Interlinkages between human development, residential energy consumption, and energy efficiency for the EU-27 Member States, 2010–2018

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This study aims to highlight the importance of human development in light of residential energy consumption and its relationship with energy efficiency. It investigates the influence of the human development indicator (HDI) on residential energy consumption inequality for the EU-27 Member States for the period of 2010–2018 by using the Gini coefficient. It also analyses the effect of the HDI components life expectancy, education, and gross national income (GNI) on residential energy use with the help of the least squares dummy variable (LSDV) model. The novel results indicate that territorial inequality in energy use would drop if all member states had the same HDI value. The LSDV model results show that life expectancy negatively influences energy consumption, the education index has no effect, and GNI shows a positive relationship. In addition, energy efficiency is found to exert a significant influence on human development on the basis of the energy efficiency scores for all member states. The results divide the member states into high, low, and average groups according to their energy efficiency scores and HDI values. Through this classification, this study provides policy recommendations for each group.

Keywords:
human development,
energy consumption,
life expectancy,
education,
gross national income (GNI),
energy efficiency

Introduction

Energy is an essential factor in our daily lives. Our relationship with energy is vital as it enables us to perform our daily life activities. Energy is used for heating, cooling, lighting, transportation, and industry. In addition, it is a prerequisite for human development and sustainability. Access to secure energy sources, such as electricity and clean cooking fuel, is fundamental for maintaining a high quality of life. This affects health, life expectancy, productivity, education, agricultural activities, and income. Developed nations, for instance, consume more energy than developing nations, and they have a higher level of human development (Gaye 2013). The lack of access to such sources is a serious problem that leads to energy poverty. It occurs in energy-poor households because of high energy expenditure, low income, and poor building efficiency. People living in poorly insulated buildings are more likely to experience health problems. These building conditions also contribute to lower productivity and higher mortality rates. Currently, energy poverty is an alarming problem in Europe and is a growing concern for the European Union (EU).

Meanwhile, climate change is emerging as a major concern, and its mitigation is the greatest priority for the EU. One of the critical engines that help form greenhouse gas (GHG) emissions is fossil fuel-based energy consumption (Jaber 2022). The EU attempts to reduce GHG emissions by reducing energy consumption, improving energy efficiency, and increasing the share of renewable sources. Recently, the union introduced the 'Fit for 55' package to revise and expand the EU's carbon emission trading scheme (ETS). One of the main features of this package is the extension of the EU's ETS to cover households and the transport sector.

On the one hand, the package is promising as it promotes further reduction of CO_2 emissions so that it reaches 55% from the 1990 levels by 2030. On the other hand, the extension to new sectors, particularly the residential one, is expected to considerably increase energy prices and utility bills, which may put energy-poor households in jeopardy. The union is set to support these households through a social climate fund as the introduction of the EU ETS to the household sector will affect energy-poor households. However, the amount of funding available will be insufficient to deliver widespread renovations and renewables (righttoenergy.org 2021).

This research studies the relationship between human development level, residential energy consumption, and energy efficiency to prove that high energy consumption relates to a high human development level and vice versa. The HDI is expected to positively affect energy use to a certain level before saturation, and energy efficiency negatively affects it. The main goal is to suggest some policy recommendations to achieve the European climate goals, including reducing residential energy use without negatively impacting poor households or human development, particularly in states with low energy efficiency performance and relatively low HDI. These targets could be achieved by improving the energy efficiency of buildings instead of restricting the affordability of energy sources. In this way, energy consumption will be effectively reduced. It is also one of the best ways to mitigate climate change, reduce GHG emissions, and maintain human health. Reducing energy use by improving energy efficiency reduces monthly energy bills and makes energy more affordable for families.

Literature review

Human development is defined as enlarging people's freedom and opportunities and improving their well-being (Measure of America no date). In the past, it was believed that more energy consumption leads to a higher level of human development. This belief has since changed because of climate change and the issue of energy efficiency. Although energy is an essential factor for all activities, it is the main cause of GHG emissions, which harm the environment. Regardless of its positive or negative effect, energy consumption inevitably affects human development. Access to modern energy services is necessary to satisfy human needs and drive economic and human development because electricity, natural gas, and other fuels are fundamental to good education and health. In addition, access to energy services guarantees a good standard of living. Meanwhile, energy consumption varies between developed and developing countries and between the rich and poor areas within these countries. Hence, the development of these regions and their citizens is driven by their access to energy that can readily be used. In sum, governments face an enormous challenge in improving energy access (Pîrlogea 2012).

Human development is measured using the HDI. The United Nations composite statistic allows for dynamic comparisons of nations' socioeconomic development levels worldwide (Müller-Frączek 2019). The relationship between the HDI and energy consumption was first studied in the 1990s by C.E. Suarez (Ediger–Tatlidil 2006). Many researchers later used the calculations to investigate this relationship further. In 2008, (Martínez–Ebenhack 2008) presented a correlation between the HDI and energy consumption in 120 countries. A robust positive correlation index was found between the two variables for each country. The study also noted a significant increase in the HDI relative to energy consumption for energy-poor countries, a moderate increase for transitioning countries, and no increase for countries that consume large amounts of energy. Meanwhile, changes in energy consumption in countries that consume less energy have an enormous impact on HDI values.

According to (Wu et al. 2010), developed countries must reduce energy consumption by enhancing energy efficiency and savings. They should improve the conditions of a high standard of life based on significantly lower energy consumption levels. However, developing countries cannot depict the experience of developed countries because the massive expansion in energy, transportation systems, and agricultural production areas are negatively restricted by different resource constraints. They must follow different paths to improve their level of human development. Therefore, they must increase their energy demand to implement potential growth in human development.

By contrast, (Pîrlogea 2012) investigated the impact of fossil fuel and renewable energy consumption on the HDI for six European countries using a panel data regression model and found that fossil fuel consumption relates negatively to the HDI for medium-HDI countries and positively for high-HDI countries. According to this study, although energy consumption enhances economic development in these countries, it does not necessarily contribute to human development. Moreover, it has adverse effects on the environment, which lead to a negative impact on health and well-being. Thus, it highly depends on how countries react to these effects.

Another study confirmed Martínez's findings regarding the response of the HDI to changes in energy consumption (Wu et al. 2012). The study used a regression model to determine the relationship between the two variables for almost all countries. They agreed that the relationship is not linear, which means that an increase in energy consumption will rapidly increase the HDI for low-HDI countries. In addition, the study calculated the inequality in energy consumption on the basis of different criteria for these countries from 1998 to 2007 by using the Lorenz curve and Gini coefficient. During this period, the Gini coefficient value dropped from 0.537 to 0.5. This result was attributed to globalisation, improvements in the infrastructure and access to electricity in developing countries, changes in the energy mix towards more efficient energy use, and the introduction of climate change mitigation policies.

The HDI has three main components: life expectancy, education level, and GNI. Life expectancy is considered an indicator of a nation's health and an excellent tool for measuring countries' development (Alam et al. 2016). According to the literature, energy consumption reduces life expectancy owing to environmental degradation. Using time series data from 2000 to 2016 for various regions, (Sarkodie et al. 2019) found that air pollution resulting from energy consumption negatively affects health and reduces life expectancy. This result matches the findings of (Wang et al. 2020) in Pakistan from 1972 to 2017 which showed that the causality interaction between the two variables is negative. According to these authors, a 1% increase in energy consumption leads to a 0.0685% decline in life expectancy. However, the relationship between these variables depends on the type of fuel used. (Wang et al. 2019) applied ordinary least squares (OLS) regression and a geographically weighted regression model to study the effect of residential energy consumption on life expectancy. They found that household coal is negatively related to life expectancy whilst electricity is positively related. In the case of Africa, (Nkalu–Edeme 2019) found that CO_2 emissions from solid fuel consumption reduce life expectancy whilst the effect of CO_2 emissions from liquid fuel consumption on life expectancy was insignificant. Hence, a country's energy mix matters; clean and sustainable energy sources are always positively correlated with these variables. Access to such sources supports disease prevention and directly contributes to universal health coverage, which is integral to ending poverty and reducing inequalities (The UN 2021).

The second component is the education level. Various methods are used to assess the quality of human capital; the most straightforward method is education level or the number of years spent in training (Szakálné Kanó et al. 2017). Access to excellent education is vital for the informed population. Through access to information, the next generation has the potential to accelerate access to affordable and clean energy, which is crucial for a sustainable future. In turn, access to reliable energy enables and improves the quality of education. It has also been associated with a better learning environment, enhanced school performance, increased opportunities, and improved staff retention (The UN 2021). Therefore, the relationship between education quality and energy consumption is bidirectional. According to (Lloyd 2017), if the energy consumption per capita for a nation is less than 500 kg of oil equivalent, 25% of learners will not complete their primary schooling. Given 1,000 kg of oil equivalent, around 5% will not complete their primary schooling; at a greater oil equivalent, all learners will be able to complete their schooling.

Nevertheless, the linkage between energy use and the quality of education may depend on the country's development level. (Inglesi-Lotz–Diez del Corral 2017) applied the Granger causality test and panel regression analysis for a group of developed and developing countries as well as an aggregate panel of developed and developing country groups for the period of 1980–2013. The result showed that education Granger-causes energy consumption for all groups but that energy consumption does not Granger-cause education. Additionally, there is a nonlinear relationship between the two variables in the aggregate group. Meanwhile, education has a negative coefficient on energy use in developed countries but a positive coefficient in developing countries. This was attributed to the fact that improving technology levels in education in developed countries will result in declining energy use. Improving education in developing countries will increase energy use owing to an increase in income. Consequently, this will entail different policy implications for developed and developing countries.

The third component is the GNI. Energy is essential for human life and economic activities; it is a humanitarian need that plays a role in economic and social development. A country's per capita energy consumption is considered a crucial indicator of its economic development. After the 18th century industrial revolution, energy demand increased, resulting in increased reliance on it. Currently, energy is a production income and is regarded as a product that forms the economy and politics of the world. Numerous studies have analysed the linkage of energy consumption to gross domestic product (GDP) rather than its linkage to GNI. Indeed, GDP is the most crucial driver of CO_2 emissions according to (Mitsis 2021). However, most previous studies investigated the relationship of GDP with household income rather than national income. Household income differs from national income because it contains other income items, such as transfers and remittances. In addition, the reallocation of income amongst sectors draws a clear distinction. For example, taxes from households and businesses to governments are a type of reallocation of national income (oecd.org no date).

One such study was conducted by (Cayla et al. 2011). They found that French households' residential and transport energy expenditures in 2008–2009 increased as their income increased. However, the relationship is not linear because expenditures decrease after a particular annual income value of 60,000 EUR. Another study (Dey 2019) investigated the causal relationship between electricity consumption and the GNI of Bangladesh from 1971 to 2014. The results showed a positive short-run unidirectional causality from electricity consumption to GNI and a positive long-run bidirectional causality between the two variables. (Chen et al. 2022) investigated this relationship for poor households in 16 counties in China and concluded that households' demand for energy increases with income after a threshold point or the poverty line. In addition, (Mutalimov et al. 2021) found that it would take four years for small companies in the Far Eastern District in Russia to reach the maximum total profit possible without market expansion. However, the volume of emissions per small company will not reach its maximum value over the next 20 years. They suggested introducing innovative solutions to prevent the harmful environmental effect of development. Overall, the positive relationship between energy consumption and income or GNI depends on the income value itself; it exists when income is within a specific range.

As indicated in the literature, there is a nonlinear relationship between energy consumption and the HDI. The strength of this relationship varies for countries depending on their level of human development, the amount of energy they use, and how they deal with the negative impact of emissions on the environment. This nonlinearity is reflected in the relationship between energy consumption and the three HDI components.

Methodology and data

The selection of the study period is due to it being the most recent and due to data availability. The variables used in this study are households' per capita energy consumption (EC), number of population (POP), annual heating degree days (HDD), human development index (HDI), education index (EI)[1], life expectancy (LE), per capita gross national income (GNI), and residential energy efficiency score (REES). Table 1 provides information on the variables and databases used in this study.

[1]The study period herein is limited by data availability. Regarding the variables, the education index provides information about the average years of schooling for adults and expected years of schooling for children. However, it may not provide a comprehensive representation of education level.

Table 1

Data description

Variable	Unit	Description	Source
EC	kg of oil equivalent (KGOE)	Households' energy consumption is divided by the population.	(Eurostat [2021a] – Energy consumption in households per capita 2021)
POP	Number of individuals	The number of individuals living in a specific area.	(World Bank (2021) – Population 2021)
HDD	Celsius (°C)	A simplification of outside air temperature data. They come with a base temperature and measure how much (in degrees) and for how long (in days) the outside temperature was below that base temperature.	(Eurostat 2019b)
HDI	Unity	A composite of the three dimensions of human development, namely, a long and healthy life measured by life expectancy, access to education measured by expected years of schooling of children at school-entry age and mean years of schooling of the adult population, and a decent standard of living measured by gross national income per capita adjusted for the price level of the country.	(HDR [2020a] – Education index)
EI	Unity	An average of years of schooling for adults and expected years of schooling for children.	(HDR [2020a] – Education index, 2020)
LE	Years	The mean number of years still to be lived by a person who has reached a certain age and is subjected to current mortality conditions throughout the rest of his or her life (age-specific probabilities of dying).	(Eurostat [2021b] – Life expectancy 2021)
GNI	USD PPP (purchasing power parity)	The aggregate income of a country generated by its production and its ownership of factors of production, less the payments paid for the use of the factors of production owned by the rest of the world, converted to international dollars using PPP rates, and divided by the number of population.	(HDR [2020b] – GNI per capita, 2020)
REES	Unity	An average of the three scores obtained for 'energy efficiency level, a moving average of the last three years'; 'energy efficiency progress based on the trend indicator since 2000'; and 'energy efficiency policies'.	(Odyssee-mure 2021)

Source: Eurostat 2019b, 2021a, b, HDR (2020a, b), UNDP.org 2020, World Bank (2021), and Odyssee-mure 2021.

Gini coefficient[2]

The Lorenz curve and Gini coefficient are the most popular methods that many researchers, such as Wu et al. (2012), Lawrence et al. (2013), and Pascual-Sáez et al. (2017), have used to measure inequalities. They measure income inequality by dividing the country's population into 10 equal deciles on the basis of income and then measure each decile's income share related to its population share. In recent years, these methods have been used to measure different types of inequality, such as energy consumption, GDP, and CO_2 emissions. The Lorenz curve is a plot where the y-axis shows the cumulative percentage of the variable whose inequality is to be measured and the x-axis shows the cumulative percentage of the population of countries, cities, areas, and deciles similar to the 10 population income deciles. It is a curve with a straight diagonal line representing perfect equality, where all countries or deciles would have an equal share of the variable. The Gini coefficient is a standard measure of inequality, defined as the area between the Lorenz curve and the equality line divided by the triangle beneath the equality line area (Ramzai 2020). The Gini coefficient is used to measure the inequality in residential energy consumption per capita for all EU-27 Member States from 2010 to 2018. The following equation is extracted from (Thakur no date) and used to calculate the Gini coefficient:

$$\text{Gini coefficient} = 1 - \sum_i (Pp_i \, x \, (ECp_i + 2 \times (1 - CECp_i))) \ldots \quad (1)$$

where Pp_i: Population percentage of country i; ECp_i: Energy consumption percentage of country I; $CECp_i$: Cumulative energy consumption percentage of country i.

Panel regression

Panel data are a combination of time series and cross-sectional data. Panel regression is a method that analyses the relationship between independent variables and one dependent variable in the panel data. It considers the effect of each independent variable adjusted to account for differences in other independent variables. The general formula for panel regression is (Brugger 2021)

$$Y_{it} = \beta_1 X_{it} + \alpha_i + u_{it} \ldots. \quad (2)$$

where Y_{it}: The dependent variable, where i = entity and t = time; α_i: Unknown intercept for each entity; X_{it}: One independent variable; β_1: Regression coefficient for the independent variable; u_{it}: The error term.

The dependencies of unobserved independent variables (unknown intercepts) on a dependent variable, leading to biased estimators in traditional linear regression models, can be controlled by panel regression. The method can address the problems of heterogeneity and endogeneity that lead to such results. Heterogeneity is the existence of the unobserved dependency of other independent variables, and

[2] The Gini coefficient has limitations in measuring inequalities. It has a sample size bias, and in some cases, it can have the same value for countries with different income distributions but equal income levels (CFI – Gini Coefficient no date).

endogeneity is the correlation between independent and unobserved independent variables.

There are three main types of regression for panel data: pooled OLS, fixed effects (FE), and random effects (RE). Pooled OLS can be described as a simple OLS model performed on panel data. It ignores time and individual characteristics and focuses only on the dependencies between individuals. However, simple OLS requires no correlation between unobserved and independent variables. Consequently, pooled OLS is inappropriate for panel data. The existence of time series and cross-sectional data poses various problems, such as heteroskedasticity and autocorrelation. Several estimation models address one or more of these problems, but the most prominent are the FE and RE models (Gujarati–Porter 2003).

The FE model determines the individual effects of unobserved independent variables as constant over time. Endogeneity can exist within FE models. The FE model assumes alpha to be a constant and subtracts the mean values from each equation term. In this way, alpha becomes zero and is neglected. However, because heterogeneity can be controlled for, it can exist within the model. RE models determine the individual effects of unobserved independent variables as random variables over time. They can switch between OLS and FE and focus on the dependencies between and within individuals.

An alternative to the FE model is the least squares dummy variable (LSDV) model, in which dummy variables represent fixed individual effects. This model yields the same results as the FE model. The LSDV model is chosen in the current study to investigate the impact of the HDI components, EI, GNI, and life expectancy on climate-normalised residential energy consumption per capita for the EU-27 Member States from 2010 to 2018. The natural logarithm transformation for all variables is used to measure relative elasticity. The LSDV model is selected for more than one reason. According to (Gujarati–Porter 2003):

1. If the number of time series units (T) is small, the number of cross-sectional units (N) is large, and the cross-sectional units are not random selections from a larger sample, then the FE model is appropriate. If the cross-sectional units in the sample are regarded as random selections, then the RE model is appropriate. In this regard, the member states are not randomly selected from a larger sample.
2. If endogeneity exists, then the RE model estimators are biased, whereas those obtained from the FE model are unbiased. The null hypothesis of the Wald test is rejected for the three regressors, indicating that they are endogenous.
3. The Hausman test is used to ensure proper selection. The Hausman test's null hypothesis, that is, the covariance between independent variables and unknown intercepts is zero, is rejected, indicating that the FE model is preferable to the RE model.

After selecting the LSDV model, the following assumptions are tested:

- Significant outliers are unlikely to exist;
- There is no perfect multicollinearity;
- The error terms are normally distributed;
- The error terms are not correlated (no autocorrelation);
- The error variance is constant (no heteroscedasticity).

The climate-normalised energy consumption is calculated using the following equation:

$$EC_C = EC \text{ x } \left(\frac{HDDref}{HDD}\right) \ldots \quad (3)$$

where EC_C: Climate-normalised households' per capita energy consumption; EC: Households' per capita energy consumption; HDD: Heating degree days; HDDref: Mean heating degree days calculated by determining the average values of the heating degree days of the study period (Energylens.com, no date).

Results and discussion

In calculating the energy inequality for the residential sector, the population of each state should be included to eliminate its effect on the results, and the per capita energy consumption values of households are needed. To better understand the inequality and Gini coefficient in Table 2, this study divides the member states into three groups on the basis of the per capita household energy consumption values in 2018. The first group accounts for 22.7% of the total population and consumes only 14% of total household energy. The second group of countries accounts for 49% of the total population and consumes 49.7% of total household energy. The third group of countries accounts for 28.3% of the total population and consumes 36.3% of the total household energy. The highest per capita energy consumption values measured in kilograms of oil equivalent are 1,032 in Finland, 828 in Luxembourg, 790 in Denmark, and 736 in Sweden. Meanwhile, the lowest values measured in kg of oil equivalent are 193 in Malta, 284 in Portugal, 317 in Bulgaria, and 321 in Spain. These results generally indicate an acceptable level of energy inequality amongst the EU-27 Member States.

It is notable that most of the countries in the first group are located in southern Europe and that most of the countries in the third group are in northern Europe. As long as the weather in northern Europe is colder than that in the south, those countries in the north consume more energy for residential heating spaces than those in the south. This is one possible factor contributing to these results.

The other possible factor is the human development level of the country; it is obvious that all countries in the third group are the most developed in the EU. The HDI represents the human development level, with values ranging from 0 to 1. The higher the HDI value for a country, the more developed it is. Table 2 also shows that the average HDI value for the first group of countries that consume a low amount of energy is 0.858; for the second group of countries that consume a moderate amount of energy, it is 0.884, and for the last group of countries that consume a high amount of energy, it is 0.919. This result shows how much these two variables correlate with each other.

Table 2

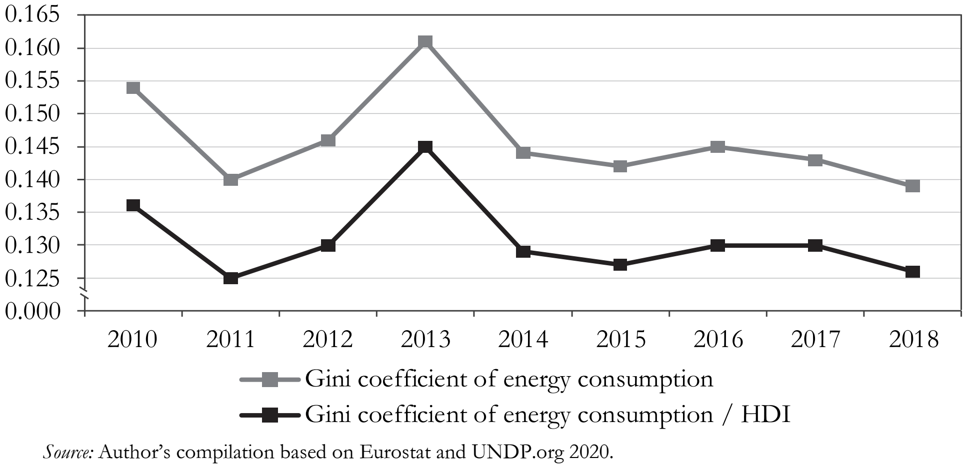
Population and household energy consumption shares in 2018 for EU-27 Member States

EU Member States	Population	Household energy consumption	Average HDI
	%		
Malta, Cyprus, Portugal, Bulgaria, Spain, Greece, Slovakia, Romania	22.7	14.0	0.858
Poland, Slovenia, Italy, Lithuania, Netherlands, Croatia, Ireland, France, Hungary, Latvia, Czech Republic	49.0	49.7	0.884
Germany, Belgium, Estonia, Austria, Sweden, Denmark, Luxembourg, Finland	28.3	36.3	0.919

Source: Author's compilation based on Eurostat 2019a and Worldbank.org 2020.

Figure 1

Gini coefficient values of a typical household's energy consumption and households' energy consumption divided by the HDI values for the EU-27 Member States (2010–2018)



Source: Author's compilation based on Eurostat and UNDP.org 2020.

To investigate the effect of HDI on residential energy use inequality, Figure 1 shows the Gini coefficient values of a typical household's energy consumption and households' energy consumption divided by the HDI values for EU-27 Member States (2010–2018). The inequality in energy consumption throughout the study period was low, and the Gini coefficient values varied from 0.154 in 2010 to 0.139 in 2018. The two lines have the same trend: they are similar to each other, but the values of the Gini coefficient for energy consumption per HDI are almost 0.02 less than the typical values for each year. Consequently, residential energy use inequality would decrease if the member states had similar HDI values. This is a novel and expected result; as the human development level is related to energy consumption, it should impact the territorial inequality in energy consumption values.

Table 3

LSDV model for climate-corrected residential energy consumption and the three HDI components, namely, education index, life expectancy, and GNI, for the EU-27 Member States from 2010 to 2018

Fixed effects, using 243 observations
Includes 27 cross-sectional units
Time series length = 9
Dependent variable: l_EC
Robust (HAC) standard errors

Variable	Coefficient	Std. Error	t-Ratio	p-value
Const	62.68966	8.61744	7.275	1.00e-07
l_EducationI	–0.928564	0.618042	–1.502	0.1450
l_GNI	0.511461	0.122390	4.179	0.0003
l_LifeE	–14.1527	2.08916	–6.774	0.0009

Effects Specification

LSDV R-Squared	0.930907	Mean dependent variable	6.286094
SE of regression	0.118110	SD dependent variable	0.421
Sum squared residuals	2.971331	Akaike info criterion	–1.319261
Log-likelihood	190.2902	Schwarz criterion	–215.7886
Within R-squared	0.374854	Hannan–Quinn criterion	–278.3713
rho	–0.178493	Durbin–Watson stat	2.034139

Joint test on named regressors – Test statistic: F(3, 26) = 34.0882 with p-value = P(F(3, 26) > 34.0882) = 3.67793e-09

Distribution free Wald test for heteroskedasticity – Null hypothesis: the units have a common error variance
Asymptotic test statistic: Chi-square(27) = 216.827 with p-value = 1.49507e-31

Test for normality of residual – Null hypothesis: error is normally distributed
Test statistic: Chi-square(2) = 2.15979 with p-value = 0.33963

Wooldridge test for autocorrelation in panel data -
Null hypothesis: No first-order autocorrelation (rho = -0.5)
Test statistic: F(1, 26) = 4.38547 with p-value = P(F(1, 26) > 4.38547) = 0.0461419

Correlation coefficients, using observations 1 – 243
5% critical value (two-tailed) = 0.1259 for n = 243

	l_LifeE	l_GNI	l_EducationI
l_EducationI	0.1198	0.3955	1.0000
l_GNI	0.6836	1.0000	
l_LifeE	1.0000		

Source: Author's compilation based on (Eurostat) and (UNDP.org 2020).

For an in-depth analysis, the relationship between climate-corrected residential energy consumption and the three HDI components for the EU-27 Member States from 2010 to 2018 is shown in Table 3. The natural logarithm of energy consumption is the dependent variable, whereas the natural logarithms of the HDI components are the independent variables. Considering the individualism of each member state, no significant outliers are detected in the data. The correlation matrix in the table shows no perfect or strong correlations between the independent variables, indicating no perfect multicollinearity. The null hypothesis for the normality and autocorrelation tests is accepted, indicating that the error is normally distributed and that there is no autocorrelation. However, the null hypothesis for the heteroskedasticity test is rejected, which means that the units do not have common error variance. As a result, robust standard errors are used to fix the heteroskedasticity issue. Table 3 shows the results of the panel regression. It displays a negative regression coefficient between energy consumption and education index and life expectancy (negative relationship) and a positive relationship between energy consumption and GNI (positive relationship). Except for the education index, the probability values for the independent variables are less than 0.05, indicating a significant relationship with energy consumption. The R-squared value is 0.9309, which is acceptable, meaning that the independent variables can explain 93.09% of the variation in the dependent variable. The model fits as the probability value is less than 0.05.

A high life expectancy value means that people live more and consume more energy. A study by (Steinberger et al. 2020) showed that the increase in energy consumption in 70 countries (80% of the world population) between 1971 and 2014 accounted for a 25% increase in life expectancy. Another study confirmed these results by presenting two variables moving in the same direction for four developing countries (China, India, Brazil, and Indonesia) over 50 years (Lloyd 2017). However, the results showed a negative relationship between energy consumption and life expectancy. This is mainly because high life expectancy requires an advanced health system and a green environment with fewer pollutants and emissions. This is consistent with the results of (Wang et al. 2020) for Pakistan.

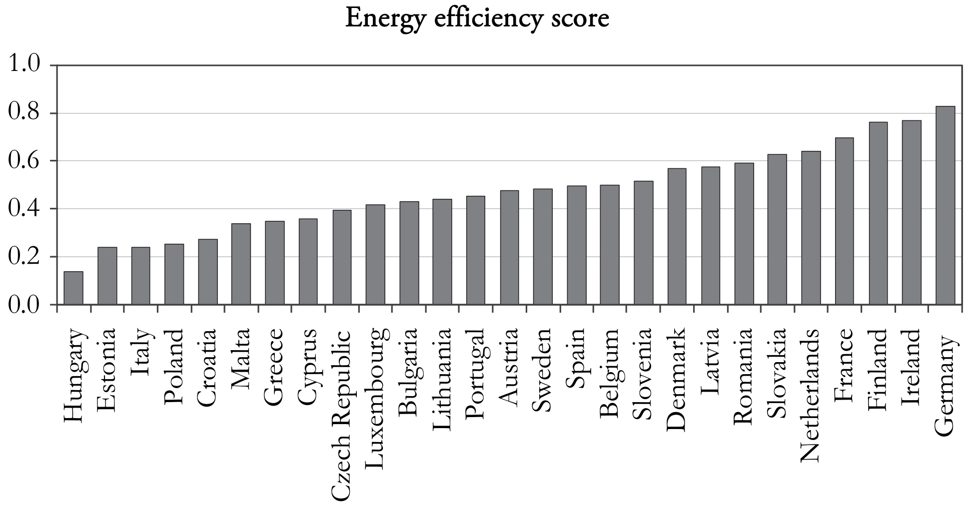
In terms of education, the literature has shown that the education level in developed countries might have an adverse effect on energy use as improving technology in education will lead to declining energy use (Inglesi-Lotz–Diez del Corral 2017). Most EU Member States are advanced countries with high-quality educational systems. Furthermore, education influences the behaviour of households to become more energy-conservative (Liu et al. 2015). However, the results show that education in Europe does not affect residential energy consumption and that there is no direct link between education level and residential energy consumption.

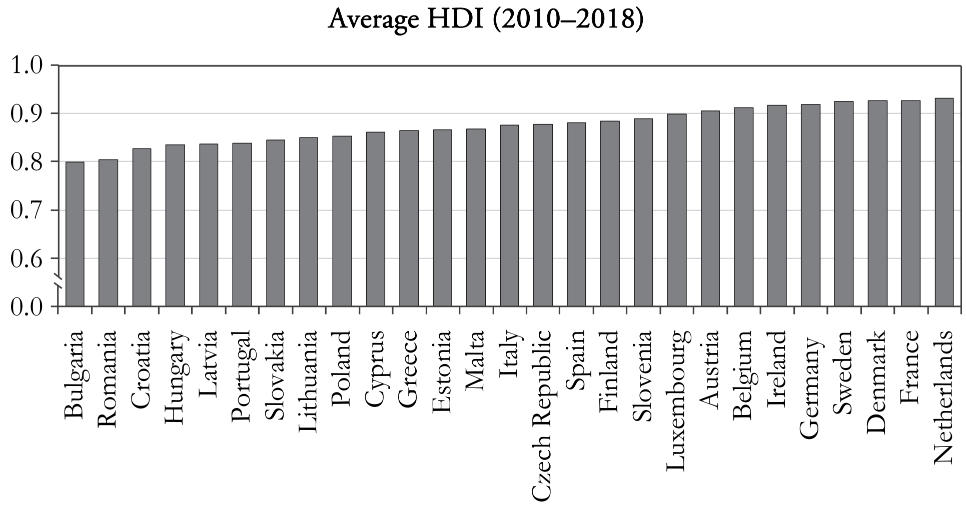
Consistent with the works of (Cayla et al. 2011, Chen et al. 2022), GNI has a positive impact on energy consumption. The cumulative reduction in EU energy consumption from a combination of outsourcing activities and efficiency gains since

1990 has been significant, resulting in approximately 40% less energy use, half of which is due to deindustrialisation. Therefore, prospects for decoupling economic growth and energy are limited, given that half of it is more virtual than real (Moreau–Vuille 2019). Given the non-achievement of absolute decoupling and for a specific income range, the more income households have, the more they will spend on energy and use it more.

Figure 2

Average HDI value for the study period (2010–2018) and residential energy efficiency scores for all Member States





Source: Author's compilation based on (Eurostat) and (Odyssee-mure 2021).

Nevertheless, the decoupling of economic growth and energy consumption can be achieved using different tools, one of which is to improve the energy efficiency of buildings and appliances. Figure 2 displays the average HDI values for the study period (2010–2018) and the residential energy efficiency scores for all member states. This score varies from 0 to 1 and combines three energy efficiency measures: current level, performance since 2000 (trend), and strength of policies. Energy efficiency is a critical factor that should be considered when examining the effects of human development on energy consumption. It reduces the energy required to deliver a product or a service. At the same time, it offers a range of other benefits, including improved economic performance and competitiveness, job growth, energy security, and better health. As a result, it helps reduce energy consumption and increase human development. Figure 2 shows that most developed states have a higher energy efficiency score than less developed states. Germany, Ireland, Finland, France, the Netherlands, and Denmark have the highest energy efficiency scores. All of these states are amongst the highest energy consumers in the EU. If all the states had a similar efficiency level, the residential energy use gap between these states and others would be more significant. In addition, most of these states have very high HDI values and per capita incomes.

On the left side of the graph, Italy, Poland, Estonia, Croatia, and Hungary have the lowest energy efficiency scores. This is because their energy efficiency performance is significantly lower than average. These states have lower HDI values (less than 0.88) and income per capita than the previous group, and their households, except Estonia, consume less energy. Finally, the last group located in the middle of the graph has average energy efficiency scores. These countries have moderate HDI and income values, and they consume more energy than the previous group.

Conclusion

Human development is a mandatory process for citizens' well-being and quality of life. The provision of affordable and clean energy sources can improve this process. Thus, energy consumption plays a vital role in increasing a nation's level of human development. Nonetheless, the relationship between the two variables is nonlinear and depends on the amount of energy consumed. The investigation of the effect of the HDI on territorial inequality in residential energy consumption for the EU-27 Member States shows that the Gini coefficient values would drop around 0.02 for all years if the EU Member States had the same level of human development. Thus, decision makers in each state, particularly those with HDI values less than 0.9, and the EU should consider the influence of human development on energy inequality for the household sector by improving the education and health sectors and putting more effort into decoupling economic growth and energy consumption.

Moreover, the EU's life expectancy negatively affects residential energy use. Although education level shows a negative but insignificant relationship, the more the EU develops these sectors, the less energy will be used. Accordingly, GHG emissions will decrease. By contrast, GNI shows a positive effect on residential energy use, indicating that the decoupling process between energy consumption and economic growth is still not fully achieved in EU Member States.

Energy efficiency should be considered when considering the decoupling process and raising the level of human development. There are three groups of countries based on the energy scores of the EU-27. The first group, comprising Germany, Ireland, Finland, France, the Netherlands, and Denmark, has high energy efficiency scores and HDI values. Consequently, it is preferable to introduce the EU ETS as a pilot system in these states. These nations consume more energy, have higher energy efficiency levels, and have a higher income per capita than the other member states. Hence, it is better to start reducing their high household energy use. In addition, households in such states can withstand the predictable increase in energy prices and utility bills as they have a high income.

The second group, which comprises Italy, Poland, Estonia, Croatia, and Hungary, has low energy efficiency scores and relatively low HDI values. Policymakers in such states should put more effort into improving their energy efficiency performance with the help and support of the EU. The EU ETS should not be applied in these states to avoid energy poverty and to ensure energy justice because households here cannot handle a rise in energy prices.

The third group, which comprises the rest of the countries, has average energy efficiency scores and HDI values. To cut their residential energy use and reach climate policy goals, they should improve their energy efficiency performance and strengthen their energy taxation framework at the EU and state levels. This could be achieved by changing the current minimum tax rates for the states under the Energy Taxation Directive and modifying the fuel type.

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