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Determinants of energy intensity in the European Union: A panel data analysis

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A B S T R A C T

The aim of this article is to analyse the energy intensity in EU-28 member states for the period 1990–2012, establish its determinants, and estimate the size and statistical significance of the effect of each determinant on energy intensity. In order to achieve this, a panel data approach was designed for EU-28 member states. The estimated model showed that energy prices, energy taxes and GDP (gross domestic product) per capita have a negative influence on energy intensity, while the growth of gross inland consumption and final energy consumption per capita positively affect energy intensity. The biggest impact on energy intensity was estimated for the price of electricity, indicating that the level and structure of this determinant should be considered and used as a valuable energy policy tool for improving energy efficiency. This policy conclusion is also supported by the fact that Denmark, Germany and Italy have the highest share of energy taxes in the structure of the final electricity price, and at the same time the lowest energy intensity.

1. Introduction

Improving energy efficiency was identified as one of three strategic goals of the EU's sustainable development until 2020 [1]. In accordance with the latest EU Energy Efficiency Plan [2], EU member states are expected to achieve 20% savings of their primary energy consumption by 2020. However, the latest impact assessment by the European Commission [3] suggests that with the present policies the EU will only achieve half of that 20% target by 2020. In order to close this gap, a new directive on energy efficiency was adopted in 2012 [4]. The Energy Efficiency Directive 2012/27/EU allows member states to set their own national energy efficiency targets on either primary or final energy consumption, primary or final energy savings, or energy intensity. In this article, the energy efficiency improvement in EU-28 member states will be analysed by taking energy intensity into account.

Energy efficiency means using fewer energy inputs while maintaining an equivalent level of economic activity, whereas energy intensity is the amount of energy used per unit of activity. Measuring energy efficiency and its change over time is often approximated by energy intensity as one of the sustainable development indicators [5,6]. The characteristics of efficient indicators are that they are relevant to the aim, comprehensibility, reliability and availability of the data [7]. However, energy intensity can only be taken as a proxy for energy efficiency because changes in energy intensity are a function of several determinants, with the structure of the economy being one of the most important ones [8,9].

This article focuses on energy intensity dynamics in EU-28 member states for the period 1990–2012. The purpose is to analyse the energy intensity in those member states, establish its determinants, and estimate the size and statistical significance of the effect of each determinant on energy intensity. In order to achieve this, a panel data approach is employed in which the regression parameters are estimated by applying a fixed-effects estimator. The determinants of energy intensity that were explored based on panel data for EU-28 member states are: GDP (gross domestic product) per capita, electricity price, light fuel oil price, automotive diesel price, natural gas price, coal price, final energy consumption per capita, growth of gross inland consumption, and energy taxes.

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The Eurostat database was used as a data source due to its reliability, consistency, and relatively long time series for the analysed countries, although even here one needs to be very careful when building the dataset due to breaks in the time series. The IEA/OECD quarterly reports were used as a data source for light fuel oil and automotive diesel prices, as well as for the energy price indices.

The effect of GDP per capita on energy intensity is still an issue of empirical discussion. Having in mind that the level of energy intensity can be determined by the level of economic development, it may be expected that a higher income exerts pressure on the demand for energy and thus increases energy intensity. On the other hand, as income broadly reflects the stage of development, it is expected that it would reduce energy intensity as both households and producers use more energy-saving and more efficient technologies. Empirical analysis based on 75 countries in the period 1971–2010 showed that energy intensity declines as income increases [10]. Measuring energy intensity and its determinants in China's regional economies [11], the research showed that energy efficiency improves as income per capita rises. Accordingly, it can be expected that as the country becomes more developed its energy use will become more efficient and hence its energy intensity will fall. This hypothesis was confirmed by Galli [12] and Medlock and Soligo [13], who used panel econometric methods to explore the effect of income on total energy use. Galli used data from ten developing Asian countries spanning from 1973 to 1990, whereas Medlock and Soligo used a 28-country sample that included many OECD countries and some developing countries (mostly Asian), covering the period from 1979 to 1995.

Starting from the definition of energy intensity as the ratio between gross inland energy consumption and GDP, the impact of gross inland energy consumption on an economy's energy intensity is obviously positive. In order to analyse the dynamic effects of this variable on energy intensity, the growth of gross inland consumption will be employed as a determinant in the panel data model. A positive correlation is expected, although it would be interesting to determine the strength of the impact in this relationship. There exist articles that consider energy consumption as one of the determinants of energy intensity, but they are mostly focused on China as the world's largest energy consumer [14–16].

Final energy consumption is equivalent to just under two-thirds (65.6%) of gross inland consumption. Due to comparability across countries being restricted by the definition of the indicator, final energy consumption per capita will be used as a determinant. An empirical study that covered the 40 largest countries in the world [17] showed that energy consumption is distributed unequally among countries (almost to the same degree as income) and that, in the case of the most developed countries (United States, Canada, Australia etc.), there is a positive correlation between final energy consumption per capita and energy intensity. This is why final energy consumption per capita was used as a determinant in this research focusing on EU-28 member states.

Based on broad empirical research, it can be ascertained that energy prices have a strong impact on energy intensity [18–20]. Given that relevant data are not available for all types of energy for all EU-28 countries for the whole analysed period of 1990–2012, residential electricity price, light fuel oil price, automotive diesel price, natural gas price, and coal price will be used in the panel data model.

Taking the increasing trend of environmental taxation revenues in the EU-28 into consideration, as well as the debate on environmental taxation as an instrument for environmental policy [21–23], the implicit energy tax rate [24] will be used in the model as a determinant. It can be expected that energy taxes will improve energy efficiency if they are implemented and used effectively as an instrument of environmental policy. Several studies have analysed the social effects of energy taxes, especially the regressive effect and the impact on electricity prices [25–27,37,38]. However, there is no empirical evidence regarding the relationship (and its strength) between the implicit energy tax rate and energy intensity at the EU-28 level for an extensive time period.

This article's main novelty is that it takes several determinants of energy intensity into account within a single model, thus obtaining the net effects of these determinants on energy intensity and avoiding specification biases that arise due to incomplete model specification. Some of these determinants are scarcely analysed in the literature individually, as standalone factors of energy intensity. Namely, some determinants are empirically discussed (e.g. the impact of GDP per capita), while for others there are only very limited empirical surveys (e.g. the impact of the energy tax rate). In addition, the analysis covers all EU-28 member states over a relatively long time period, whereas the data availability of such a set of variables has up until recently been quite limited.

The article is organised as follows. In Section 2, an insight is given into the long-term evolution of energy intensity and the dynamics of relevant determinants of energy intensity that are later used in the empirical analysis are presented. The research methodology is then outlined in Section 3. In Section 4, the data used are described, an econometric model of energy intensity is specified, empirical analysis is conducted, and the results are provided. Finally, Section 5 sets out the main conclusions and policy recommendations, together with some reflections on possible limitations of the research work.

2. Main determinants of energy intensity in the European Union

Energy intensity, measured as the ratio between gross inland consumption of the five types of energy (coal, electricity, oil, natural gas, and renewable energy sources) and GDP, is expressed in kilograms of oil equivalent (kgoe) per EUR 1000. If an economy becomes more efficient in its use of energy and its GDP remains constant, then the ratio for this indicator should decrease. During the analysed period of 1990–2012, EU-28 member states managed to reduce their energy intensity by 30%. To facilitate analysis over time, the calculations are based on GDP at constant prices (currently chain-linked 2005 prices). The results are shown in Fig. 1.

In the EU-15, during the early 1990s a combination of low GDP growth, low fossil fuel prices and the generally low priority of energy saving contributed to most member states seeing a slowdown in the reduction of their energy intensity. Since then, energy efficiency improvements have become more important. The main factors leading to the new EU member states making energy intensity improvements were structural changes to the national economies and a rise in energy prices [28]. Focusing on Central and

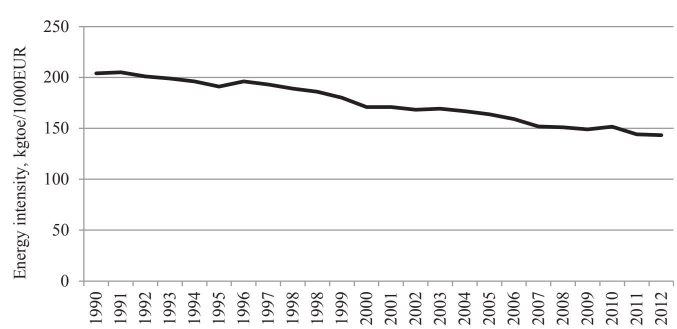

Fig. 1. Trend of energy intensity in the EU-28 for the period 1990–2012, in kgoe/1000 EUR. Source: Eurostat, data code tsdec360.

Eastern Europe and the former Soviet Union, a strong link was found between energy prices and energy intensity. The research was based on an arithmetic decomposition method of aggregate energy data over the period 1992–1998 and provided a breakdown of energy data in order to identify the main determinants of improved energy intensity.

The trend of reduced energy intensity in EU-28 member states can be determined by further specialisation in higher value added product categories with lower energy intensity, as well as by energy prices. The sectors most exposed to energy price shocks are coke and refined petroleum products, chemicals, non-metallic mineral, metals, rubber, and plastics [29]. Thus, countries with such a production structure are more sensitive to energy cost pressure, and any increases in energy prices not matched by an enhancement of energy efficiency might seriously affect the margins of their manufacturing sectors [30,31].

According to Eurostat data, energy intensity in the EU-28 dropped by 16% over the period 2000–2012 and reached 143 kgoe/1000 EUR in 2012. All member states lowered their energy intensities, while four member states recorded decreases above 30%; Slovakia (−46%), Lithuania (−40%), Romania (−37%), and Bulgaria (−36%). Despite this decrease, Bulgaria remained the most energy-intensive economy in 2012 (670 kgoe/1000 EUR), about five times above the EU average. The lowest levels of energy intensity were observed in Denmark (87 kgoe/1000 EUR) and Ireland (83 kgoe/1000 EUR). A comparison between energy intensity in 2000 and 2012 for EU-28 member states is shown in Fig. 2.

Analysis of gross inland consumption of energy in EU-28 member states for the period 1990–2012 reveals that the total energy consumption was relatively unchanged and the 2012 level was just 0.9% above the 1990 level. Twelve EU member states (Germany, the United Kingdom, and some new member states) consumed less gross inland energy in 2012 than in 1990. Therefore, gross inland consumption is interesting as a modelling variable in the dynamic sense, i.e. as a growth variable. However, the reduction in primary energy consumption can only be partly explained by energy efficiency improvements. Since GDP growth is one of the key drivers of energy consumption, the low economic performance in the period after the economic crisis escalated also has an impact on lower primary energy consumption. In addition, structural changes and fuel switches contributed to this reduction [32].

Final energy consumption recorded a continuous rise after 1990, with the fastest increase being recorded in the period 2000–2004 at 1.4% per year. After reaching a peak in 2005, final energy consumption stabilised and was then decreasing almost continuously until 2012 by a total of 7% [33]. This trend was partly influenced by the economic downturn. However, the level of final energy consumption in 2012 was merely 2% higher than in 1990. Between 1990 and 2012, the industry sector reduced its final energy consumption by 23%. These changes reflect sector-specific levels of energy efficiency improvements, but also relate to structural changes in the EU economy, particularly the shift away from energy-intensive industry (iron and steel, chemical and petrochemical) to a service-based economy. In contrast, energy consumption in the services and transport sectors rose by almost one-third over the same time period. Except for annual fluctuations due to weather changes, consumption in residential and agriculture sectors remained more or less stable during the whole analysed period (see Fig. 3).

Another important determinant to be used in the panel data model is the electricity price for the residential sector, especially if one takes account of the trends in the residential sector's final energy consumption and the rising share of electricity in final consumption, which rose by 36% in the analysed period [33,37]. Residential electricity prices (excluding taxes and levies) had remained stable for about 15 years before they soared in the second half of 2005. Taxes had an upward trend after 2003, with a moderate increase until 2005. This can be explained by the introduction of CO_2 quotas in the ETS (Emissions Trading Scheme) in 2005, and by the EU policy aimed at cutting CO_2 emissions, also established in 2005. With regard to national policies, support for electricity generation from renewable sources translated into charges of growing weight. In order to compare residential electricity prices and corresponding taxes and levies over time, long-term Eurostat data were employed (see Fig. 4).

In the period 2008–2012, the average residential electricity prices of EU-28 member states rose by 18%, corresponding to an increase of 3 euro cents per kWh, of which 1.56 cents per kWh were attributable to taxes (including VAT (value-added tax)) and 0.86 cent per kWh to network charges and costs [34]. While taxes and levies on average accounted for 15% of the price in kWh in 1990, their share had risen to 32% at the end of 2012. The final price charged to electricity consumers depends on the structure of electricity tariffs and contracts, which normally contain a number of determinants like fixed charges and unit prices that vary relative to the amount of electricity used and the period of consumption. As formation of the electricity price is mainly based on the intersection of a merit order supply curve and demand at each point in time, this has led to various price developments in different European electricity submarkets. In this time period, high volatility and considerable differences in electricity spot market prices are observed between different sub-markets. Regarding the magnitude

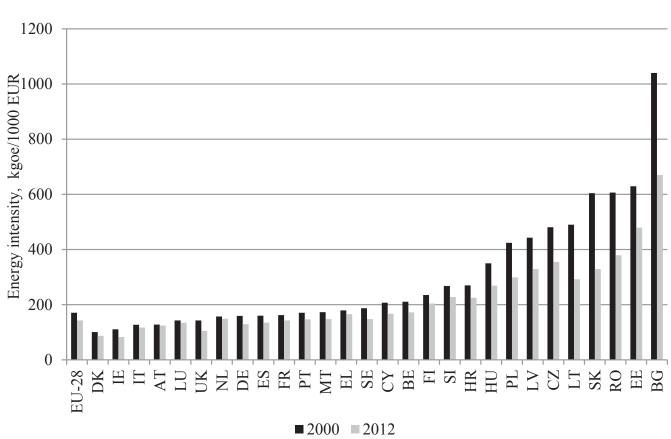

Fig. 2. Energy intensity in the EU-28 in 2000 and 2012, in kgoe/1000 EUR. Source: Eurostat, data code tsdec360.

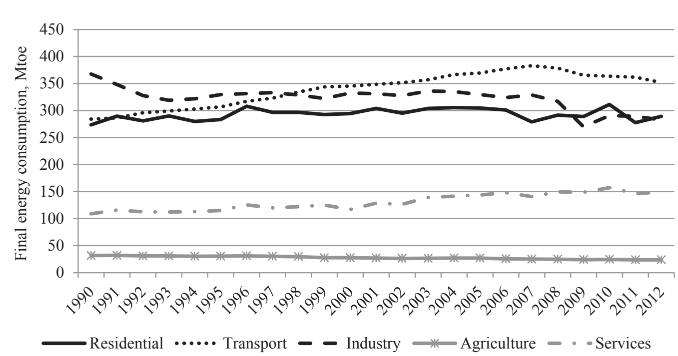

Fig. 3. Final energy consumption by sector in the EU-28 for the period 1990–2012, in Mtoe. Source: Eurostat, data code tsdpc320.

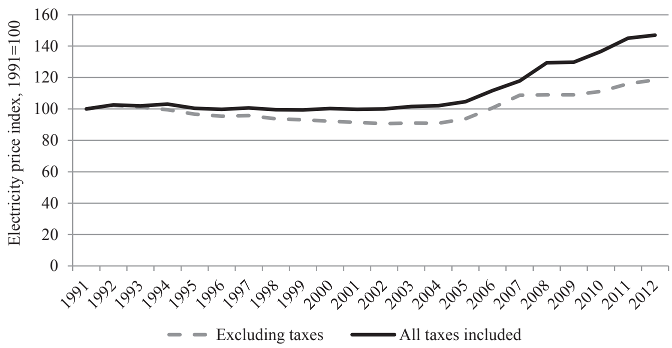

Fig. 4. Electricity prices for residential consumers in the EU-15 for the period 1991–2012, 1991 = 100. Source: Eurostat, data codes nrg_pc_204 and nrg_pc_204h.

of prices, the reason for the high prices in 2008 in Continental Europe was the low hydro availability [35].

Fig. 5 shows electricity prices for a household with an annual consumption of between 2500 and 5000 kWh, including VAT and other environmental taxes. These prices are weighted by national residential consumption to provide the EU averages.

At the EU-28 level, according to Eurostat data for the second semester of 2012 the highest electricity prices were obtained by medium-size residential consumers in Denmark, Cyprus and Germany, while the lowest prices were enjoyed by households in Bulgaria, Romania and Estonia. Compared to Bulgaria (9.55 cents per kWh), the price of electricity for households in Denmark was more than three times higher (29.72 cents per kWh). The average price for the EU-28 (weighted with 2010 national consumption for the residential sector) is 19.54 cents per kWh.

Considering the structure of the electricity price, it should be noted that residential consumers pay the smallest tax contribution (4.7%) in the United Kingdom, where a relatively low VAT rate is applied to the basic price, without applying other taxes. In contrast, Denmark charges the highest taxes, where more than half of the final price (56%) accounts for environmental taxes. Denmark has a comprehensive environmental tax system and is the country with the highest implicit tax rate on energy (energy tax revenues relative to final energy consumption) in the EU-28. Based on Eurostat data for 2012, the implicit tax on energy in Denmark was EUR 303 per toe, while the lowest level of this indicator was recorded in Slovakia (EUR 47 per toe) and Bulgaria (EUR 65 per toe). The overall energy tax revenues are highest in Slovenia, Bulgaria and Estonia (3.1%, 2.5% and 2.5% of GDP, respectively). This is not due to high tax rates per se, but to high levels of final energy consumption.

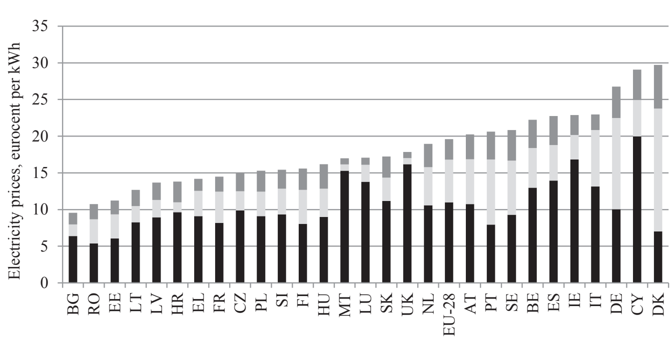

Fig. 5. Electricity prices for residential consumers in the EU-28 in 2012, in cents per kWh. Source: Eurostat, data code nrg_pc_204.

Even though the electricity price explains (by far) the highest share of variance of energy intensity, measured by the standardised regression coefficients in regression models based on our dataset, other energy prices will be used in the model as well. On average, consumer energy prices had an upward trend in Europe in the analysed period. After a historic peak in the third quarter of 2008, consumer energy prices fell sharply in the first quarter of the 2009, and since then the total energy index has recorded an increase. Based on the International Energy Agency statistics database, indices of real energy prices for end users were calculated. Using 2005 as the base year, the total energy end-use price index (including electricity, natural gas, coal, and oil) in 2012 was 126.5. Coal energy prices recorded the highest increase (40.3%), followed by natural gas (41.2%), electricity prices (22%), and oil products (25.4%). Fig. 6 shows the trend of household index of energy prices, including electricity, natural gas, coal, and oil products (such as automotive diesel, light fuel oil etc).

3. Research methodology

The primary objective of this research is to determine the relationship between the energy intensity of an economy and its determinants. This will be done by applying a panel data model for the EU-28 region, based on data for the period 1990–2012. The data were provided by Eurostat (http://epp.eurostat.ec.europa.eu) and International Energy Agency quarterly reports (Energy Prices and Taxes, [36]), where the time period covered stretches from 1990 to 2012 for 29 entities: EU-28, Austria, Belgium, Bulgaria, Croatia, Cyprus, the Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, the Netherlands, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden, and the United Kingdom.

Energy intensity of the economy (*EI*) was the dependant variable in the empirical model. The variable was measured as the ratio between gross inland consumption of energy and GDP, and expressed in kilograms of oil equivalent (kgoe) per EUR 1000. The calculation of energy intensity was based on GDP at constant prices (currently chain-linked 2000 prices) and exchange rate adjustments were taken into consideration. The explanatory variables of the empirical model were founded in the previous section as determinants of energy intensity. These include: (1) GDP per capita, (2) electricity price, (3) light fuel oil price, (4) automotive diesel price, (5) natural gas price, (6) coal price, (7) final energy consumption per capita, (8) growth of gross inland consumption, and (9) energy taxes.

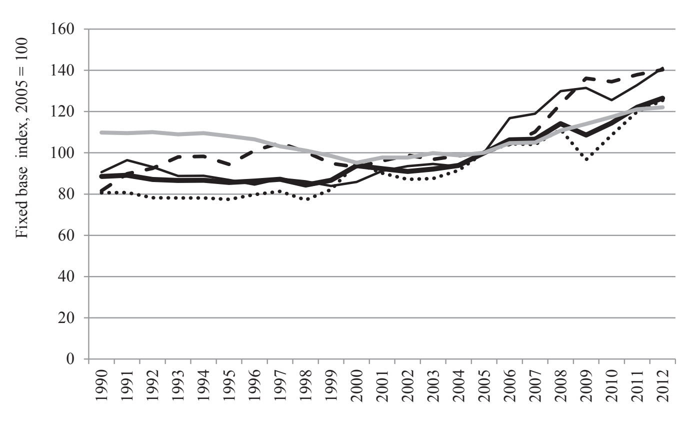

Fig. 6. Indices of real energy prices for end-users in the EU, 2005 = 100. Source: IEA, Energy Prices and Taxes.

GDP per capita (*GDP*) is expressed in EUR 1000 per inhabitant, where GDP is measured at market prices. Electricity price for residential consumers (*EP*) is defined as the average national price in EUR per kWh including taxes, levies, non-tax levies, fees and VAT (value-added tax), applicable for the second semester of each year for medium-size household consumers (with annual consumption of between 2500 kWh and 5000 kWh). *LFOP* (Light fuel oil price) is expressed in EUR per 1000 L and it is defined as an average price for households including excise tax and VAT. Automotive *DIESP* (diesel price) is expressed per litre and it is defined as an average price for non-commercial use (including excise tax and VAT). Natural *GASP* (gas price) and *COALP* (coal price) are expressed as fixed-base indices, with the base being set in 2005. Final energy consumption per capita (*FEC*) expresses the sum of energy supplied to final consumers by using a common energy unit (ktoe). Gross inland consumption is calculated as the sum of primary production, recovered products, total imports, and variations of stocks, less total exports and bunkers. It corresponds to the addition of final consumption, distribution losses, transformation losses and statistical differences. It covers five energy sources (electricity, oil, gas, renewables and coal) and is expressed in thousand tonnes of oil equivalent (toe). The growth of *GIC* (gross inland consumption) is employed in this research. Implicit *ET* (energy tax) is defined as the ratio between energy tax revenues and final energy consumption calculated for a calendar year. The implicit energy tax rate is measured in EUR per tonne of oil equivalent. As the implicit tax rate's expected effects on energy intensity are dynamic, the first and the second lag of energy tax are employed in the econometric analysis.

Each country's system has its own properties (individual effects) and hence the panel data econometric technique fits well with the available information and allows testing for any country-level differences among EU-28 member states. Data on the preceding variables are available for each entity, which means that there are $n = 29$ cross-sectional units and $T = 23$ time periods. The study uses panel data (longitudinal or cross sectional time-series data), which observe the behaviour of entities across time. The panel is unbalanced, meaning that there are some missing observations, i.e. for some countries the values of variables for all years (in the pre-2000 period) are not observed.

The pooled regression is not applicable to this research as the least-squares estimator is inconsistent due to individual country effects. Bearing this in mind, a fixed-effects estimator and a random-effects estimator can be used in such a situation. The Hausman test rejected the null hypothesis under which the random-effects estimator is consistent (the Hausman test statistic was statistically significant in all model specifications, with $p-$values below 0.05), thus only the fixed-effects estimator is consistent in this case, although not necessarily efficient. Application of the least-squares dummy variable version of the fixed-effects estimator provides a model in which the intercept will vary for each entity, while the slope coefficients will be constant across entities.

Modelling the fixed effects by using the least-squares dummy variable estimator thus results in the following model:

$$\mathbf{EI} = \mathbf{D}\boldsymbol{\alpha} + \mathbf{X}\boldsymbol{\beta} + \mathbf{u}, \tag{1}$$

where $\mathbf{EI} \in \mathbb{R}^{nT\times 1}$ is a vector of energy intensity, $\mathbf{D} \in \mathbb{R}^{nT\times n}$ represents a vector of dummy variables for EU-28 member states, $\mathbf{X} \in \mathbb{R}^{nT\times k}$ is a matrix of numerical explanatory variables, and $\mathbf{u} \in \mathbb{R}^{nT\times 1}$ is the disturbance term. Vector $\boldsymbol{\alpha} \in \mathbb{R}^{n\times 1}$ represents the individual effects of the panel data structure, as $D_{2i} = 1$ if the observation belongs to Austria, otherwise it is 0, $D_{3i} = 1$, if the observation belongs to Belgium, otherwise it is 0 etc. Since there are 29 entities, 28 dummy variables are used to avoid the so-called "dummy variable trap", whereas the first column of **D** is comprised of ones. It means that there is no dummy for the EU-28, as α_1 represents the intercept for the EU-28 and $\alpha_2, \alpha_3, \ldots, \alpha_{29}$ are the differential intercept coefficients that show how much the intercepts of Austria, Belgium etc. differ from the intercept for EU-28. Numerical explanatory variables **X** include GDP per capita (*GDP*), *EP* (electricity price), *LFOP* (light fuel oil price), automotive *DIESP* (diesel price), natural *GASP* (gas price), *COALP* (coal price), final energy consumption per capita (*FEC*), growth of *GIC* (gross inland consumption), and lagged *ET* (energy taxes). Vector $\boldsymbol{\beta} \in \mathbb{R}^{k\times 1}$ represents the corresponding regression coefficients, and the disturbance term is distributed as $u_{it} \sim (0, \Sigma)$.

In addition, it was attempted to capture the structural characteristics and changes of the individual economies and EU-wide structural changes that affect the energy intensity by including additional dummy variables. Some of these dummy variables relate to the restructuring of industrial companies, introduction of new technologies and innovations, decrease of the final energy consumption in the industry sector, national programmes for improvement of energy efficiency, adoption of new EU regulation targeted at energy efficiency, and the introduction of ETS (Emission Trading Scheme). It turned out that the regression coefficients of the numerical explanatory variables, even though quantitatively somewhat different, remained qualitatively unchanged. The model fit did not improve significantly either. Therefore, these additional dummy variables were not included in the final model specifications.[3]

Other numerical control variables were also employed, such as industry-specific final energy consumption, production, imports, energy dependency, energy saving in final energy consumption etc., and a broader lag structure for energy taxes. None of these model specifications changed the regression coefficients of the existing numerical explanatory variables qualitatively, even though they were of course quantitatively somewhat different, and are thus not reported in the final model specifications.[4] This does, however, indicate robustness of the reported model specifications.

4. Results and discussion

In order to establish the relationship between the energy intensity of an economy and its determinants, the model (1) was estimated based on data for EU-28 member states. To obtain consistent and unbiased estimates of regression coefficients, the required model diagnostics were carried out in all estimated model specifications. The assumption of homoscedasticity was tested by the modified Wald test for group-wise heteroscedasticity, which did not reject the null hypothesis. The assumption of no autocorrelation was tested by the Cumby–Huizinga test for autocorrelation. As the null hypothesis of no autocorrelation was rejected at several lag orders, the HAC (heteroscedasticity and autocorrelation consistent) estimator of variance was applied to calculate the standard errors of the regression coefficients.

Several model specifications of the model (1) were estimated. First, as both energy consumption and GDP in principle define the energy intensity, the effects of these two explanatory variables on energy intensity were measured separately in distinct model specifications, to avoid forcing a nonlinear relation to fit a linear

[3] Even though the structural dummy variables were not included in the final model specifications, these results are available upon request from the authors.

[4] The results of econometric estimation of the other model specifications, i.e. with different above-mentioned combinations of numerical control variables and with a broader lag structure for energy taxes, are available upon request from the authors.

Table 1
Estimation of the panel data model of energy intensity, specifications 1 and 2.

Energy intensity	Specification 1			Specification 2		
	Coefficient		HAC Std. Err.	Coefficient		HAC Std. Err.
Electricity price	−549.41	***	70.43	−612.02	***	63.70
GDP per capita	−1.6603	***	0.3034			
Final energy consumption per capita				0.1377	***	0.0242
Growth of gross inland consumption				163.90	***	37.56
Energy tax, one-year lag	−0.1263	***	0.0287	−0.1065	**	0.0487
Energy tax, two-year lag	−0.1702	***	0.0461	−0.1637	***	0.0567
Austria	−34.00	***	4.26	−31.64	***	5.00
Belgium	37.77	***	5.74	45.76	***	7.44
Bulgaria	697.93	***	31.77	690.18	***	32.52
Croatia	68.45	*	37.25	49.61		98.73
Cyprus	33.54	***	4.70	27.28	***	7.95
Czech Republic	355.61	***	15.03	360.14	***	15.32
Denmark	−21.00	**	9.02	−30.96	**	14.67
Estonia	364.78	***	16.59	371.72	***	17.09
Finland	40.94	***	6.25	47.55	***	8.49
France	−13.19	***	3.71	−16.36	***	3.62
Germany	−14.91		4.25	−24.73	***	6.98
Greece	−4.26		6.61	5.13	***	0.90
Hungary	225.67	***	12.52	232.66	***	11.69
Ireland	160.02	***	40.65	168.12	***	44.03
Italy	−0.87		5.25	−0.01		5.60
Latvia	104.64	***	11.16	114.18	***	11.25
Lithuania	188.27	***	20.65	187.31	***	20.83
Luxembourg	123.39		14.87	111.20		112.78
Malta	11.27	*	6.42	26.54	**	13.18
Netherlands	19.11	***	4.71	15.87	***	4.34
Poland	182.81	***	12.58	185.93	***	13.13
Portugal	−0.23		3.77	−7.42		8.48
Romania	387.37	***	21.37	386.17	***	22.54
Slovenia	74.90	***	6.12	77.46	***	6.40
Slovakia	349.88	***	26.94	353.25	***	28.70
Spain	−1.55	***	3.39	−2.10	***	0.86
Sweden	10.71	**	5.38	11.75	*	7.07
United Kingdom	−40.30	***	8.27	−42.05	***	9.28
Intercept (EU)	187.32	***	40.99	206.39	***	44.19
Number of observations	387			387		
Number of groups	29			29		
F-statistic	256.33			230.27		
p-value	0.000			0.000		
log *L*	−1847.71			−1841.82		

Note: Asterisks *, ** and *** denote statistical significance below the 0.1, 0.05 and 0.01 probability levels, respectively. Source: Own calculations.

relationship. In these two model specifications, reported in Table 1, only one of the available energy prices was used, i.e. the electricity price. This was done in order to preserve as many observations as possible in the model (and as much variability as possible, ensuring the estimator efficiency), as there is much less data available on other energy prices. In addition, the electricity price explains by far the highest share of variance of energy intensity, measured by the standardised regression coefficients.

Table 2 reports the estimation results from additional model specifications, where four more energy prices were added as explanatory variables, but with substantially less model observations due to missing data. Due to multicollinearity issues, again two separate model specifications were estimated, including light fuel oil price and automotive diesel price in model specification 3, and gas price index and coal price index in model specification 4. The two sets of the remaining explanatory variables, i.e. the separation between GDP per capita and final energy consumption per capita, was preserved from model specifications 1 and 2 (Table 1). Tables 1 and 2 show the estimates of regression coefficients from the empirical model specifications, whereas the average estimates (means of all four model specifications) shall be interpreted hereinafter.

Tables 1 and 2 show that the residential electricity price has a statistically significant negative effect on energy intensity. Namely, for every 1 cent/kWh increase in residential prices, energy intensity on average decreases in the EU-28 by 4.88 kgoe/1000EUR (specification mean). This result shows an important effect of electricity price on energy intensity in the EU-28 region, having in mind that in 2012 the average energy intensity in the EU-28 was 143 kgoe/1000 EUR and the average household electricity price was 19.54 cents per kWh.

Other energy prices also had statistically significant negative, though much smaller effects on energy intensity, in terms of both strength and explanatory power. Namely, for every 1 EUR/1000 L increase in light fuel oil price, energy intensity on average decreases in the EU member states by 0.04 kgoe/1000EUR and for every 1 cent per litre increase in light fuel oil price, energy intensity on average decreases by 0.50 kgoe/1000EUR (both are specification means). Similarly, a 1 percentage point increase in gas prices decreases on average the energy intensity in the EU member states by 0.34 kgoe/1000EUR and a 1 percentage point increase in coal prices decreases on average the energy intensity by 1.27 kgoe/1000EUR (specification means).

Final energy consumption per capita has a statistically significant positive effect on energy intensity as well. Namely, if final energy consumption per capita at current prices increases by 1000 toe per inhabitant, energy intensity on average will increase in the EU-28 by 0.20 kgoe/1000EUR (specification mean). This

Table 2
Estimation of the panel data model of energy intensity, specifications 3 and 4.

Energy intensity	Specification 3			Specification 4		
	Coefficient		HAC Std. Err.	Coefficient		HAC Std. Err.
Electricity price	−465.89	***	95.49	−326.26	***	111.09
Light fuel oil price	−0.0391	***	0.0098			
Automotive diesel price	−49.66	***	15.71			
Gas price index				−0.3425	***	0.0760
Coal price index				−1.2677	***	0.1843
GDP per capita	−1.8246	***	0.3276			
Final energy consumption per capita				0.2615	***	0.0463
Growth of gross inland consumption				134.30	***	45.45
Energy tax, one-year lag	−0.1158	**	0.0588	−0.0946	*	0.0561
Energy tax, two-year lag	−0.1936	***	0.0524	−0.1705	***	0.0558
Austria	−39.51	***	4.83	−53.63	***	7.25
Belgium	37.46	***	6.07	44.22		40.57
Bulgaria	668.11	***	21.79	763.60	***	33.83
Croatia	194.97	**	88.53	125.72	**	61.30
Cyprus	32.85	***	5.03	21.76	***	7.50
Czech Republic	388.49	***	16.25	380.23	***	14.25
Denmark	−30.28	***	8.68	−47.51	**	19.21
Estonia	406.01	***	18.17	407.79	***	23.41
Finland	54.24	***	5.66			
France	−6.89	**	2.88	−2.83	***	0.58
Germany	−2.13		6.71	−5.97		8.19
Greece	−14.68	**	7.15	39.10	***	12.12
Hungary				233.09	***	15.38
Ireland	57.19	***	4.62	74.97	***	9.23
Italy	−13.50	***	4.79			
Latvia	139.36	***	11.62	138.92	***	14.90
Lithuania	217.92	***	17.32	249.65	***	18.50
Luxembourg	227.40		330.85	31.54	**	13.12
Malta	12.34	***	3.46			
Netherlands	10.34	**	4.25			
Poland	211.46	***	12.07	208.26	***	11.89
Portugal	13.56	***	4.48	−3.68		8.85
Romania	387.71	***	15.05	418.90	***	25.76
Slovenia	80.20	***	4.57	71.50	***	6.99
Slovakia				368.53	***	28.36
Spain	−4.52		3.24			
Sweden	4.14		5.45			
United Kingdom	−28.28	***	8.88	−46.33	***	11.75
Intercept (EU)	273.00	***	14.28	245.65	***	61.85
Number of observations	325			271		
Number of groups	27			23		
F-statistic	336.12			356.78		
p-value	0.000			0.000		
log *L*	−1407.15			−1262.68		

Note: Asterisks *, ** and *** denote statistical significance below the 0.1, 0.05 and 0.01 probability levels, respectively. Source: Own calculations.

result is in line with the results of survey [17], which found that in the most developed economies (United States, Canada, Australia etc.) there is a positive correlation between final energy consumption per capita and energy intensity. Likewise, the effect of growth of inland energy consumption on energy intensity is positive and statistically significant. Namely, if the growth of inland energy consumption increases by 1 percentage point, energy intensity will on average increase in the EU-28 by 0.15 kgoe/1000EUR (specification mean), other determinants of energy intensity being unchanged. Even though the latter two determinants are statistically significant, the strength of these two net effects (other explanatory variables being unchanged) is relatively low.

The effects of implicit energy taxes on energy intensity are somewhat more complicated. Namely, as the expected effects of the implicit tax rate on energy intensity are dynamic, the first and the second lag of energy tax are employed in the regression model. It turned out that both effects are negative and statistically significant. If energy taxes increase in the current year by EUR 1 per tonne of oil equivalent, energy intensity will on average decrease in the EU-28 by 0.11 kgoe/1000EUR with a one-year lag and by 0.17 kgoe/1000EUR with a two-year lag (specification means). Taking into consideration that the average implicit energy tax (calculated as energy revenues per final energy consumption) for the EU-28 in 2012 was EUR 172 per toe, this result shows that this determinant does not have a big impact on energy intensity, although the impact rose with the time lag. However, the implicit tax rate on energy as an indicator has some shortcomings because it treats all kinds of energy consumption equally, regardless of their environmental impacts. Even though in many countries renewable energy sources are subject to lower tax rates than fossil fuels (or wholly exempted in order to provide incentives to switch over to environment-friendly energy sources), an inconsistent situation could emerge in which a country with a high share of renewables has a lower implicit tax rate on energy than a country with a high share of fossil fuels in its final energy consumption. On the other hand, the analysis of the energy price structure showed that those countries with a high share of energy taxes usually have low energy intensity.

GDP per capita has a relatively weak, although statistically significant negative effect on energy intensity. Namely, if GDP per capita at current prices increases by EUR 1000 per inhabitant, energy intensity will on average decrease in the EU-28 by 1.74 kgoe/

1000EUR (specification mean). As already mentioned, this effect is relatively small on average, but one needs to bear in mind that a country's standard of living is also incorporated in several other explanatory variables of the model and this estimate is thus the direct, net effect of GDP per capita on energy intensity. This result is in accordance with the mentioned studies [10,11] and confirms that income reflects the level of economic development, which is closely related to energy efficiency improvements. Generally speaking, economically developed countries have competitive industries and a high level of specialisation in technology development sectors.

The country-specific conditional mean of energy intensity is estimated by adding a dummy variable for each country. The estimated regression coefficients for some countries were not statistically significant, not even at the 10 percent level (see Tables 1 and 2), meaning that energy intensity in these countries is not statistically significantly different from the conditional mean of the EU-28. The conditional mean of energy intensity for the EU-28 was 228.09 kgoe/1000EUR (specification mean). The regression coefficients of the remaining dummy variables were statistically significant and demonstrate the deviation in energy intensity of a particular country from the conditional mean of the EU-28. Countries with a negative dummy variable regression coefficient thus had a lower conditional mean of energy intensity, while countries with a positive dummy variable regression coefficient had a higher conditional mean of energy intensity than the EU-28 average.

Fig. 7 compares the deviations in energy intensity of a particular member state from the EU-28 average based on official Eurostat statistics (calculated as means for 1992–2012) with the differential intercept coefficients $\alpha_2, \alpha_3, \ldots, \alpha_{29}$ from our model (calculated as means of all four model specifications). As can be seen from Fig. 7, the conditional mean estimates of energy intensity correspond to the official data quite well, with very little overestimation (the highest being 31.89 kgoe/1000EUR for Italy) and some more underestimation (the highest being 210.53 kgoe/1000EUR for Latvia). These deviations are also in line by and large with the official statistics presented in Fig. 2, where energy intensity in the EU-28 member states is shown only for 2000 and 2012. In addition, the individual (fixed) effects were jointly statistically significant, as the corresponding F-test statistic had a p-value of 0.000 in all model specifications.

5. Conclusion

Energy intensity is an important indicator of sustainable development and therefore of particular interest for research. However, in neither theory nor practice is there clear scientific and professional agreement on the determinants that affect energy intensity, or on the direction and strength of their influence. The aim of this research was thus to analyse energy intensity in the EU-28, and to study the determinants with a relevant impact on energy intensity, in particular the growth of gross inland consumption, GDP per capita, final energy consumption per capita, energy prices, and energy taxes. The research is based on panel data for the period 1990–2012, where the regression parameters are estimated by a fixed-effects estimator.

It was established that energy prices, energy taxes and GDP per capita have a negative influence on energy intensity, while the growth of gross inland consumption and final energy consumption per capita positively affect energy intensity. The highest impact on energy intensity, both in terms of strength and explanatory power, was estimated for energy prices, whereas the other determinants were less important. This result implies that energy prices and among these the electricity price in particular should be considered as a valuable energy policy instrument for improving energy efficiency, especially in the new EU member states (Bulgaria, Romania, Estonia, Lithuania and Latvia) that at the same time have low electricity prices and high energy intensity. On the other hand, some countries are observed with high energy prices and low energy intensity (Denmark, Italy and Germany).

Therefore, findings from the research provide useful policy implications for further enhancing energy efficiency in the EU. However, what should be considered is a policy mix rather than a single policy in isolation. The observed evidence showed that taxation has been a major driver of increasing residential energy prices in recent years in some EU countries (e.g. in Denmark), which at the same time have had a low level of energy intensity. In order to substantially increase energy efficiency, it will be essential to learn from those countries that have made the most rapid progress towards this goal.

Any study on the determinants of an economy's energy intensity has certain limitations that must be considered. A key limitation relates to the availability of data because the selection of determinants of energy intensity in an empirical analysis depends on a consistent time series for a sufficiently long period. Moreover, the more disaggregated the data, the more precise and meaningful the measures of energy intensity. Identifying the determinants that affect energy intensity contributes to the knowledge about this phenomenon as a very important indicator of sustainable development.

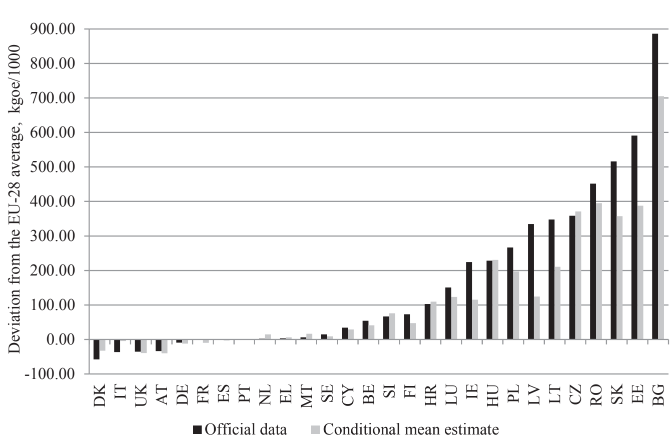

Fig. 7. Deviations in energy intensity from the EU-28 average, in kgoe/1000 EUR. Source: Eurostat, data code tsdec360; own calculations.

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