypothesis H1b is not supported, as the variable EN-TAX is not statistically significant ($p=0.406$).

In the case of supply-side policies based on RES-E and eco-innovation, and their influence on sustainable energy consumption patterns, hypothesis H2 is partially supported by the analysis. According to the results obtained from model 1, among the three explanatory variables used, the share of RES-E in total installed electricity capacity has a negative and significant impact on energy intensity ($\beta=-334.363$ $p=0.089$). This means that a more efficient and productive use of energy, which implies a reduction in energy intensity, can be achieved through clean energy policies. The other two variables do not have a significant impact on the reduction in energy intensity ($p=0.503$ for RES-GEN and $p=0.132$ for ECO-INN). On the other hand, none of the three variables studied has a significant impact on the reduction in electricity consumption per capita, according to the results of model 2. It should be noted that the factor that clearly seems to have the most influence on electricity consumption is the price of electricity (EL-PR), as deduced from model 2 ($\beta=-4.447$ $p=0.000$).

Finally, hypothesis H3 conjectured a possible influence of competitive energy markets on the development of sustainable energy consumption. However, the results obtained in both models lead us to reject hypothesis H3. Neither the main electricity generator's market share (MARK-SH) nor the number of electricity generation companies (NUM-COM) seem to have a significant influence on reducing electricity consumption or energy intensity (MARK-SH, $p=0.388$ in model 1 and $p=0.214$ in model 2; NUM-COM, $p=0.500$ in model 1 and $p=0.862$ in model 2).

With respect to the degree of accuracy and fit of the results obtained, several conclusions are drawn from Tables 6 and 7. In model 1 (fixed effects), the *p* value for the *F* test for overall significance has a value of 0.001, which means that the model fits the data better than the intercept-only model. In addition, the model achieves a reasonably acceptable R^2 value for a social science study, according to Ozili (2023).

With regard to model 2 (random effects), a X^2 goodness-of-fit test is used, yielding a p value of 0.000. In this second case, we obtain a lower R^2 value than in model 1, but given that several of the explanatory variables are significant, we can draw appropriate conclusions from the model, in line with Ozili (2023).

5 Discussion and conclusions

5.1 Findings and discussion

Sustainable production and consumption have been prioritised in EU policies with the aim of meeting climate and environmental targets. Nevertheless, while major advances have been made from the production perspective, less progress has been made from that of consumption. This highlights the need to move ahead with research in this area, especially in energy consumption, since it is one of the most consumed resources in the world.

This paper has analysed the effects of energy taxes, renewable energy, and energy competitive markets on sustainable energy consumption in the EU-28 from 2008 to 2019, using panel data methodology. The research analyses the sustainable consumption of energy in two ways: its total magnitude and the efficiency of its use. In the first case through per capita electricity consumption by households, and in the second through the relationship between energy consumption and GDP, taken as energy intensity.

The first hypothesis assumes that the demand incentives for sustainable energy consumption based on energy taxes will lead to its increase. The results obtained in both models partially support this hypothesis. The claim that energy tax policies have a positive impact on a more efficient and productive use of energy appears to have been verified. In other words, energy taxes can be an effective measure to promote investment of green production technologies, with the consequent improvement in sustainability. These results align with those obtained by Abbas et al. (2023), Yahoo and Othman (2017) and Abdmouheh et al. (2015).

However, the results shows that this specific type of policy to promote sustainable energy consumption does not have a significant effect on reducing total electricity consumption per capita. The tax rate may not be high enough to achieve a shift in energy consumption patterns. Similar results have been obtained in previous studies by Pineiro-Villaverde and García-Alvarez (2022) and Hale (2018), which highlight the need to review this EU policy. Reinforcing actions from the demand side should be implemented, including energy taxes and ecolabel licences, to meet sustainable development targets (Ge et al., 2022; Yu et al., 2022; Zafar et al., 2022; Zhuang et al., 2022).

The second hypothesis asserts that supply policies supported by RES-E and eco-innovation will have a positive influence on the development of sustainable energy consumption patterns. This research allows us to conclude at this point that efficient energy use is enhanced when clean energy policies lead to a greater installed capacity of renewable energy generation. Thus, as the share of RES-E increases, less primary energy is required to provide the same number of energy services. Moreover, renewable energies that do not require fuel input (e.g. hydro, solar or wind) inherently improve efficiency as they do not require thermal conversion. These results align with those obtained by Shah et al., (2023a, 2023b) and Voigt et al. (2014).

The research also shows that eco-innovation has not played such an important role, at least not as much as might be expected in promoting sustainable consumption. The results demonstrate that although eco-innovation has some impact on sustainable energy consumption by reducing environmental impact or saving resources, as indicated by other studies (Khurshid et al., 2022; Polzin et al., 2016; Yi, 2015), this is not especially significant compared to other factors such as RES-E capacity. This can be accounted for by the need to eliminate persisting regulatory barriers in the EU.

Finally, the third hypothesis questions the influence of competitive energy markets on sustainable energy consumption. From the research, we can conclude that neither the main electricity generator's market share nor the number of electricity generating companies have played a particularly significant role in promoting sustainable energy consumption. It should be said that a greater market share or a smaller number of companies, especially when this entails a dominant position and there is no regulatory or civil society pressure, can be a disincentive to invest in cleaner and more sustainable energy. Here, it would be advisable to foster greater competitiveness in several energy markets in the EU, to achieve a more sustainable energy supply, as pointed out by Li et al. (2022), Wolgast et al. (2022) and Szulecki et al. (2015). In summary, we can state that both energy tax policies and the use of clean energy are useful tools to achieve a more efficient and productive, and therefore more sustainable, use of energy. On the other hand, these same mechanisms have not played such an important or effective role when it comes to reducing total energy consumption. In this case, the price of electricity is the greatest determinant, and therefore, the factor that should be given the most weight.

5.2 Policy recommendations

The results highlight the need to establish reinforcement measures in various areas to promote more sustainable energy consumption.

The continuation of policies to promote renewable energy generation, given that these have proven to be useful for this purpose, and investment in improving generation technology to make it more efficient, are essential measures in this framework.

Nevertheless, actions related to the demand perspective should be reinforced. The promotion of campaigns that give consumers more information about product lifecycle and repair issues should be strengthened. For example, actions related to replacing old electrical appliances with others that are more energy efficient would be appropriate. Likewise, campaigns around the environmental and climate consequences of excessive resources consumption might encourage them towards more efficient energy consumption.

Reinforcing actions and more aggressive efforts to apply energy tax policies might therefore be necessary, together with public awareness campaigns, given that Hale (2018) showed consumers' environmental awareness is the main driver of sustainable consumption.

To strengthen the competitiveness of energy markets, barriers to entry should be reduced, while better informed and more aware consumers would exert the pressure necessary to motivate companies to promote cleaner and more efficient energy generation.

6 Research limitations and future research

This research has the following limitations that should be considered when presenting future lines of research.

With regard to the Panel Data Method, we should bear in mind that the sample does not include many countries, which might have affected the results. Future research should consider this issue by expanding the sample, for example to analysing OECD countries, which would give us a larger number of observations.

Turning to our analysis of the effects of energy supply policies, based on the development of clean production technologies, this might be more exhaustive if political factors related to the development of clean production technologies were studied. This analysis is based on the share of RES-E in total installed electricity generation capacity and in electricity generation from RES-E. Nevertheless, the introduction of the specific RES-E support mechanism (feed-in tariff, renewable portfolio standard, etc.) into the analysis, as well as the study of the main design elements (duration, magnitude of the incentive) would provide more information as to which specific policies lead to more sustainable consumption (as a consequence of greater development of RES-E installed capacity).

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Authors and Affiliations

María Teresa García-Álvarez[1] · Gustavo Pineiro-Villaverde[2] · Isabel Soares[3]

✉ María Teresa García-Álvarez
mtgarcia@udc.es

Gustavo Pineiro-Villaverde
gustavo.pineiro@udc.es

Isabel Soares
isoares@fep.up.pt

[1] Department of Business, Faculty of Economy and Business, University of A Coruna, Campus Elvina s/n, 15071 A Coruna, Spain

[2] Doctoral Program in Economic Analysis and Business, Faculty of Economy and Business, University of A Coruna, Campus Elvina s/n, 15071 A Coruna, Spain

[3] Faculty of Economics, University of Porto, Rua Dr Roberto Frias s/n, 4200-464 Porto, Portugal