Farewell to the European Union's east-west divide: Decoupling energy lifts the well-being of households, 2000–2018

Tekla Szép
Institute of World and Regional
Economics, Faculty of Economics,
University of Miskolc,
Hungary
E-mail: regtekla@uni-miskolc.hu

Géza Tóth
Hungarian Central Statistical Office;
Institute of World and Regional
Economics, Faculty of Economics,
University of Miskolc
Hungary
E-mail: Geza.Toth@ksh.hu

Michael Carnegie LaBelle
Department of Environmental
Sciences and Policy, Department of
Economics and Business,
Central European University,
Budapest, Hungary
E-mail: Labellem@ceu.edu

The authors conducted an analysis of the 27 European Union (EU) member states between 2000 and 2018 to examine the relationship between human well-being and the per capita residential energy use. They combined several quantitative techniques (cross-sectional and longitudinal analysis, i.e. descriptive statistics, inequality metrics, and decoupling indicators) with qualitative analytical tools to obtain a broad analysis. A moderate positive relationship was detected between residential energy use per capita and human development. The Gini coefficients and the Hoover index reveal dramatic differences in the inter-country distribution of residential energy use. However, the territorial distribution and spatial inequalities of residential energy consumption per capita are consistent with the differences in economic development and show moderate and declining differences. At the EU level, the authors found that the delinking process had become dominant by 2018, and 19 of the 27 member states had already reached the saturation point. The differences among EU member states cannot be narrowed down to a simple perception of a deep East-West divide; by today, this division has changed, and the differences are unclear. The basic classification of the EU member states (i.e. old member states and post-communist economies) is no longer valid, which indicates that some adjustments should be made for energy analysis.

Regional Statistics, Vol. 12. No. 3. 2022: 159–190; DOI: 10.15196/RS120307

Keywords:
residential energy use,
decoupling,
human well-being,
saturation point,
capability approach

Highlights
- Nineteen member states of the EU have reached the saturation point.
- The strength of the relationship between HDI and residential energy use is declining.
- The distribution of residential energy use does not follow the East-West divide.
- The explanatory power of the East-West division is limited.

Introduction

Empirical evidence shows that growing human well-being leads to a rapid increase in final energy consumption. However, as countries develop, the strength of the relationship weakens, the importance of human development declines, and the push effect on energy use diminishes (Wu et al. 2012). The decoupling analysis and determination of the saturation point are crucial, especially if we consider our latest challenges (issues around energy transition, climate change mitigation, decarbonisation, etc.).

Households significantly influence the environmental, energy, and climate goals of the European Union (EU) (2030 and 2050 targets). In 2018, the household sector (as the second-largest end-use sector, after transport) was responsible for 26.09% of the final energy consumption in the EU (Eurostat 2020). Nevertheless, the relationship between human well-being and residential energy use, national differences in this relationship, and inequalities are underrepresented research areas of energy economics (Wu et al. 2012).

This study has a dual purpose. First, we examine the trends in the distribution of residential energy use in the EU member states between 2000–2018. Second, we analyse the delinking of residential energy use from human well-being to determine the saturation points.

The remainder of this paper is organised as follows. The theoretical background section reviews relevant literature. The data and methodology section introduces the applied data (databases) and methodology; (i)The Gini coefficient, the Hoover index (and its alternative approach), and the rank correlation coefficient are applied to analyse the territorial differences and inequalities of the involved variables; (ii) the decoupling factor is used to determine the saturation points of the EU member states. The following section presents the results, including our main findings on inequalities and decoupling. Finally, the paper presents the conclusions.

Theoretical background

Decoupling as an environmental objective is listed in many strategies (OECD 2002). In OECD (2002), decoupling refers to breaking the link between environmental pressure and economic or social driving forces (e.g. economic growth, gross domestic product [GDP], or human development index [HDI]. Environmental pressure can be linked to pollution, energy sources and other environmental resources (mainly land and water). Decoupling is distinguished into resource and impact decoupling (UNEP 2011). Additionally, a distinction can be made between relative (weak) and absolute (strong) decoupling (OECD 2002). Relative decoupling means that the growth rate of the environmental variable is lower than that of the economic indicator (usually GDP). In the absolute case, resource use declines or stagnates.

Studies describing the decoupling of environmental pressure from economic growth can be grouped in several ways. Some publications focus on emissions, while others focus on energy use. Some studies examine only one country (Conte Grand 2016) or a group of countries (Wang et al. 2013), while others perform a global analysis (Akizu-Gardoki et al. 2018, Bithas–Kalimeris 2013, Csereklyei–Stern 2015). National-level analysis and sectoral papers have been produced more frequently (Andreoni–Galmarini 2012). In most cases, the results show that decoupling can be proved (especially relative decoupling); however, this is not a steady process. Szlávik–Sebestyénné Szép (2017) highlight that decoupling is not a permanent process even after one and half decades; the positive tendency can be reversed (such as in Poland in 1994–2009, regarding final energy consumption and economic growth).

In recent years, several studies have focused on the relationship between energy consumption and human well-being (Arto et al. 2016, Brecha 2019, Jacmart et al. 1979, Jacobson et al. 2005, Ouedraogo 2013, Pasternak 2000, Steinberger–Roberts 2010, Wu et al. 2012). Several approaches have been proposed for this purpose. Certain studies analyse the decoupling, determining the saturation points or thresholds (Akizu-Gardoki et al. 2018, Arto et al. 2016, Brecha 2019, Dias et al. 2006, Krugmann–Goldemberg 1983, Martínez–Ebenhack 2008, Pasternak 2000, Steinberger–Roberts 2009, 2010, Tran et al. 2019), while others consider the spatial inequalities (e.g. Gaye 2007, Jacmart et al. 1979, Jacobson et al. 2005, Pachauri–Spreng 2004, Wu et al. 2012), or examine the causal relations (e.g. Assadzadeh–Nategh 2015, Jorgenson et al. 2014, Kanagawa–Nakata 2008, Mazur 2011, Nadimi–Tokimatsu 2018, Ouedraogo 2013, Pasten–Santamarina 2012, Ray et al. 2016, Sušnik–van der Zaag 2017, Sweidan–Alwaked 2016). Some overlaps can be found among these topics; however, researchers approach these issues in a complex way, as in most cases. This study examines the relationship between spatial inequalities and decoupling.

Most studies highlight a strong correlation between these two indicators, but the relationship continues to weaken as the human development indicator (HDI) grows, and a divergence process can be identified. When the delinking of the energy use from human development (so-called decoupling) occurs, it is referred to as a turning point or a saturation point (Arto et al. 2016, Martínez–Ebenhack 2008) or plateau (e.g., Mazur 2011, Nadimi–Tokimatsu 2018, Pasternak 2000). Beyond this point, the correlation becomes very weak (referring to the neutrality hypothesis; see more details in Tran et al. 2019). Increasing energy use beyond this level does not necessarily contribute to a higher development stage, and higher levels of well-being can be sustained with declining energy consumption (Martínez–Ebenhack 2008, Mazur 2011, Steinberger–Roberts 2010, Tran et al. 2019).

However, a new strand of empirical work can be identified, highlighting the importance of energy quality and concluding a different strength of association. Ouedraogo (2013) analyses 15 developing countries between 1988–2008 and indicates that a 1% increase in per capita electricity consumption still results in HDI growth (by 0.22%), while a 1% increase in per capita energy consumption reduces the HDI by 0.8%. These results are also confirmed by Tran et al. (2019), whose study goes beyond previous studies and were unable to confirm the existence of even a non-linear relationship between HDI growth and energy consumption (its global sample, or different development groups).

One group of studies focus on determining the minimum quantity of energy (thresholds or minimum levels) needed to achieve a certain level of human development (Brecha 2019, Dutta et al. 2018, Krugmann–Goldemberg 1983, Leung–Meisen 2005, Martínez–Ebenhack 2008, Pasternak 2000, Steinberger–Roberts 2009, 2010). In Steinberger–Roberts (2009), this certain level coincides with the 'high human development' category defined by the United Nations Development Programme (UNDP) (i.e. a life expectancy of 70 years at birth, a gross domestic product (GDP) of 10,000 USD, a literacy rate of 80%, and an HDI of 0.8). According to their results, the energy threshold was 60 GJ per capita in 2005 (predicted to decline to 45 GJ per capita in 2030). However, Mazur (2011) indicates a significantly higher level of energy use: in 2006, all nations consuming above 40 MWh (144 GJ) per capita had life expectancies near 80 years. Dias et al. (2006) also set a higher level of HDI (0.85) and found that to achieve this development stage, approximately 2.9 tep[1] (121.42 GJ) per capita is needed.

In the Indian context (Dutta et al. 2018), the threshold value was approximately 2,400 kgoe per capita (100.48 GJ), beyond which the country could reach the highest quality of life. Brecha (2019) concluded in 2014 that there was no country with an HDI score of 0.8 or above that had less than 40 GJ final energy consumption per capita. Practically, this means that achieving the high HDI level requires at least this amount of energy use. Based on these studies, we conclude that the dispersion of thresholds is quite high. Furthermore, most researchers agree that these minimum levels are constantly declining due to technological development and time.

---

[1] 1 tep = 41.868 GJ. This represents one kW of electricity supplied for one hour. The average TEP residential customer uses about 9,500 kWh per year (Tucson Electric Power 2020).

The following research questions are examined in the current study:

1. Can a significant relationship be identified between HDI and residential energy use in the European Union? How can this relationship be described?
2. Did the territorial disparities of residential energy use decrease or increase in the last two decades? Can a significant difference be identified between East and West?
3. Which member states of the European Union reached the saturation point (delinking of residential energy consumption from HDI)? And at what HDI range was it achieved?

Data and methodology

This study combines several quantitative techniques (cross-sectional and longitudinal analyses) with qualitative analytical tools, allowing a comprehensive analysis. The sample period is from 2000–2018. For the cross-sectional analysis, three years were highlighted: 2000, 2008, and 2018. The chosen starting (2000) and ending years (2018) are justified by the availability and adequacy of the data. Furthermore, 2008 was chosen as the intermediate year because it was the peak in European energy use before the 2008–2009 financial crisis, and the time interval of 2009–2013 (as a result of the 2008–2009 global crisis) can be interpreted as a structural break (see more details in Szlávik–Sebestyénné Szép (2017)).

The 27 EU member states are grouped into two main groups and seven subgroups based on LaBelle (2020) for meaningful comparisons:

1. Fourteen old member states plus Cyprus and Malta *(Group 1)*:
   a. Scandinavian (Denmark [DK], Finland [FI], Sweden [SE]),
   b. Western (Austria [AT], Belgium [BE], France [FR], Germany [DE], Ireland [IE], Luxembourg [LU], the Netherlands [NL]),
   c. Mediterranean (Cyprus [CY], Greece [EL], Italy [IT], Malta [MT], Portugal [PT], Spain [ES]);
2. Eleven post-communist member states *(Group 2)*:
   a. Baltics (Estonia [EE], Latvia [LV], Lithuania [LT]),
   b. Visegrad Four (V4) countries (Czech Republic [CZ], Hungary [HU], Poland [PL], Slovakia [SK]),
   c. Former Yugoslavia (Croatia [HR] and Slovenia [SI]),
   d. Later joiners (Bulgaria [BG] and Romania [RO]).

This classification system supports a deeper comparison of country groups and subgroups (highlighting the differences between the 'East' and 'West'). This may be explained by the different development trajectories and economic characteristics. In the post-communist member states (due to significant political and economic changes), a transition from centrally controlled economies to market economies occurred after the collapse of the communist regime in the USSR and CEE in 1989–1992 and continues to unfold.

These ex-communist countries inherited an energy-intensive industrial sector dominated by heavy industry, and they still struggle with high dependence on primary energy resources and other raw materials. Before the regime change, an excessive concentration of production in mining and quarrying and the manufacture of basic metals characterised their economy. Subsequently, the economic structure changed dramatically, and the energy intensity improved owing to de-industrialisation processes combined with technological advancement. However, compared to *Group 1*, lower energy efficiency in the end-use sectors may be observed in *Group 2*. In the residential sector, energy poverty is still a problem, explained by poor (technically obsolete and deteriorating) buildings, relatively high energy prices, and low levels of disposable income (LaBelle–Georgiev 2016, Weiner–S. Szép 2020).

The annual data listed in Table 1 are applied to the calculations collected from Eurostat and the UNDP. Notably, the energy data are in tons of oil equivalent (toe), following internationally accepted rules and conventions. Such energy use measures (rather than SI metric units) are commonly used in energy, environmental, and sustainability studies (Jorgenson et al. 2014). The World Bank, International Energy Agency, and Eurostat provided these data in this unit of measure.

Table 1

Data and their abbreviations

Abbreviation	Indicator	Source
HDI	Human development index	UNDP (2020)
POP	Population on 1 January – total [persons]	Eurostat (2020)
H_FENUSE	Final consumption - other sectors - households - energy use [toe]	Eurostat (2020)
H_FENUSEcap	Final *energy consumption in households per capita* (Final consumption - other sectors - households - energy use/ Population on 1 January – total) [toe]	own calculation based on Eurostat (2020)
GDPcap	Gross domestic product at market prices [Current prices, EUR per capita]	Eurostat (2020)
H_FCEXcap	Final consumption expenditure of households per capita [Current prices, EUR per capita]	Eurostat (2020)

Several types of indicators are used in the existing literature to approach energy use, such as electricity consumption (Assadzadeh–Nategh 2015, Brecha 2019, Kanagawa–Nakata 2008, Leung–Meisen 2005, Pasternak 2000), per capita energy footprint (Arto et al. 2016), total primary energy footprint (Akizu-Gardoki et al. 2018), total primary energy consumption (Steinberger–Roberts 2009), and quality energy usage (Ray et al. 2016). We choose a sectoral indicator that serves our research goals better. The motivation behind this study is to examine the effect of human development on energy use in the household sector. Therefore, the residential energy use per capita is chosen as the dependent variable. The indicator and initial data are not climate-corrected for several reasons. The energy use per capita of the households is compared with their expenditures and GDP per capita data. If the energy use data is climate-corrected, the other data must also be so; otherwise, the monetary indicators will be distorted. Therefore, due to the methodological problems, real data is preferred in this study. However, where it is possible, the results are adjusted to the same climate (EU average climate).

In the current study, we accept Steinberger–Roberts's (2010) arguments and the definition they use for human well-being (the "capability approach" introduced by Amartya Sen). Consequently, human well-being is measured using the HDI developed by the UNDP. The HDI methodology is presented in detail in the UNDP (2020). The HDI is a widely used composite indicator, employed by Steinberger–Roberts (2010), and by Arto et al. (2016), Brecha (2019), Dias et al. (2006), Steinberger–Roberts (2010), Wu et al. (2012), Mazur (2011), and Kanagawa–Nakata (2008). The purpose of the HDI is to measure the three key dimensions of human development: a long and healthy life, knowledge, and a decent standard of living (UNDP 2020).

The capabilities approach applies to the amount of energy consumption translating into GDP per capita in energy consumption. However, the ultimate measure is the capability to function, to make choices, which is a measure of the quality of life (Sen 1990). This study establishes energy consumption and delinking human well-being from residential energy consumption as an environmentally sustainable path. However, although some countries consume less energy per capita, their economic growth is linked to their energy consumption (as will be shown). This is a moral quandary because those countries not delinking human development and low consumption are at a developmental disadvantage in terms of quality of life. They must consume *more* energy to achieve a better quality of life. Their life choices (freedom) improve if they consume to a certain level and then delink their economic activity (and development) from energy consumption. This calls into question a general definition in economics; Sen shows that efficiency is "whether someone's position has improved without anyone's position having gone down" (Sen 1990, p. 10). In an epoch of climate change, any increase in fossil fuel improves an individual's quality of life but damages the long-term health of the Earth and society. This trade-off of the capabilities approach is addressed at the end with the analysis results.

The main methodological steps begin by exploring several important features of HDI and residential energy use per capita in different country groups. First, descriptive statistics (mean, median, minimum, maximum, standard deviation, skewness, excess kurtosis) are calculated, and the normality of data is checked. A significant linear relationship among HDI, GDP per capita, final consumption expenditure of households per capita, and residential energy use per capita is assumed. Second, is calculating the Pearson's correlation coefficients (with a correlation matrix) for selected years (cross-sectional data) and longitudinal data. Next, the null hypothesis is rejected (i.e. we accept the first hypothesis for correlation). The direction of the correlation allows us to classify the countries in an alternative way, serving as a basis for later analysis. Third, bivariate linear regression models (for selected years) are conducted to confirm the relationship between human well-being and residential energy use per capita. The next step involves inequalities, measured with the help of the Gini coefficient, Hoover index, and rank correlation coefficient. Finally, the decoupling ratio is determined, allowing us to determine the HDI value at which the decoupling is most likely to occur.

Pearson's correlation coefficient

Pearson's correlation coefficient is a standard tool for examining the relationship between two variables (a linear relationship is assumed). It shows the direction and strength of the association between the studied variables, and the results can range from -1 to +1. A value of +1 refers to the total positive linear correlation, whereas -1 indicates a total negative linear correlation.

$$r = \frac{cov(x, y)}{s(x) * s(y)} \tag{1}$$

Here, *x* and *y* are the examined variables.

Measuring territorial differences and inequalities

The territorial differences and disparities of a selected variable can be analysed in absolute terms, and the results can be compared to similar data of member states. Alternatively, the examination can be conducted in a relative method, and the results may be expressed (spatial inequalities of residential energy use) with reference to the economic-social inequalities (e.g. HDI, GDP, final consumption expenditure of households, etc.). The first method leads us to analyse the absolute concentrations and the second to that of the relative concentrations (Kincses 2014). In this study, the latter is preferred.

To assess the disparities in residential energy use per capita, we propose a set of methods (Gini coefficients, Hoover index, rank correlation coefficient) commonly used by economists (see Pál et al. 2021, Mitsis 2021, Shimamoto 2019, Dudek–Sedefoğlu 2019) (primarily in regional economics), but less known in energy economics. The applied methods provide in-depth information about the distribution of energy use and allow inter-country comparisons.

Gini coefficient

The Gini coefficient is defined as the ratio of the area between the Lorenz curve and the diagonal to the area of the triangle below the diagonal. The coefficient is a measure of statistical dispersion representing the inequality of a selected variable among different countries (or any other territorial units or social groups). The higher the value of the Gini coefficient, the higher the disparity (it can range from 0 to 1) (Jacmart et al. 1979, Kincses 2015, Türkan–Ozel 2019). A Gini coefficient of zero expresses perfect equality, while a Gini coefficient of 1 refers to the maximal inequality among values. The Gini index (or coefficient) is calculated as follows:

$$G = \frac{1}{2 * \bar{x} * n^2} \sum_i \sum_j |x_i - x_j| \tag{2}$$

Here, *n* is the number of observations (i.e. the sample of size), $\bar{x}$ is the average of x_i, x_i is the distribution rate of a territorially related characteristic in the i^th^ country, and x_j is the distribution rate of a territorially related characteristic in the j^th^ country (Nemes Nagy 2005).

Hoover index

The Hoover index is a simple tool for measuring territorial inequalities (i.e. the deviation from the preferred equal distribution). According to Nemes Nagy (2005), the Hoover index allows us to measure the difference in the territorial distribution of two quantitative criteria. The Hoover index ranges from 0–100%. It shows the percentage of the examined attribution that needs to be redeployed among the examined territorial units to make its spatial distribution exactly the same as that of the examined other attributions (Béres-Virág–Vinogradov 2018, Nemes Nagy 2005, Kóti 2018, Pénzes 2020). The index is symmetrical, and the ranks of the two examined distributions can be changed.

$$H = \frac{1}{2} * \sum_{i=1}^{n} |x_i - f_i| \tag{3}$$

and

$$\sum x_i = 100 \tag{4}$$

$$\sum f_i = 100 \tag{5}$$

where, x_i and f_i are distribution rates.

Decomposition of inequalities by subgroups – alternative approach of Hoover index

The Hoover index can be decomposed based on different country groups. The grouping is possible because the additions in the formula can be replaced. Different country groups (subgroups of old member states plus Cyprus and Malta and subgroups of post-communist member states) serve as the basis for grouping. The applied formula is as follows (Kincses 2015):

$$H = \frac{1}{2} * \sum_{i=1}^{n} |x_i - f_i| = \\ = \frac{1}{2}\left(\sum_{j=Scandinavian} |x_j - f_j| + \sum_{k=Western} |x_k - f_k| + \sum_{l=Baltics} |x_l - f_l| + \right. \\ + \sum_{m=Mediterranean} |x_m - f_m| + \sum_{n=V4} |x_n - f_n| + \\ \left. + \sum_{o=former\ Yugoslavia} |x_o - f_o| + \sum_{p=later\ joiners} |x_p - f_p| \right) \tag{6}$$

Rank correlation coefficient

The rank correlation coefficient measures the degree of similarity between two rankings and may highlight the changes in the rank in time. The coefficient is high (but the maximum value is 1) when observations have a similar rank (Kincses 2015, Nemes Nagy 2005, Egidi et al. 2021).

$$r_s = 1 - \frac{6 * \sum_{i=1}^{n} {d_i}^2}{n * (n^2 - 1)} \tag{7}$$

Here, *n* is the number of observations (i.e. the sample of size), *and d_i* is the difference between the two ranks of each observation.

Decoupling

A unified and generally accepted methodology for decoupling has not been developed yet. Presently, many alternative approaches coexist (e.g. econometric models and index decomposition methods). However, the formula (or decoupling factors) created by the OECD (2002) and UNEP (2011) are most often applied.

Many researchers argue that the literature on decoupling mainly focuses on economic growth, but this is unacceptable from the sustainability perspective (e.g. Sorrell 2010). Accordingly, in the current research, the basic idea of decoupling is how human well-being (which has a strong effect on energy consumption) at the national level can be delinked from additional energy use.

The main objective of this subchapter is to analyse the decoupling between residential energy use per capita and HDI. Hereinafter, the changes in these variables are formulated:

$$e = \frac{H\_FENUSEcap_t - H\_FENUSEcap_{t-1}}{H\_FENUSEcap_{t-1}} = \frac{H\_FENUSEcap_t}{H\_FENUSEcap_{t-1}} - 1 \tag{8}$$

Here, *e* is the growth rate of the residential energy use per capita, *H_FENUSEcap* is the residential energy use per capita, *and t* is the current year.

$$g = \frac{HDI_t - HDI_{t-1}}{HDI_{t-1}} = \frac{HDI_t}{HDI_{t-1}} - 1 \tag{9}$$

Here, *g* is the growth rate of *HDI* and *HDI* is the human development indicator.

When analysing decoupling, measuring the changes in intensity is crucial (i.e. the energy intensity of human well-being; Jorgenson et al. (2014) use the same term):

$$i = \frac{\left(\frac{H\_FENUSEcap_t}{HDI_t}\right) - \left(\frac{H_{FENUSEcap_{t-1}}}{HDI_{t-1}}\right)}{\frac{H\_FENUSEcap_{t-1}}{HDI_{t-1}}} = \frac{H\_FENUSEcap_t}{HDI_t} \Big/ \frac{H\_FENUSEcap_{t-1}}{HDI_{t-1}} - 1 \tag{10}$$

Two indicators are introduced to measure decoupling: the *decoupling ratio* and *decoupling factor*. Following the pioneering work of the OECD (2002), the decoupling factor is determined as follows (OECD 2002, p. 19):

$$decoupling\ ratio = \frac{EP_t/DF_{t-1}}{DF_t/DF_{t-1}} = \frac{H\_FENUSEcap_t/HDI_t}{H\_FENUSEcap_{t-1}/HDI_{t-1}} \tag{11}$$

Here, *EP* is the environmental pressure (in our case, the environmental pressure is the residential energy use per capita), and *DF* is the driving force (HDI). The decoupling factor is expressed as follows:

$$decoupling\ factor = 1 - decoupling\ ratio = 1 - \frac{H\_FENUSEcap_t}{HDI_t} \Big/ \frac{H\_FENUSEcap_{t-1}}{HDI_{t-1}} \tag{12}$$

Thus:

$$decoupling\ factor = -i \tag{13}$$

Hereinafter we denote the decoupling factor as D:

$$D = -i \tag{14}$$

Suppose *D>0*, the trends of the examined indicators are separated (the intensity decreases, which means that the growth rate of the residential energy use per capita is lower than the growth rate of HDI); thus, the decoupling is fulfilled. The maximum value of *D* is 1. If *D≤0*, decoupling does not occur (the growth rate of residential energy use per capita exceeds the growth rate of HDI), a case of non-decoupling.

Table 2 provides a deeper interpretation of the possible results (including 13 different cases). Conte Grand (2016) focuses on the economic driving forces while considering all possible cases of economic growth. However, only Cases 1, 3, 5, 6, and 13 are highlighted in this study. In reality, due to the features of the respective statistical data and services, the other cases are quite rare.

In Case 1, the rate of residential energy use per capita fluctuation and HDI growth are positive. Additionally, the energy consumption increases more than the actual increase in human well-being (it results in a positive *i*). Here, the term expansive negative decoupling refers to the absence of decoupling. Case 3 is a decoupling situation, but its extent is quite weak. Both residential energy use per capita and the HDI increase; however, *i* is negative (called relative decoupling). This means that the push effect of human well-being weakens (but still exists). Case 5 shows absolute or strong decoupling when human well-being increases with declining residential energy use per capita. In Case 6, the actual level of HDI does not change, indicating a non-decoupling situation. In Case 13, the growth rate of HDI is negative, and the energy consumption also drops, the case of recessive decoupling (this is a less desirable case, as declining HDI can never be a specific objective).

Table 2

Possible cases of decoupling indicators

Case	e	g	i	D=-i	Specific cases of decoupling
1	>0	>0	>0	<0 non-decoupling	Expansive negative decoupling
2	e=g>0	>0	=0	=0 non- decoupling	Expansive coupling
3	>0	>0	<0	>0 decoupling	Weak decoupling
4	=0	>0	<0	>0 decoupling	–
5	<0	>0	<0	>0 decoupling	Strong decoupling
6	e=i>0	=0	>0	<0 non- decoupling	–
7	e=g=i=0	=0	=0	=0 non- decoupling	Indeterminate, not defined
8	e=i<0	=0	<0	>0 decoupling	–
9	<0	<0	>0	<0 non- decoupling	Weak negative decoupling
10	=0	<0	>0	<0 non-decoupling	–
11	>0	<0	>0	<0 non-decoupling	Strong negative decoupling
12	e=g<0	<0	=0	=0 non-decoupling	Recessive coupling
13	<0	<0	<0	>0 decoupling	Recessive decoupling

Note: White signifies cases of non-decoupling and grey signal cases of decoupling.
Source: Own edition based on Conte Grand (2016, p. 653).

Results

We found significant territorial disparities among the nations. This is true for different country groups and within these groups. The improper distribution of energy use combined with other well-known dimensions of energy security (i.e. affordability, accessibility, availability, and acceptability, the so-called 4A concept) may cause significant social, environmental, and economic inequalities among different social groups or territorial units (Jacobson et al. 2005, Wu et al. 2012).

Figure 1 shows the group average of HDI and residential energy use per capita by country group in 2000, 2008, and 2018. In *Group 1*, only Western countries' residential energy use per capita decreased significantly. In the Scandinavian, Baltics, V4, and later joiners, an increase in the energy use of the household sector can be observed. In the Mediterranean and former Yugoslavia country groups, 2008 shows a peak point, and after this year, the energy use slightly decreases.

Figure 1

Average HDI and residential energy use per capita in the different country groups, 2000, 2008 and 2018

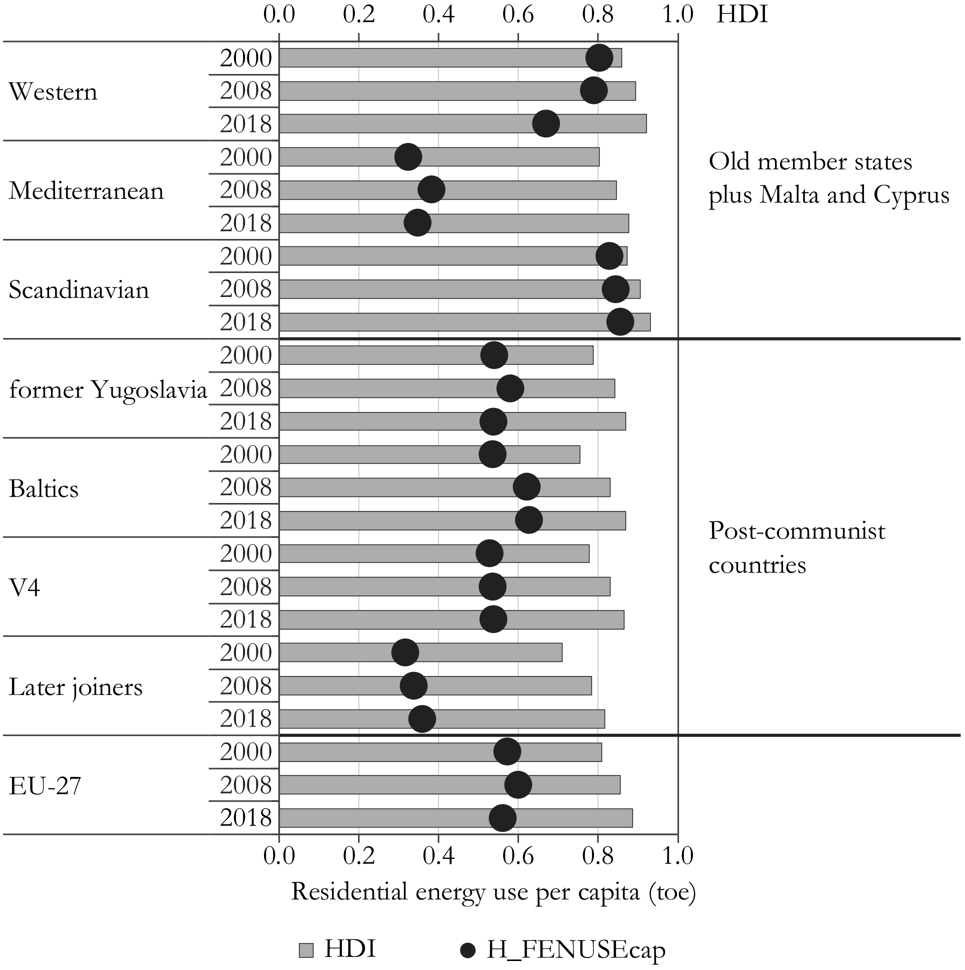


Table 3 presents the summary statistics for HDI, GDP per capita, final consumption expenditure of households per capita, and residential energy use per capita. These statistics are available from the authors upon request.

Notably, although our main purpose is to examine the relationship between HDI and residential energy use, monetary indicators (GDP per capita and final consumption expenditure of households) are also used as a basis for comparison. Furthermore, it should be noted that the HDI cannot be used to measure inequalities in certain territorial inequality indicators because the scaling of the HDI indicator does not allow this.

Table 3

Summary statistics (EU member states, 2000, 2008 and 2018)

Variable	Mean	Median	Minimum	Maximum	Std. Dev.	Skewness	Ex. kurtosis
				2000			
HDI	0.81	0.81	0.71	0.9	0.05	–0.23	–0.94
GDPcap	17,073	14,400	1,760	52,820	12,635	0.81	0.37
H_FCEXcap	8,697	8,975	1,170	19,420	5,377	0.08	–1.3
H_FENUSEcap	0.57	0.56	0.2	1.08	0.23	0.23	–0.68
				2008			
HDI	0.86	0.86	0.77	0.92	0.04	–0.21	–0.96
GDPcap	24,523	21,840	4,880	77,940	15,932	1.38	2.58
H_FCEXcap	12,284	13,640	3,190	24,660	5,901.90	0.15	–1.18
H_FENUSEcap	0.60	0.60	0.17	1.06	0.21	0.02	–0.42
				2018			
HDI	0.89	0.89	0.82	0.94	0.04	–0.21	–0.82
GDPcap	30,321	24,290	7,980	98,640	20,132	1.63	3.03
H_FCEXcap	14,281	12,430	4,720	27,740	6,329.60	0.29	–1.10
H_FENUSEcap	0.56	0.56	0.20	1.03	0.19	0.21	–0.13

While the HDI, GDP per capita, and final consumption expenditure of households per capita grow steadily, the residential energy use per capita increases from 2000 to 2008 (reaching a peak point), but subsequently, it reduces. In 2018 the mean value of the residential energy use per capita was 0.56 toe (23.43 GJ). Moreover, the standard deviation of this indicator decreases, showing that the values tend to be closer to the mean. In the case of HDI, similar tendencies are observed. Nevertheless, the economic performance of the member states (GDP per capita, final consumption expenditure of households per capita) improves substantially at the cost of growing inequality.

One fundamental task of this study is to determine the location and variability of the dataset (skewness and kurtosis). Positive skew (in the case of GDP per capita, final consumption expenditure of households per capita, residential energy use per capita) refers to a fatter tail on the right side of the distribution (i.e. the mean is greater than the median). The HDI shows a negative skew. The GDP per capita shows negative excess kurtosis, indicating a platykurtic distribution, while a leptokurtic distribution characterises the other indicators with positive results.

Next, the normality of data is checked. This is done before calculating a linear regression model to avoid spurious regression. All data are tested against the null hypothesis (the distribution is normal), which cannot be rejected in any case. We must accept that the data are normally distributed.

Table 4

Correlation coefficients (EU member states, cross-sectional data* for 2000, 2008, 2018 and panel data** between 2000–2018)

HDI	GDPcap	H_FCEXcap	H_FENUSEcap	
2000				
1.000	0.859	0.899	0.691	HDI
	1.000	0.969	0.719	GDPcap
		1.000	0.627	H_FCEXcap
			1.000	H_FENUSEcap
2008				
1.000	0.7879	0.861	0.714	HDI
	1.000	0.935	0.729	GDPcap
		1.000	0.635	H_FCEXcap
			1.000	H_FENUSEcap
2018				
1.000	0.737	0.836	0.574	HDI
	1.000	0.902	0.558	GDPcap
		1.000	0.587	H_FCEXcap
			1.000	H_FENUSEcap
2000–2018				
1.000	0.761	0.85	0.548	HDI
	1.000	0.935	0.614	GDPcap
		1.000	0.565	H_FCEXcap
			1.000	H_FENUSEcap

Note: *5% critical value (two-tailed) = 0.3809 for n = 27.
**5% critical value (two-tailed) = 0.0866 for n = 513.

We analyse the causal relationship between residential energy use and human well-being. First, this is tested by calculating Pearson's correlation coefficients (Table 4) and bivariate linear regression models (for selected years) (Figure 2). We considered the residential energy use per capita as the dependent variable and HDI as the explanatory variable. The resulting fit parameters describe the relationship between them. We use the goodness-of-fit R^2 (coefficient of determination) to assess the model fit.

Residential energy use per capita significantly correlates with GDP per capita, final consumption expenditure of households per capita, and HDI (Table 4). From 2000–2008, the correlation coefficients increase slightly; however, for 2018, the strength of the relationships decreases, indicating decoupling.

In the case of the tests on panel data (2000–2018), a moderate positive relationship is detected between energy use and human development (correlation coefficient of 0.55) in EU member states; however, it is weaker than the correlation coefficient for energy consumption and economic growth (its value is 0.61).

Table 5

Correlation coefficients of HDI and residential energy use per capita (toe) in EU member states, using the observations between 2000–2018 5% critical value (two-tailed) = 0.4555 for n = 19

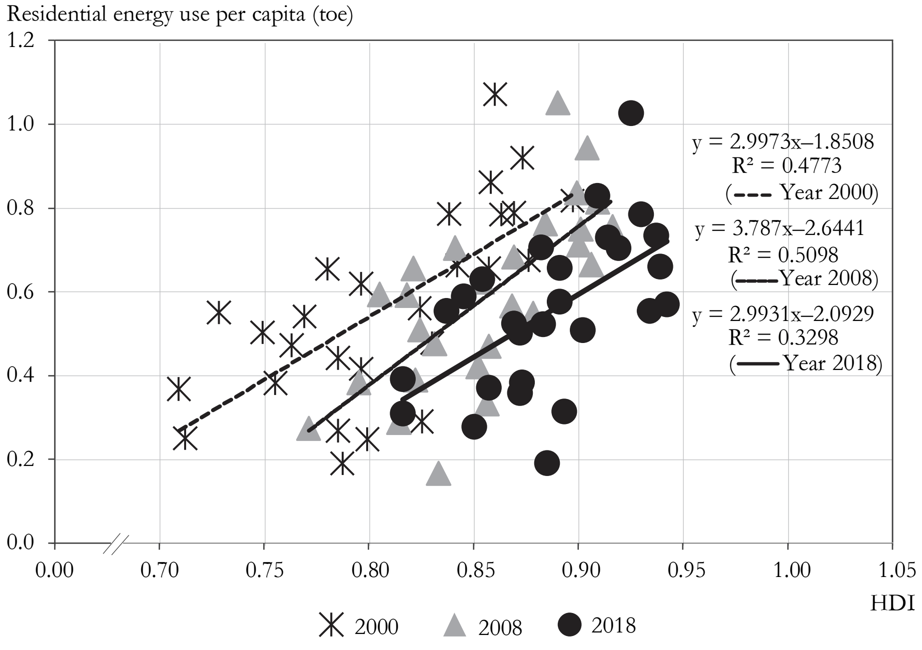
	Correlation coefficients (cases with negative coefficients) *Group 3*		Correlation coefficients (cases with positive coefficients) *Group 4*
Old member states plus Cyprus and Malta – *Group 1*			
Scandinavian			
Denmark	–0.327	Finland	0.389
Sweden	–0.565		
Western			
Austria	–0.395		
Belgium	–0.885		
France	–0.703		
Germany	–0.821		
Ireland	–0.708		
Luxembourg	–0.828		
Netherlands	–0.712		
Mediterranean			
Greece	–0.364	Cyprus	0.694
Malta	–0.412	Italy	0.383
Portugal	–0.545		
Spain	–0.049		
Post-communist member states – *Group 2*			
V4			
Slovakia	–0.911	Czech Republic	0.081
		Hungary	0.242
		Poland	0.468
Baltics			
		Estonia	0.435
		Latvia	0.146
		Lithuania	0.882
Later joiners			
		Bulgaria	0.881
		Romania	0.735
Former Yugoslavia			
Croatia	–0.057		
Slovenia	–0.304		

At this stage of the investigation, we conducted an additional analysis. Correlation coefficients are calculated for individual countries for the period 2000–2018. Based on the direction of the relationship (positive or negative correlation), two country groups are created (Groups 3 and 4), serving as a basis for later decoupling analysis. Table 5 shows the results by country and presents this classification. Italy is an outlier and demonstrates a divergence process from the Mediterranean country group, confirming the findings of Jacmart et al. (1979).

The next step includes running bivariate linear regression models regarding the correlation and normality test results. Accordingly, the residential energy use per capita is plotted against HDI for EU member states in Figure 2 (the conventional method is followed, with the explanatory variable plotted on the x or horizontal axis and the dependent variable plotted on the y or vertical axis). The R^2 value decreased from 2000 to 2018 (0.48 in 2000 and 0.33 in 2018), indicating a weakening (but still positive) relationship and the decoupling process. R^2 indicates the percentage variance in the dependent variable (residential energy use per capita) that the HDI (an independent variable) explains collectively.

Figure 2

Data and regressions of HDI vs residential energy use per capita (toe) in the EU member states, 2000, 2008 and 2018



Source: Own edition based on UNDP (2020) and Eurostat (2020) data.

Inequalities

The Gini coefficients are estimated from Lorenz curves and are presented in Table 6. The Lorenz curves demonstrate the inter-country inequalities in residential energy use (but neglect the intra-country disparities). The cumulative percentage of residential energy use per capita in EU member states is plotted against the share of these countries' consumer population (or against the share of the GDP per capita or final consumption expenditure of household per capita in the EU member states).

The main purpose of this subsection is to measure the social and economic inequalities among EU member states. Following Wu et al. (2012), all countries have an equal right to consume energy for social and economic development.

In the first case (Table 6), the Gini coefficients on residential energy use per capita basis for the total population follow an increasing trend and show a relatively high spatial concentration. This reveals dramatic differences in the intercountry distribution of residential energy use. The Gini coefficients on residential energy use per capita basis for GDP per capita and the residential final consumption expenditure per capita are similar and show lower concentration levels. In these two cases, the Gini coefficients show that the territorial distribution of residential energy use per capita tends to become less unequal. Thus, the territorial distribution and spatial inequalities of residential energy consumption per capita represent the differences in economic development (GDP per capita and residential final consumption expenditure per capita), and a strong relationship is identified between them.

Table 6

Gini coefficients and Hoover index results in the EU member states

Index compared to the residential energy use per capita	2000		2008		2018	
	Gini	Hoover (%)	Gini	Hoover (%)	Gini	Hoover (%)
POP	0.621	51.176	0.659	50.82	0.630	51.166
GDPcap	0.332	22.647	0.245	17.972	0.277	19.999
H_FCEXcap	0.291	21.662	0.225	16.365	0.213	16.322

The Hoover index (Table 6) shows that in 2000, 51.18% of the residential energy use per capita would need to be redeployed among the EU member states to match the characteristics of the population and create territorial equality. This relatively high number on the Hoover index highlights significant territorial inequality.

By examining the territorial distribution of the residential energy use per capita compared to the GDP per capita and the final consumption expenditure of households per capita, the Hoover index is no higher than 23%; moreover, it shows a decreasing tendency from 2000 to 2018. This means that the household energy use mainly depends on their final consumption expenditure (and eventually on their income situation). However, the territorial distribution of the two indices (i.e.

residential energy use per capita and the final consumption expenditure of households per capita) is slightly different. The results confirm that the households' energy use is consistent with their economic development.

Next, inequalities related to residential energy use are analysed in detail, highlighting which country groups have distorted the territorial distribution of indicators related to the household sector.

Table 7

Decomposition results of Hoover index

Index compared to the residential energy use per capita	Country groups	2000	2008	2018
Population	Old member states plus Cyprus and Malta	37.219	36.993	36.555
	Scandinavian	5.781	5.553	6.069
	Western	20.854	20.145	19.286
	Mediterranean	10.584	11.295	11.200
	Post-communist member states	13.957	13.827	14.611
	Baltics	4.352	4.977	5.533
	V4	5.339	4.839	5.089
	Former Yugoslavia	2.733	2.856	2.860
	Later joiners	1.532	1.155	1.129
	Hoover index (EU member states)	51.176	50.820	51.166
GDPcap	Old member states plus Cyprus and Malta	11.583	9.296	10.975
	Scandinavian	2.086	1.513	1.768
	Western	5.734	5.068	7.133
	Mediterranean	3.763	2.715	2.074
	Post-communist member states	11.064	8.675	9.023
	Baltics	4.025	3.189	3.099
	V4	4.662	2.994	3.261
	Former Yugoslavia	1.724	1.319	1.433
	Later joiners	0.653	1.173	1.230
	Hoover index (EU member states)	22.647	17.972	19.999
H_FCEXcap	Old member states plus Cyprus and Malta	11.274	8.680	8.785
	Scandinavian	1.458	1.043	1.228
	Western	4.034	2.699	3.776
	Mediterranean	5.782	4.938	3.781
	Post-communist member states	10.388	7.685	7.537
	Baltics	3.801	2.812	2.558
	V4	4.498	2.793	2.927
	Former Yugoslavia	1.496	1.155	1.157
	Later joiners	0.592	0.924	0.894
	Hoover index (EU member states)	21.662	16.365	16.322

Following our analysis, we conclude that primarily the Western countries from *Group 1* and the V4 and Baltics from *Group 2* are responsible for the greatest difference in the distribution (regarding the selected variables). In the case of residential energy use per capita compared to the population, the difference in the distribution was two times higher in *Group 1* than in *Group 2*. In the other two cases (GDP per capita and final consumption expenditure of households per capita), the explanatory power of the two main country groups is nearly similar.

Decomposing the Hoover index further (residential energy use per capita compared to population), the results show that in 2000, the Western and V4 countries have distorted territorial distribution of indicators. In 2000, the degree of redeployment needed to create territorial equality was 51.18%, and the role of Western countries was 20.85 percentage points, while the role of V4 was 5.34 percentage points. In 2008 and 2018, the role of the Baltics became significant. Thus, the relatively high concentration index (51.18% in 2000, 50.82%, and 51.17% in later years) is primarily caused by the difference in the distribution experienced in the Western and V4 countries in 2000 (by 51.17%). However, in 2008 and 2018, the Baltics took the lead from the V4 countries in the post-communist member states.

Table 8

Rank correlation coefficients

	2000–2008	2008–2018	2000–2018
H_FENUSEcap	0.965	0.891	0.913
Population	0.996	0.990	0.992
GDPcap	0.931	0.849	0.899
H_FCEXcap	0.925	0.915	0.922
HDI	0.900	0.852	0.869

The rank correlation coefficients (Table 8) for all years and in all cases are close to 1, indicating small or minor changes in the rank (the observations have a similar rank).

Considering the Hoover index and rank correlation results, most redistribution (declining inequalities) occurred among predefined country groups and not within groups.

Decoupling

The key purpose of this subsection is to examine the delinking of residential energy use per capita from human well-being in EU member states. However, the classification of different countries (regarding decoupling) is not the only goal. Additionally, we aim to determine the starting year of decoupling (the saturation points) with associated levels of HDI and residential energy use.

Table 9

The realised cases of decoupling in the EU member states (2000–2018)

		01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18
Western	BE	1	5	1	1	1	*5*	5	5	5	5	5	5	5	5	5	5	5	5
	FR	1	5	1	1	1	*5*	5	3	3	1	5	5	3	5	5	5	5	5
	DE	1	1	*3*	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
	AT	1	6	1	*5*	3	3	5	5	5	3	5	3	3	5	5	5	5	5
	NL	1	1	1	*5*	5	5	5	5	5	1	5	5	5	5	5	5	5	5
	LU	1	3	1	1	1	*3*	5	5	5	5	5	5	5	5	5	5	5	5
	IE	1	3	1	1	1	1	3	1	1	1	*5*	5	5	5	5	5	5	5
Scandinavian	DK	1	1	1	1	1	1	1	*3*	3	1	3	3	3	5	5	3	3	3
	FI	1	1	1	1	1	1	1	1	1	1	1	1	1	1	3	1	1	1
	SE	1	*5*	3	13	1	5	5	5	5	1	5	1	5	5	5	5	5	5
Mediterranean	IT	1	1	1	1	1	1	1	1	1	1	1	1	1	3	1	1	1	1
	EL	1	1	1	1	1	1	1	1	3	5	1	1	*5*	5	5	5	5	5
	ES	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	*3*	3
	CY	5	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	MT	5	1	1	1	*5*	5	5	5	5	5	5	5	5	5	5	5	5	5
	PT	1	1	1	1	1	1	1	1	1	*3*	5	5	5	5	5	3	5	3
Baltics	EE	1	*3*	3	3	5	5	1	3	1	1	3	1	3	3	5	3	3	3
	LV	1	1	1	1	1	1	1	1	1	1	1	1	3	3	5	3	3	3
	LT	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
V4	HU	1	1	1	1	1	1	1	1	1	1	1	1	1	3	1	1	1	3
	PL	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	SK	1	1	1	1	*5*	5	5	5	5	5	5	5	5	5	5	5	5	5
	CZ	*5*	5	5	5	5	5	5	5	3	5	5	3	5	5	5	5	5	N/A
Later joiners	BG	5	1	1	1	1	1	3	1	1	1	1	1	1	1	1	1	1	1
	RO	*5*	5	5	5	5	5	5	3	3	3	3	3	3	5	5	3	3	3
Former Yugoslavia	HR	1	1	1	1	1	1	1	1	1	1	1	1	1	3	1	1	1	3
	SI	5	1	1	1	1	3	5	5	1	1	1	*3*	3	5	5	5	5	5

Note: Grey indicates the cases of decoupling; white indicates cases of non-decoupling (classification in Table 1). Bold italic font refers to saturation points (when decoupling becomes stable).

Table 9 presents five different but repeating cases of decoupling (Case 1, 3, 5, 6, 13). While Cases 6 and 13 appear only once each in the results. Cases 1, 3 and 5 are much more common and dominate the results. In Austria, the year 2002 was specific (Case 6); the HDI (0.838) fell back to the 2000 levels (g=0), and the residential energy use per capita increased only slightly (to 0.798 toe), resulting in non-decoupling. Case 13 occurred only in Sweden in 2004. Although residential energy use per capita declined compared to the initial years (in 2004, it was 0.796), the HDI also suffered a slight decrease (although the rate of HDI decline was to a lesser extent). Recessive decoupling is discernible, acknowledging that this is a less desirable case.

Non-decoupling (Case 1) can be identified in 238 cases, 49.07% of the total number of cases (485) between 2000 and 2018; however, during the second half of the examined period (2008–2018), the proportion of expansive negative decoupling cases was lower. Case 1 was observed in 103 of 269 cases (38.29%) between 2008 and 2018. After 2008, relative decoupling (Case 3) and absolute decoupling (Case 5) followed each other in many countries (e.g. Denmark, Estonia, Latvia, Romania, and Slovenia), but absolute decoupling was more common than relative decoupling. At the EU level, the delinking process (i.e. strong decoupling) became dominant at the end of the investigated period.

However, differences were detected among country groups (illustrating the East-West differences) and within the groups. The group of Western countries was the only one in which similar tendencies were identified, and the direction of change was almost the same. The other country groups showed higher levels of inequalities, confirming the results of the previous subsection.

The resulting estimations of decoupling effects are optimistic, as these economies achieved absolute or relative decoupling during a significant part of the period considered. Therefore, decoupling became a permanent process in most cases, and these positive tendencies were not reversed.

Next, the results of the decoupling factor are shown in two separate figures (Figures 3 and 4). The EU member states are split into Group 3 and Group 4 based on the correlation coefficients (whether positive or negative, based on Table 5).

Figure 3 shows that the decoupling factor (*D*) shows improving positive trends in all countries, and in 2018, Croatia (the last one in *Group 3*) crossed the zero level and became positive. The year 2009 can be interpreted as a structural break, confirming that 2008–2009 represents a turning point in residential energy use. However, 2006, 2010, and 2013 can be identified as breakout points. After these points, the decoupling factor decreases slightly, but the resistance levels increase.

Figure 3

Decoupling factors (D, 2000–2018) for selected EU member states (Group 3)

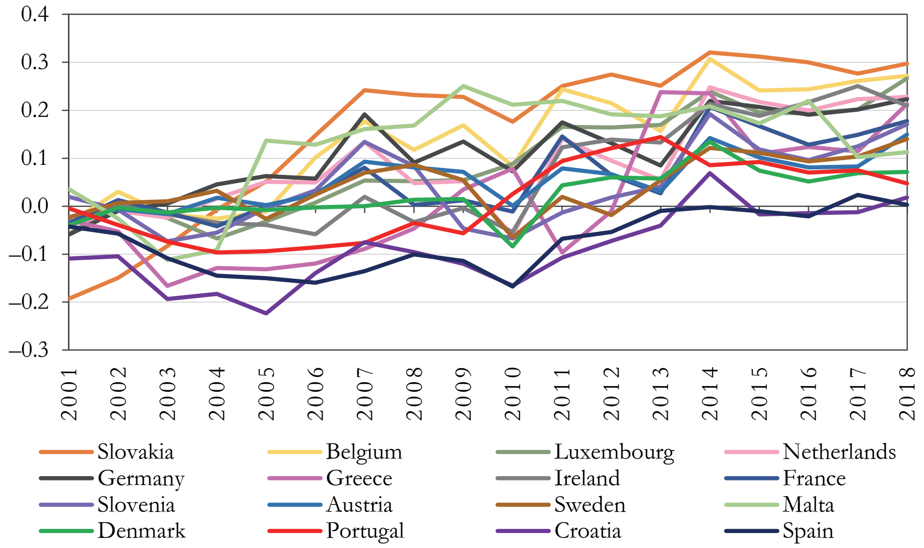
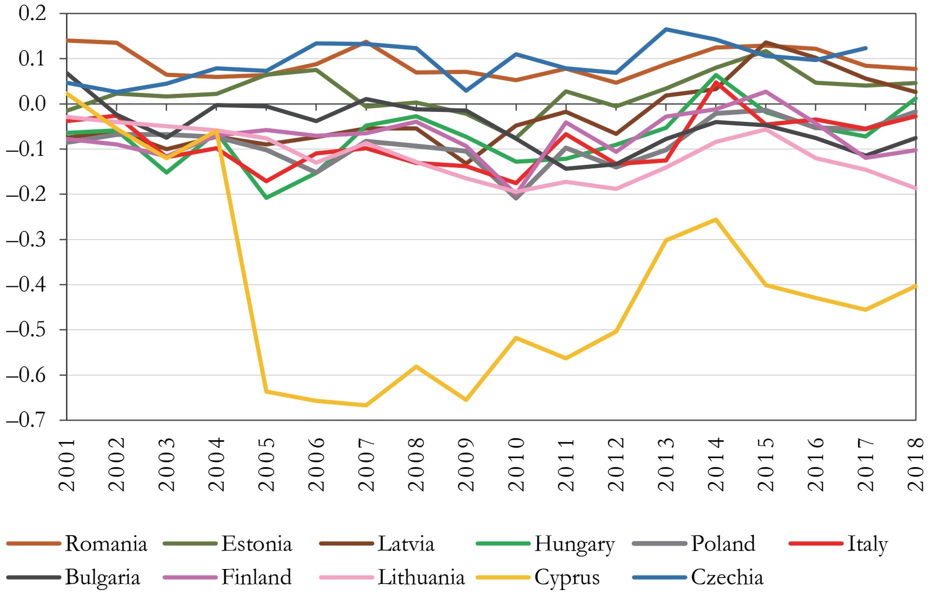


Figure 4

Decoupling factors (D, 2000–2018) for selected EU member states (Group 4)



The decoupling factor results presented in Figure 4 for *Group 4* are less solid and coherent than those in Figure 3. In 2018, only five of the 11 countries showed positive results (absolute or weak decoupling). Moreover, the trend is typically declining. Cyprus is an outlier; it is far behind other member states.

The key purpose of this study is to determine the HDI levels at which decoupling (delinking of the residential energy use per capita from human well-being) is realised. Table 10 lists these saturation points. It shows the year when the link is cut (from Table 9), and the trend of the two variables is separated.

Table 10

Saturation points

Country	year	HDI	GDPcap	H_FCEXcap	H_FENUSEcap		
			(current prices, EUR per capita)		[TOE]	[GJ]	[GJ] climate corrected$^{a)}$
Group 3							
Belgium	2006	0.896	30,830	15,120	0.855	35.797	41.771
France	2006	0.865	29,050	15,230	0.670	28.052	34.010
Germany	2003	0.889	27,120	14,860	0.809	33.871	34.371
Austria	2004	0.849	29,670	15,440	0.790	33.076	30.560
Netherlands	2004	0.886	32,510	15,820	0.679	28.428	31.295
Luxembourg	2006	0.884	71,490	23,420	1.101	46.097	51.650
Ireland	2011	0.894	37,310	16,980	0.606	25.372	27.906
Denmark	2008	0.909	43,990	20,220	0.822	34.415	36.159
Sweden	2002	0.903	31,600	14,380	0.824	34.499	26.844
Greece	2013	0.858	16,480	11,210	0.347	14.528	19.993
Malta	2005	0.828	12,730	7,810	0.179	7.494	8.734
Portugal	2010	0.822	16,990	10,890	0.281	11.765	13.815
Spain	2017	0.891	24,970	14,320	0.314	13.147	16.376
Slovakia	2005	0.794	7,310	3,950	0.473	19.804	18.970
Slovenia	2012	0.876	17,630	9,970	0.593	24.828	26.993
Group 4							
Estonia	2002	0.799	5,660	3,050	0.662	27.717	23.228
Latvia	2013	0.834	11,350	6,890	0.626	26.209	23.152
Czech Republic	2001	0.806	7,370	3,640	0.685	28.680	27.363
Romania	2001	0.715	N/A	N/A	0.325	13.607	14.276

a) The residential energy use per capita is *adjusted* to the same *climate* (*EU* average *climate*) as previously described in Szép et al. (2021).

In *Group 3*, 15 of the 16 countries (93.8%) were already past the saturation point. In *Group 4*, only four of 11 (36.4%) met the conditions of weak or strong decoupling.

In *Group 3*, the decoupling points were identified with an average HDI level of 0.87. Decoupling cannot happen with a lower HDI level than 0.794. However, the maximum HDI was 0.909. In *Group 4*, these numbers were 0.789, 0.715, and 0.834, respectively. By comparing these results with previous research findings, it can be stated that the *Group 3* saturation points are similar to those reported in the literature, while the results for *Group 4* are marginally lower. Arto et al. (2016) identify an HDI of 0.80 as a saturation point (for both the selected 40 countries and the EU member states) and found that the correlation coefficients decrease significantly, immediately after this point. Martínez–Ebenhack (2008) found a higher saturation point (in the case of 'energy-advantaged nations residing in the industrialised world'), an HDI above 0.90 (Martínez–Ebenhack 2008, p. 1432). Thus, the higher technological level is the main explanatory factor for the different saturation points.

This technological level is connected to the historical development of each country. Countries that are still linked by (residential) energy use and human well-being rely on communist-era technologies and resources, even if they are not apparent on the surface. However, this heritage still heavily impacts their national and sectoral energy use. For example, Finland is not a post-communist country but relies heavily on imported gas from Russia. It remains wedded to Russian technology, along with Hungary; both countries are building new nuclear power plants with Rosatom (a Russian nuclear power company). Poland is heavily reliant on inefficient and outdated coal power plants, with significant coal and gas imports from Russia. The Baltic states of Estonia, Latvia, and Lithuania are somewhat more mixed, as the first two have marginally decoupled their human well-being (Estonia in 2002, Latvia in 2013), leaving Lithuania coupled to energy consumption, despite shutting down its Soviet-era nuclear power plant. Lithuania's high levels of residential heating needs, connected to an inability to pay monthly utility bills, may indicate a tight connection between household income and the cost of energy services. Lithuania's fraught relationship with Russia means that it has paid a higher rate for imported gas than its Baltic neighbours since post-Soviet independence.

Similarly, further south, Croatia may also show a more direct connection between income levels and the cost of utilities. Neighbouring Slovenia, with a higher level of personal income and standard of living, gradually moved to decouple consumption and HDI. The Czech Republic and Slovakia remain post-communist outliers. Their progress may be based on policies contrary to other post-communist countries, although more research is required on this topic. Due to higher energy prices, there was a greater emphasis on energy efficiency in these two nations, rather than securing low-cost power generation sources, as other post-communist countries. Finally, while Romania is decoupled, this may reflect the crash of the industrial sector along with its heavy reliance on hydropower and nuclear energy. Like its regional neighbours Croatia and Hungary, Bulgaria may reflect government-suppressed household utility prices, making energy-efficient investments uneconomical. This policy approach contrasts the Czech Republic and Slovakia, where efficiency improvements assisted decoupling. Cyprus and Italy may also reflect the connection between high import costs and decoupling. Overall, there may be a relationship between the cost of resources and technologies in energy production and imports, leading countries to maintain a coupled relationship between HDI and energy consumption in the household sector.

There is another factor in the difference between decoupled and uncoupled states, such as Western European states and the Czech Republic and Slovakia, against former communist states, which is the efficiency of the cultures. The decoupling allows freedom to live, and they are in an 'achieved state.' These countries can choose their level of consumption, which then has a limited impact on their quality of life (Sen 1990, p. 8). This achieved state is valuable and notable in decoupled energy-consuming countries, reflected in the higher HDI level. The higher HDI points towards greater affordability and productivity in terms of energy consumption; income goes towards other endeavours besides the basic necessity of consuming energy.

Getting to the heart of the capabilities approach, which the HDI stems from, energy consumption is tied to the level of freedom. It is defined here as the freedom to live life as one wishes compared to living life how one would hate to live (Sen 1990, p. 9), that is, holding the right to choose how one lives. Equality of society is at the point of energy decoupling; in contrast, coupled economies reflect inequality within and outside their countries. Power asymmetries can develop, leading to "weakening the effectiveness of policies" concerning institutional authority, political representation, and inequalities in health and education (UNDP 2019, p. 11). Energy consumption coupled with GDP affects inequality of life – notably, the capability of individuals and societies to choose how to live.

This calls into question a general definition of economics. Sen (1990, p. 10) points out that efficiency is "whether someone's position has improved without anyone's position having gone down". Rather than staying with this definition, he expands into "Pareto efficiency" defined in other metrics (such as HDI) tied to living standards. There is a dilemma in both these assessments: if energy consumption is tied to economic growth and decoupling can only occur at a set point, then greater energy consumption for a higher HDI must occur in an environmentally sustainable manner. Suppose economic growth is fuelled by environmentally damaging fuels (e.g. fossil fuels, unsustainable biomass) in coupled economies, then just the pursuit of a decoupled life and higher HDI reduces the quality of life for all.

Countries with lower HDIs hold a moral and political right to reach economic and HDI parity with high HDI countries in the EU context. In a real-world context, which Sen (1990, 1995) repeatedly returns to, countries like Poland and Hungary tie their economic development to fossil fuels and resist ambitious 2030 and 2050 carbon reduction goals (Mathiesen–Oroschakoff 2020). In this context, there are only two options attached to increasing energy consumption levels to achieve equal HDI to

Western Europe: 1) increase the use of fossil fuels, or 2) receive EU monetary support to pay for energy infrastructure upgrades. However, even additional EU funds may be insufficient to delink GDP growth from energy consumption. Moreover, inequality in other areas in each country may prevent higher HDI growth (UNDP 2019).

Conclusion

The current statistical analysis confirms that the relationship between residential energy use per capita and human well-being is undeniable, even in countries with very high human development (for HDI of 0.80 and); however, its strength weakens.

As measured by the Gini coefficient and Hoover index, residential energy use inequality was found to be different based on different indices. For both indices, it can be concluded that the results for residential energy use per capita basis for the total population are much higher. In the other two cases (residential energy use per capita basis for GDP per capita and final consumption expenditure of household per capita), the results show a level of concentration.

After the turn of the century, the decoupling factor in most EU member states became positive, giving rise to optimism. At least in 19 countries, the delinking of residential energy use per capita from HDI can be observed. In the long run, this has led to economic and social development with a decreasing energy growth rate in the household sector, thereby contributing to energy sustainability. Technological development, climate change mitigation policies, and changing attitudes facilitate meeting the needs of the population in less energy-intensive ways.

Our key findings are the following:

1. The territorial distribution and spatial inequalities of residential energy consumption per capita are consistent with the differences in economic development and show moderate and declining differences. Most of the redistribution (declining inequalities) occurred among predefined country groups, not within groups.
2. The energy use of households is significantly influenced by economic development and final consumption expenditure (and eventually by their income situation).
3. At the EU level, the delinking process (i.e. strong decoupling) became dominant by 2018, and 19 member states of the 27 had already reached the saturation point.
4. The differences among EU member states cannot be narrowed down to the simple perception of a deep East-West divide. Currently, this division has been altered, and the differences are unclear. The basic classification of the EU member states (i.e. old member states and post-communist economies) is no longer valid, and at least for energy analysis, some adjustments should be made. Thus, a more sophisticated classification system should be developed.

5. The member states below the saturation points (HDI is coupled with residential energy consumption) need more energy in the household sector to increase their HDI. The decoupling can happen only at a higher level of HDI. In these countries, more intense energy efficiency improvements are required.
6. The pursuit of higher HDI by low HDI countries requires targeted policies to decouple energy consumption from economic growth. The use of fossil fuels to increase HDI is inefficient and detracts from the quality of life on Earth. GDP growth requires greater energy production from sustainable energy sources for lower HDI EU countries.

REFERENCES

Akizu-Gardoki, O.–Bueno, G.–Wiedmann, T.–Lopez-Guede, J. M.–Arto, I.–Hernandez, P.–Moran, D. (2018): Decoupling between human development and energy consumption within footprint accounts *Journal of Cleaner Production* 202: 1145–1157. https://doi.org/10.1016/j.jclepro.2018.08.235

Andreoni, V.–Galmarini, S. (2012): Decoupling economic growth from carbon dioxide emissions: A decomposition analysis of Italian energy consumption *Energy* 44 (1): 682–691. https://doi.org/10.1016/j.energy.2012.05.024

Arto, I.–Capellán-Pérez, I.–Lago, R.–Bueno, G.–Bermejo, R. (2016): The energy requirements of a developed world *Energy for Sustainable Development* 33: 1–13. https://doi.org/10.1016/j.esd.2016.04.001

Assadzadeh, A.–Nategh, H. (2015): *The relationship between per capita electricity consumption and human development indices* Proceedings of 6th IASTEM International Conference pp. 1–7., 29th November 2015, Berlin.

Béres-Virág, Á.–Vinogradov, S.(2018): Territorial disparities in Hungarian tourism 2003–2013 *Studia Mundi – Economica* 5 (3): 91–101. https://doi.org/10.18531/Studia.Mundi.2018.05.03.91-101

Bithas, K.–Kalimeris, P. (2013): Re-estimating the decoupling effect: Is there an actual transition towards a less energy-intensive economy? *Energy* 51: 78–84. https://doi.org/10.1016/j.energy.2012.11.033

Brecha, R. J. (2019): Threshold electricity consumption enables multiple sustainable development goals *Sustainability* 11: 5047. https://doi.org/10.3390/su11185047

Conte Grand, M. (2016): Carbon emission targets and decoupling indicators *Ecological Indicators* 67: 649–656. https://doi.org/10.1016/j.ecolind.2016.03.042

Csereklyei, Z.–Stern, D. I. (2015): Global energy use: Decoupling or convergence? *Energy Economics* 51: 633–641. https://doi.org/10.1016/j.eneco.2015.08.029

Dias, R. A.–Mattos, C. R.. P.–Balestieri, J. A. (2006): The limits of human development and the use of energy and natural resources *Energy Policy* 34 (9): 1026–1031. https://doi.org/10.1016/j.enpol.2004.09.008

Dudek, H.–Sedefoğlu, G. (2019): Modelling severe material deprivation rates in EU regions using fractional response regression *Regional Statistics* 9 (2): 130–147. https://doi.org/10.15196/RS090210

DUTTA, S.–LANVIN, B.–WUNSCH-VINCENT, S. (eds.) (2018): *The global innovation index 2018: Energizing the world with innovation* World Intellectual Property Organization, Geneva.

EGIDI, G.–EDWARDS, M.–CIVIDINO, S.–GAMBELLA, F.–SALVATI, L. (2021): Exploring non-linear relationships among redundant variables through non-parametric principal component analysis: An empirical analysis with land-use data *Regional Statistics* 11 (1): 25–41. https://doi.org/10.15196/ RS110105

JACMART, M. C.–ARDITI, M.–ARDITI, I. (1979): The world distribution of commercial energy consumption *Energy Policy* 7 (3): 199–207.
https://doi.org/10.1016/0301-4215(79)90063-6

JACOBSON, A.–MILMAN, A. D.–KAMMEN, D. M. (2005): Letting the (energy) Gini out of the bottle: Lorenz curves of cumulative electricity consumption and Gini coefficients as metrics of energy distribution and equity *Energy Policy* 33 (14): 1825–1832.
https://doi.org/10.1016/j.enpol.2004.02.017

JORGENSON, A. K.–ALEKSEYKO, A.–GIEDRAITIS, V. (2014): Energy consumption, human well-being and economic development in central and eastern European nations: A cautionary tale of sustainability *Energy Policy* 66: 419–427.
https://doi.org/10.1016/j.enpol.2013.11.020

KANAGAWA, M.–NAKATA, T. (2008): Assessment of access to electricity and the socio-economic impacts in rural areas of developing countries *Energy Policy* 36 (6): 2016–2029.
https://doi.org/10.1016/j.enpol.2008.01.041

KINCSES, Á. (2014): A Magyarországon élő külföldi állampolgárok területi koncentrációja, 2001–2011 *Területi Statisztika* 54 (5): 531–549.
https://doi.org/10.15196/TS590502

KINCSES, Á. (2015): *A nemzetközi migráció Magyarországon és a Kárpát-medence magyar migrációs hálózatai a 21. század elején* Központi Statisztikai Hivatal, Budapest.

KÓTI, T. (2018): Spatial differences regarding the chance to leave supported public employment in Hungary's rural periphery *Regional Statistics* 8 (2): 109–134.
https://doi.org/10.15196/RS080210

KRUGMANN, H.–GOLDEMBERG, J. (1983): The energy cost of satisfying basic human needs *Technological Forecasting and Social Change* 24 (1): 45–60.
https://doi.org/10.1016/0040-1625(83)90062-8

LABELLE, M. C. (2020): *Energy cultures. Technology, justice, and geopolitics in Eastern Europe* Edward Elgar Publishing, Cheltenham.

MARTÍNEZ, D. M.–EBENHACK, B. W. (2008): Understanding the role of energy consumption in human development through the use of saturation phenomena *Energy Policy* 36 (4): 1430–1435.
https://doi.org/10.1016/j.enpol.2007.12.016

MAZUR, A. (2011): Does increasing energy or electricity consumption improve quality of life in industrial nations? *Energy Policy* 39: 2568–2572.
https://doi.org/10.1016/j.enpol.2011.02.024

MITSIS, P. (2021): Examining the environmental Kuznets curve hypothesis using Bayesian model averaging *Regional Statistics* 11 (1): 3–24.
https://doi.org/10.15196/RS110102

NADIMI, R.–TOKIMATSU, K. (2018): Modeling of quality of life in terms of energy and electricity consumption *Applied Energy* 212: 1282–1294. https://doi.org/10.1016/j.apenergy.2018.01.006

NEMES NAGY, J. (2005): *Regionális elemzési módszerek* ELTE Regionális Földrajzi Tanszék, MTA-ELTE Regionális Tudományi Kutatócsoport, Budapest.

OECD (2002) *Indicators to measure decoupling of environmental pressure from economic growth* Organisation for Economic Co-operation and Development, Washington.

OUEDRAOGO, N. S. (2013): Energy consumption and human development: Evidence from a panel cointegration and error correction model *Energy* 63: 28–41. https://doi.org/10.1016/j.energy.2013.09.067

PACHAURI, S.–SPRENG, D. (2004): Energy use and energy access in relation to poverty *Economic and Political Weekly* 39 (3): 271–278.

PÁL, V.–LADOS, G.–ILCSIKNÉ MAKRA, ZS.–BOROS, L.–UZZOLI, A.–FABULA, SZ. (2021): Concentration and inequality in the geographic distribution of physicians in the European Union, 2006–2018 *Regional Statistics* 11 (3): 3–28. https://doi.org/10.15196/RS110308

PASTEN, C.–SANTAMARINA, J. C. (2012): Energy and quality of life *Energy Policy* 49: 468–476. https://doi.org/10.1016/j.enpol.2012.06.051

PASTERNAK, A. D. (2000): *Global energy futures and human development: a framework for analysis* U.S. Department of Energy, Lawrence Livermore National Laboratory, Livermore, CA.

PÉNZES, J. (2020): The impact of the Trianon Peace Treaty on the border zones – an attempt to analyse the historic territorial development pattern and its changes in Hungary *Regional Statistics* 10 (1): 60–81. https://doi.org/10.15196/RS100102

RAY, S.–GHOSH, B.–BARDHAN, S.–BHATTACHARYYA, B. (2016): Studies on the impact of energy quality on human development index *Renewable Energy* 92: 117–126. https://doi.org/10.1016/j.renene.2016.01.061

SHIMAMOTO, K. (2019): Empirical analysis of the distribution of urban parks in Japan *Regional Statistics* 9 (2): 148–172. https://doi.org/10.15196/RS090203

SEN, A. (1990): Development as Capability Expansion. In: GRIFFIN, K.–KNIGHT, J. (eds.): *Human development and the international development strategy for the 1990s.* pp. 41–58., Palgrave Macmillan, London. https://doi.org/10.1007/978-1-349-21136-4_3

SEN, A. (1995): *Inequality reexamined* Oxford University Press, Oxford. https://doi.org/10.1093/0198289286.001.0001

SORRELL, S. (2010): Energy, economic growth and environmental sustainability: Five propositions *Sustainability* 2: 1784–1809. https://doi.org/10.3390/su2061784

STEINBERGER, J. K.–ROBERTS, J. T. (2009): *Across a moving threshold: Energy, carbon and the efficiency of meeting global human development needs* Social Ecology Working Paper 114, Institute of Social Ecology, Vienna.

STEINBERGER, J. K.–ROBERTS, J. T. (2010): From constraint to sufficiency: The decoupling of energy and carbon from human needs, 1975–2005 *Ecological Economics* 70 (2): 425–433. https://doi.org/10.1016/j.ecolecon.2010.09.014

SUŠNIK, J.–VAN DER ZAAG, P. (2017): Correlation and causation between the UN human development index and national and personal wealth and resource exploitation *Economic Research-Ekonomska Istraživanja* 30 (1): 1705–1723. https://doi.org/10.1080/1331677X.2017.1383175

SWEIDAN, O. D.–ALWAKED, A. A. (2016): Economic development and the energy intensity of human well-being: Evidence from the GCC countries *Renewable and Sustainable Energy Reviews* 55: 1363–1369. https://doi.org/10.1016/j.rser.2015.06.001

SZÉP, T.–PÁLVÖLGYI, T.–KÁRMÁN-TAMUS, É. (2021): A comprehensive indicator set for measuring the sustainable energy performance in the European Union. In: *Entrepreneurship in the Raw Materials Sector* Proceedings of the International Conference of the University of Miskolc, Faculty of Economics, Miskolc (LIMBRA).

SZLÁVIK, J.–SEBESTYÉNNÉ SZÉP, T. (2017): Delinking of energy consumption and economic growth in the Visegrad Group *Geographia Technica* 12 (2): 139–149. https://doi.org/10.21163/GT_2017.122.12

TRAN, N. V.–TRAN, Q.V.–DO, L.T.T.–DINH, L. H.–DO, H. T. T. (2019): Trade off between environment, energy consumption and human development: Do levels of economic development matter? *Energy* 173: 483–493. https://doi.org/10.1016/j.energy.2019.02.042

TÜRKAN, S.–OZEL, G. (2019): Determinants of electricity consumption based on the NUTS 2 regions of Turkey: A panel data approach *Regional Statistics* 9 (1): 120–134. https://doi.org/10.15196/RS090105

UNEP (ed.) (2011): *Decoupling natural resource use and environmental impacts from economic growth* United Nations Environment Programme, Kenya, UNEP.

WANG, H.–HASHIMOTO, S.–YUE, Q.–MORIGUCHI, Y.–LU, Z. (2013): Decoupling Analysis of Four Selected Countries *Journal of Industrial Ecology* 17 (4): 618–629. https://doi.org/10.1111/jiec.12005

WEINER, C.–S. SZÉP, T. (2020): *The Hungarian utility cost reduction programme: An impact assessment* Working paper (259), Centre for Economic and Regional Studies – Institute of World Economics, Budapest.

WU, Q.–MASLYUK, S.–CLULOW, V. (2012): Energy consumption inequality and human development *2010 International Conference on Management Science & Engineering 17th Annual Conference Proceedings* pp. 1398–1409. https://doi.org/10.1109/ICMSE.2010.5719973.

INTERNET SOURCES

UNDP – UNITED NATIONS DEVELOPMENT PROGRAMME (2019): Human development report 2019: beyond income, beyond averages, beyond today: inequalities in human development in the 21st century https://reliefweb.int/sites/reliefweb.int/files/resources/hdr2019.pdf (downloaded: May 2021)

GAYE, A. (2007): *Access to energy and human development* Human Development Report Office OCCASIONAL PAPER 2007/25. http://hdr.undp.org/sites/default/files/gaye_amie.pdf (downloaded: May 2021)

LABELLE, M. C.–GEORGIEV, A. (2016): *The socio-political capture of utilities: The expense of low energy prices in Bulgaria and Hungary* https://erranet.org/download/socio-political-capture-of-utilities-bulgaria-hungary/ (downloaded: May 2021)

LEUNG, C. S.–MEISEN, P. (2005): How electricity consumption affects social and economic development by comparing low, medium and high human development countries Global Energy Network Institute San Diego, California. http://www.geni.org/globalenergy/issues/global/qualityoflife/HDI-vs-Electricity-Consumption-2005-07-18.pdf (downloaded: May 2021)

MATHIESEN, K.–OROSCHAKOFF, K. (2020) 'Rather exhausted' EU leaders sign off on higher 2030 climate goals *POLITICO* https://www.politico.eu/article/eu-leaders-agree-to-cut-emissions-55-percent-by-2030/ (downloaded: 12 December 2020).

TUCSON ELECTRIC POWER (2020): *Energy terms, defined* https://www.tep.com/news/energy-terms-defined/ (downloaded: 22 July 2020).

UNDP (2020): *Human development data (1990–2018) Human Development Reports* http://hdr.undp.org/en/data (downloaded: 4 June 2020).

DATABASE

EUROSTAT (2020): Database https://ec.europa.eu/eurostat/data/database (accessed 5 May 2020).