STUDIA REGIONALIA

Journal of the Polish Academy of Sciences:
Committee for Spatial Economy and Regional Planning
&
European Regional Science Association
(ERSA) Polish Section

Volume 48, 2016, pp. 25–52
doi: 10.12657/studreg-48-02

INADEQUACY OF ENERGY EFFICIENCY MEASUREMENTS BASED ON GDP

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Abstract: Improving energy efficiency is key to moving toward sustainable development. It contributes to the reduction of energy consumption and carbon emissions, as well as to climate change mitigation. Indicators of energy efficiency play an important role in this field because their improvement is targeted by policy makers. Indicators based on the ratio between energy consumption and gross domestic product (GDP) are currently used by multiple key organizations, including Eurostat and the World Bank, as the main energy efficiency indicators. This study examines the most widely used indicators and identifies their deficiencies. Over the last decades, these indicators tend to show a continuous strong improvement, signifying positive progress toward energy efficiency, even in cases when the physical consumption of energy has increased significantly. This phenomenon is based on GDP adjustment. The energy intensity of economies, used currently to measure energy efficiency, masks problems and has led to the green labeling of wealthier economies. An analysis of energy efficiencies reported for multiple countries and the structure of their energy spending shows that the reported values are counterproductive for comparing economies in the context of environmental protection. The indicators sanction economies with low energy consumption and low or moderate GDP. The economies belonging to the group of the largest energy spenders *per capita* are labeled highly efficient because of GDP adjustment. Decision makers are therefore prompted to focus on GDP growth even at the cost of a major increase in energy consumption. An additional problem in the indicators is that they do not properly model international trade. The responsibility for energy spending is shifted toward the producers of energy-intensive goods and services. Energy intensity is a useful indicator to measure the resistance of an economy to the volatilities of energy prices. However, the challenges in the fields of environmental pollution and climate change are related to physical processes and energy consumption rather than to changes in the GDP or the monetary valuation of products and services. Indicators measuring energy efficiency as GDP per unit of energy use are inadequate and misleading as principal tools to measure energy efficiency.

Keywords: Climate change, energy efficiency, energy intensity, GDP, measurement

JEL codes: O13, Q43, E01

Introduction

This study covers the main indicators used by the European Union (EU) and the World Bank to measure energy efficiency. Policies implemented within EU countries, as well as World Bank recommendations, target the improvement of established energy efficiency indicators. Thus, the measurements are relevant for energy policies on the regional level. Improving energy efficiency has a major potential in reducing energy use and supporting sustainable development. However, no consensus exists on the overall speed improvement of energy efficiency or overall energy savings. While some authors and institutions praise the rapid increase in energy efficiency, others perceive the situation more critically (The World Bank 2009: 59). Considering the reasons behind the different views and analyzing how the situation can be improved are both important.

The research problem involves determining to what extent the indicators currently used by the EU and the World Bank are adequate in indicating changes in energy efficiency relevant to sustainable development in terms of real energy savings and climate change mitigation. If the analysis determines deficits, the sources of inaccuracies should be identified. A detailed description of an alternative indicator is beyond the scope of this study. However, a secondary goal is to outline a solution that addresses the deficits of the current approach. Special attention should be given to improving the analytical capabilities of the measurements for supporting regional development policies.

1. Measuring energy efficiency

The most widely used type of energy efficiency indicators is monetary-based. Energy intensity is calculated as a ratio between energy consumption and monetary output – energy per GDP for an economy or energy per unit of industrial output for a company. Energy efficiency is defined as the reciprocal of energy intensity. Both Eurostat and The World Bank employ GDP-based indexes for their main energy efficiency indicators. The EU considers “energy intensity” of the economies of its member states as the overall indicator of energy efficiency (Eurostat, Energy Intensity… 2015):

> *This indicator is the ratio between the gross inland consumption of energy and the gross domestic product (GDP) for a given calendar year. It measures the energy consumption of an economy and its overall energy efficiency. The gross inland consumption of energy is calculated as the sum of the gross inland consumption of five energy types: coal, electricity, oil, natural gas and renewable energy sources. The GDP figures are taken at chain linked volumes with reference year 2010. The energy intensity ratio is determined by dividing the gross inland consumption by the GDP. Since gross inland consumption is measured in kgoe (kilogram of oil equivalent) and GDP in 1 000 EUR, this ratio is measured in kgoe per 1 000 EUR.*

An alternative to this approach is calculating the indicator based only on physical parameters. The "Economy-wide Energy Intensity Index" (EEII) established by the US Energy Information Administration (US EIA) (153) is a one of the prominent indicators. It measures energy intensity of economies based on energy consumption rather than the relationship between GDP and energy expenditure. Some experts suggest that composite energy efficiency indexes based are superior to monitory-based indexes such as energy-GDP ratios for measuring energy efficiency (Ang 2005). We will discuss this approach in the final section of the paper and compare it with the Real Energy Efficiency index which shall be presented later in the paper.

"Total-factor energy efficiency" (TFEE) is another prominent method which has been used in studies on China and multiple developing countries (Jin-Li Hu & Shih-Chuan Wang 2006; Xing-Ping Zhang *et al.* 2011). TFEE is based on data envelopment analysis (DEA). The TFEE methodology relies on estimating deviations from an energy efficiency frontier calculated using multiple parameters including energy consumption, labor, capital stock, and GDP (Jin-Li Hu & Shih-Chuan Wang 2006). The approach operated using a mathematical linear-programming procedure which calculates the efficiency frontier for multiple decision-making units (DMU) (Wang 2014: 1530). The DEA procedure takes as an input a set of units, their inputs, and output. In the case of TFEE, units are a set of countries or regions, input per unit – energy consumption, information on labor and capital stock and output per unit – economy performance (GDP). The algorithm computes the efficiency frontier consisting of DMUs which are not dominated by other DMUs in terms of more efficient expenditure of inputs per generated unit of output.

2. Energy intensity of the economy

This paper focuses on GDP-based energy efficiency and energy intensity measurements. They are widely used and have been selected by the EU and the World Bank as main energy efficiency indicators. Energy intensity and energy efficiency are reciprocal. Figure 1 is a chart of the energy intensities of EU economies, published by Eurostat. Major differences in the energy intensities between the member states are evident.

In addition to demonstrating sharp discrepancies between the energy intensities of EU economies, the data published by Eurostat show a continuous improvement of the indicator throughout the EU during the last 12 years (Table 1).

The proportional reduction in the energy intensity indicator for almost all European countries during the reviewed period is significant (Table 2). The countries that showed the largest relative reduction in the indicator between 2002 and 2014 were Lithuania (51.4%), Romania (43.7%), Slovakia (47.2%), Bulgaria (36.1%), Poland (32.7%), and Ireland (31.1%). All countries that already had above-average energy efficiency further reduced their energy intensity, including France (−17.8%), the United Kingdom (−30.7%), and Germany (−20.5%) (Table 2).

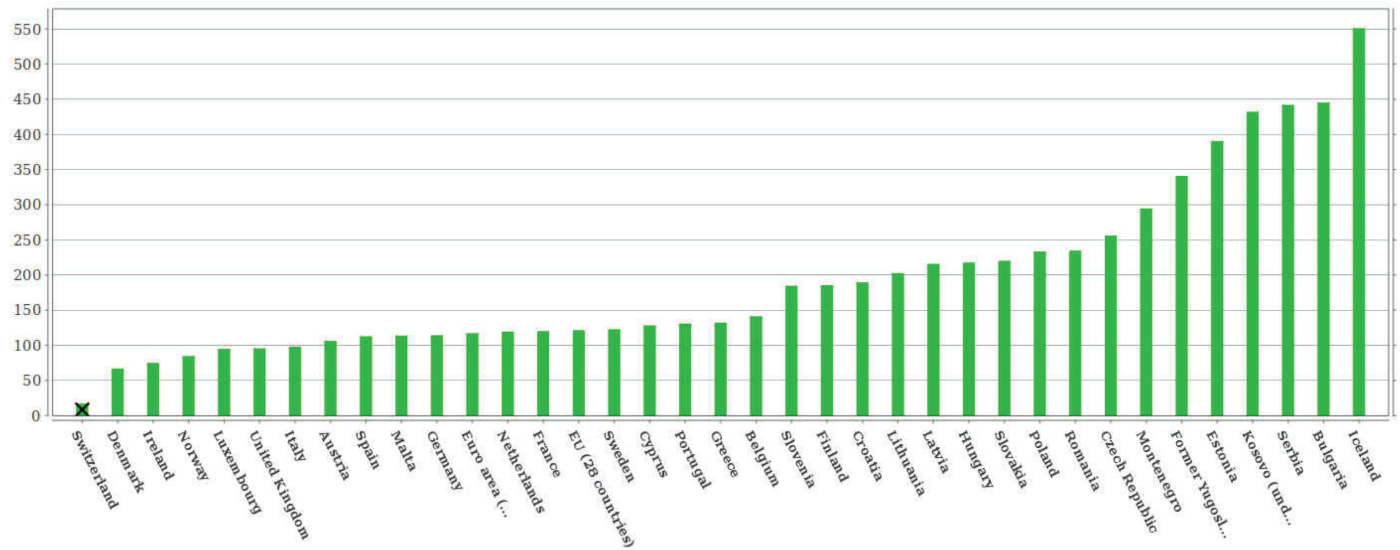

Fig. 1. Energy intensity of the economy (kg of oil equivalent per thousand EUR of the GDP) for EU members, candidate states, and Norway for year 2014
Source: (Eurostat 2017).

Table 1. Energy intensity of the economy. Gross inland consumption of energy divided by the GDP (kg of oil equivalent per 1,000 EUR) for Years 2002–2014

	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
Denmark	87.4	90.6	85.8	81.3	84.1	81.3	78.4	79.2	82.4	75.5	72.6	73.1	66.7
Ireland	108.7	102.1	98	93.5	90.3	88.8	91.5	90.6	90.7	83	83.3	82	74.9
Luxembourg	124.3	129.2	137.6	135.9	127.2	115.1	116	115.6	116.2	112.1	109.5	102.2	94.8
United Kingdom	137.9	136	133	130	124.9	117.6	116.6	115	115.9	106.5	108.2	105.2	95.6
Italy	111.2	116.7	115.3	116.6	113.2	111.5	111.6	110.1	110.9	106.9	105.6	103.5	97.9
Austria	118	123.8	123.3	123.8	120.3	114.7	113.9	111.3	116.6	110.1	108.8	110.2	106.2
Spain	140.6	141	142.8	140.7	135.2	132	126.5	120.8	120.5	120.1	123.3	116.9	112.7
Malta	147.7	158.4	162.2	162.8	150.1	153.4	148.1	136.6	141.8	139.6	142.3	121.4	113.7
Germany	143.6	143.4	142.8	140.9	139.8	128.4	128.6	128	129.1	118.4	118.5	120.1	114.1
Netherlands	143.4	147.5	147.3	142.4	136.2	131	128.6	129.9	136.3	125.3	127.2	126.9	119.4
France	146.1	147.4	145.5	143.8	138.5	133.9	134.3	132.3	133.6	126.2	126.1	126	120.1
EU (28 countries)	152.6	153.8	151.7	149.2	145.1	138.5	137.6	135.6	137.6	130.3	129.9	128.2	121.5
Sweden	165.5	157	156.3	149.5	138.8	134.2	134.3	130.5	137.6	131.2	131.8	128.4	122.7
Cyprus	160.8	169.8	152.4	148.9	148	147.4	149.4	147.9	142	138.9	134.1	123.9	128.1
Portugal	154.7	152.2	154.6	157.4	147.8	144.1	139.6	142	135	133.8	131.2	133.6	130.7
Greece	143.9	139.6	135.1	136.7	130.1	125.7	127.4	128	127.6	135.8	145.2	131.9	132.1
Belgium	176.9	183.3	178	173.4	166.1	158	163.2	159.8	167.5	153.3	146.8	152	141.2

	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
Slovenia	230.4	226.6	223.8	220.2	208.4	195.1	199.7	197	202.6	201	198.6	195.7	184.5
Finland	212.3	219.9	213.5	192.2	200.8	189.9	181.8	186.8	198.5	186.8	183.5	181.8	185.6
Croatia	233.7	237.4	228	222.5	210.9	209.2	199.4	208.1	209.5	207.3	201.9	197.7	189.6
Lithuania	417	392.6	376.2	329.5	300.8	294.9	286.6	307.3	242.2	235.8	229.9	209.3	202.5
Latvia	294	288.2	273	252.3	234	218.2	217.5	243.9	260.2	231.6	230.9	220.9	215.7
Hungary	296.8	291.5	275.1	278	266.2	258.9	254.8	257.4	261.5	250.1	238.3	225.7	217.7
Slovakia	416.9	393.7	368.6	355.1	324.7	277.3	269	260.7	264.2	250.3	236.3	237.1	220.1
Poland	346.9	346.5	329.7	321.7	318.2	297.1	288.2	270.6	278.3	265.3	252.8	250.3	233.3
Romania	417.1	412.3	375.1	357.2	342.1	318.8	293	278.3	282.5	285.4	274.4	243	234.7
Czech Republic	354.8	358.6	350.3	325.4	312.5	296.2	281.9	277.8	285.7	269.8	270.5	267.9	256.3
Estonia	416	427.8	412.3	373.9	331.1	344.4	352.2	372	417.9	390.4	370.3	400.2	390.5
Bulgaria	696.6	683.8	630.6	614	593.2	542.8	509.2	463.9	464.9	490.1	467.8	426.3	445.2

Source: Own elaboration based on data from (Eurostat 2017) (Tables 1 and 2).

Table 2. Improvement of the energy intensity indicator in the EU. Gross inland consumption of energy divided by the GDP (kg of oil equivalent per 1,000 EUR) – Change in percent in years 2002–2014

	2002–2003	2002–2004	2002–2005	2002–2006	2002–2007	2002–2008	2002–2009	2002–2010	2002–2011	2002–2012	2002–2013	2002–2014
Denmark	3.7	-1.8	-7.0	-3.8	-7.0	-10.3	-9.4	-5.7	-13.6	-16.9	-16.4	-23.7
Ireland	-6.1	-9.8	-14.0	-16.9	-18.3	-15.8	-16.7	-16.6	-23.6	-23.4	-24.6	-31.1
Luxembourg	3.9	10.7	9.3	2.3	-7.4	-6.7	-7.0	-6.5	-9.8	-11.9	-17.8	-23.7
United Kingdom	-1.4	-3.6	-5.7	-9.4	-14.7	-15.4	-16.6	-16.0	-22.8	-21.5	-23.7	-30.7
Italy	4.9	3.7	4.9	1.8	0.3	0.4	-1.0	-0.3	-3.9	-5.0	-6.9	-12.0
Austria	4.9	4.5	4.9	1.9	-2.8	-3.5	-5.7	-1.2	-6.7	-7.8	-6.6	-10.0
Spain	0.3	1.6	0.1	-3.8	-6.1	-10.0	-14.1	-14.3	-14.6	-12.3	-16.9	-19.8
Malta	7.2	9.8	10.2	1.6	3.9	0.3	-7.5	-4.0	-5.5	-3.7	-17.8	-23.0
Germany	-0.1	-0.6	-1.9	-2.6	-10.6	-10.4	-10.9	-10.1	-17.5	-17.5	-16.4	
Netherlands	2.9	2.7	-0.7	-5.0	-8.6	-10.3	-9.4	-5.0	-12.6	-11.3	-11.5	-16.7
France	0.9	-0.4	-1.6	-5.2	-8.4	-8.1	-9.4	-8.6	-13.6	-13.7	-13.8	-17.8
EU (28 countries)	0.8	-0.6	-2.2	-4.9	-9.2	-9.8	-11.1	-9.8	-14.6	-14.9	-16.0	-20.4
Sweden	-5.1	-5.6	-9.7	-16.1	-18.9	-18.9	-21.1	-16.9	-20.7	-20.4	-22.4	-25.9
Cyprus	5.6	-5.2	-7.4	-8.0	-8.3	-7.1	-8.0	-11.7	-13.6	-16.6	-22.9	-20.3
Portugal	-1.6	-0.1	1.7	-4.5	-6.9	-9.8	-8.2	-12.7	-13.5	-15.2	-13.6	-15.5
Greece	-3.0	-6.1	-5.0	-9.6	-12.6	-11.5	-11.0	-11.3	-5.6	0.9	-8.3	-8.2
Belgium	3.6	0.6	-2.0	-6.1	-10.7	-7.7	-9.7	-5.3	-13.3	-17.0	-14.1	-20.2
Slovenia	-1.6	-2.9	-4.4	-9.5	-15.3	-13.3	-14.5	-12.1	-12.8	-13.8	-15.1	-19.9
Finland	3.6	0.6	-9.5	-5.4	-10.6	-14.4	-12.0	-6.5	-12.0	-13.6	-14.4	-12.6

	2002–2003	2002–2004	2002–2005	2002–2006	2002–2007	2002–2008	2002–2009	2002–2010	2002–2011	2002–2012	2002–2013	2002–2014
Croatia	1.6	-2.4	-4.8	-9.8	-10.5	-14.7	-11.0	-10.4	-11.3	-13.6	-15.4	-18.9
Lithuania	-5.9	-9.8	-21.0	-27.9	-29.3	-31.3	-26.3	-41.9	-43.5	-44.9	-49.8	-51.4
Latvia	-2.0	-7.1	-14.2	-20.4	-25.8	-26.0	-17.0	-11.5	-21.2	-21.5	-24.9	-26.6
Hungary	-1.8	-7.3	-6.3	-10.3	-12.8	-14.2	-13.3	-11.9	-15.7	-19.7	-24.0	-26.7
Slovakia	-5.6	-11.6	-14.8	-22.1	-33.5	-35.5	-37.5	-36.6	-40.0	-43.3	-43.1	-47.2
Poland	-0.1	-5.0	-7.3	-8.3	-14.4	-16.9	-22.0	-19.8	-23.5	-27.1	-27.8	-32.7
Romania	-1.2	-10.1	-14.4	-18.0	-23.6	-29.8	-33.3	-32.3	-31.6	-34.2	-41.7	-43.7
Czech Republic	1.1	-1.3	-8.3	-11.9	-16.5	-20.5	-21.7	-19.5	-24.0	-23.8	-24.5	-27.8
Estonia	2.8	-0.9	-10.1	-20.4	-17.2	-15.3	-10.6	0.5	-6.2	-11.0	-3.8	-6.1
Bulgaria	-1.8	-9.5	-11.9	-14.8	-22.1	-26.9	-33.4	-33.3	-29.6	-32.8	-38.8	-36.1

The World Bank and the Organisation for Economic Co-operation and Development use similar indicators to measure energy efficiency: gross domestic product (GDP) per unit of energy use (PPP $ per kg of oil equivalent) (The World Bank 2014a) and energy use (kg of oil equivalent) per $1,000 GDP (constant 2011 PPP) (The World Bank 2014b). They are reciprocal forms of the energy intensity indicator used by the EU.

Estimations of the World Bank show a sharp increase in energy efficiency only between 2005 and 2012. The world indicator increased from 5.9 to 7.6, marking a 28.8% increase in GDP per unit of energy use.

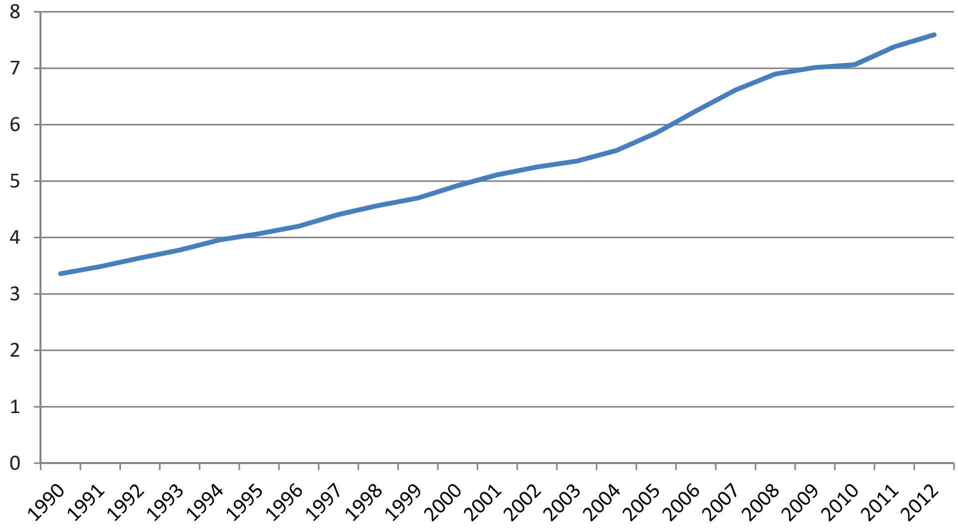

Fig. 2. GDP per unit of energy use (PPP $ per kg of oil equivalent) for the years 1990–2012
Source: (The World Bank 2014a).

Improvement in the discussed indicators has been used to proclaim large leaps forward in energy efficiency as well as setting targets for future years (European Commission 2014).

According to the Energy Efficiency Directive of the European Union (European Commission 2012), in order to reach the efficiency target by 2020, EU member states have set targets based on reducing the energy intensity of their economies (European Commission 2012):

> *To reach the EU's 20% energy efficiency target by 2020, individual EU countries have set their own indicative national energy efficiency targets. Depending on country preferences, these targets can be based on primary or final energy consumption, primary or final energy savings, or energy intensity.*

However, these indicators have limited usefulness in relation to the analysis of, for example, climate change mitigation. Environmental pollution and climate change are related to physical processes rather than changes in Gross Domestic Product. A lower energy intensity of an economy denotes the fact that energy plays a smaller role in the value of products and services produced by that economy. Therefore, such an economy is less susceptible to volatilities in energy prices due to the relative lesser effect higher prices would have on it. Regardless of this fact, a lower energy intensity of an economy does not necessarily mean that the economy consumes less energy. It can also result from the higher evaluation of the products and services it creates. Climate change is triggered by the global emission of greenhouse gases and does not depend on the valuation of products and services.

3. Total energy consumption *vs.* energy intensity

Here, we will consider the historical development of total energy consumption and analyze how it compares to the historical development of energy intensity.

The data published by the World Bank show a continuous increase in global energy consumption *per capita* (Figure 3).

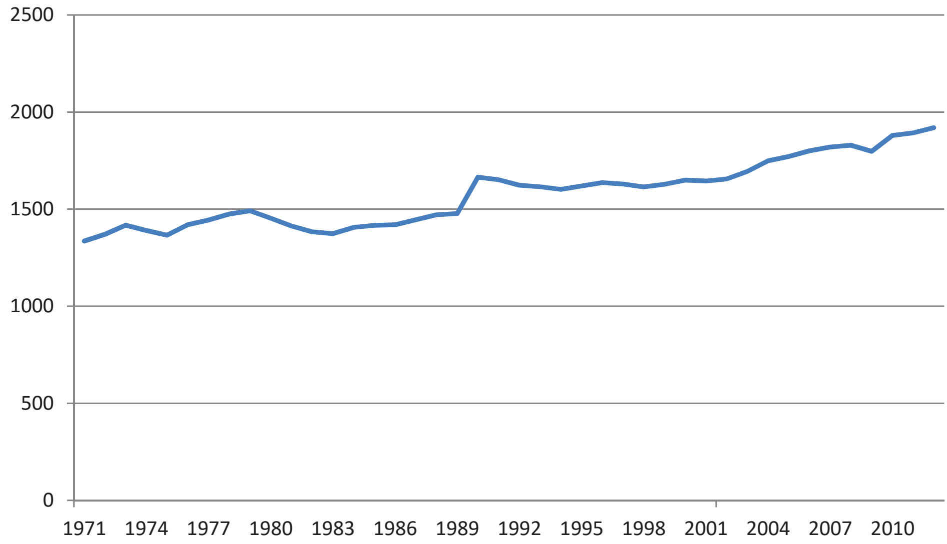

Fig. 3. Energy use (kg of oil equivalent *per capita*) – world
Source: Own elaboration based on datasets by the (World Bank 2014c).

Combined with population growth, the increased energy consumption *per capita* has led to a sharp increase in global energy use in recent decades (Figure 4).

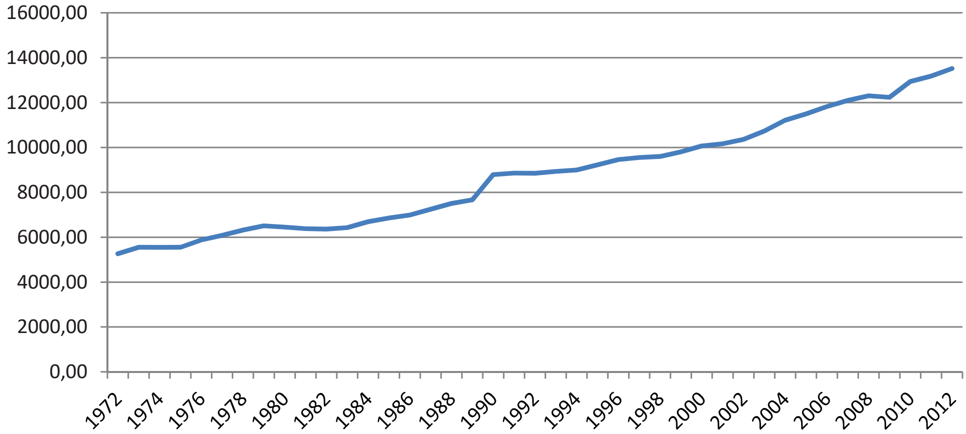

Fig. 4. Global total energy use (million tons of oil equivalent) in the years 1972–2012[1]
Source: Own elaboration based on datasets from the (World Bank 2014c, 2016).

Between 2005 and 2012, one can observe a strong increase in consumption *per capita* (Figure 3) and about one third increase in total energy consumption (Figure 4). This trend is a clear demonstration that using the "GDP per unit of energy use" indicator as the main tool to measure energy efficiency is inadequate. During the same period, it improved by 28.8% (Figure 2).

An additional driver for the increase in global energy demand is increased access to electricity, automobiles, and general changes in global living patterns. The number of people who have access to electricity has not reached a peak, as hundreds of millions of people still do not have access to electricity (The World Bank 2014d).

We can consider the situation in the EU and verify whether the reduction in energy intensity described earlier corresponds to a reduction in energy consumption. We calculated the total consumption of energy (tons of oil equivalent) *per capita* (Table 3) based on the datasets of total energy consumption per country (Eurostat 2015a) and population (Eurostat 2015b).

Energy consumption *per capita* varies strongly between EU member states (Table 3), with Luxembourg, Finland, Sweden, Belgium, Estonia, the Netherlands, Germany, France, and Slovenia consuming more than the EU28 average amount of 3.29 tons of oil equivalent *per capita* in the year 2013. The list of EU countries with the lowest energy spending is dominated by Southern and Eastern European states, including Romania, Croatia, Malta, Portugal, Greece, Latvia, Poland, Bulgaria, Portugal, and Spain.

Considering the statistics for final energy consumption for the period between 1990 and 2012 (Figure 5), we can see that the drop in energy consumption between 2005 and 2012 was preceded by a long period of steadily increasing consumption. The overall energy consumption in 2012 is almost unchanged compared to that in 1990.

1 The time series ends in 2012 because this is the last year for which data were published.

Table 3. Consumption of energy *per capita* (tons of oil equivalent) in EU countries in the years 2005–2013[2]

Country/TOE (tons of oil equivalent) *per capita*	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**Diff. 2005–2013 in %**
Luxembourg	10.41	10.07	9.73	9.57	8.84	9.24	8.92	8.50	8.08	−22.4
Finland	6.59	7.15	7.07	6.78	6.36	6.94	6.67	6.43	6.25	−5.2
Sweden	5.66	5.48	5.44	5.37	4.91	5.44	5.28	5.25	5.14	−9.1
Belgium	5.65	5.51	5.38	5.56	5.30	5.66	5.26	4.94	5.08	−10.0
Estonia	4.13	4.06	4.58	4.44	4.01	4.61	4.65	4.62	5.08	22.9
Netherlands	5.00	4.87	5.05	5.09	4.92	5.23	4.82	4.89	4.84	−3.2
Czech Republic	4.42	4.53	4.52	4.38	4.07	4.27	4.10	4.08	4.01	−9.3
Austria	4.19	4.18	4.11	4.13	3.90	4.14	4.01	4.01	3.99	−4.6
France	4.41	4.32	4.25	4.24	4.04	4.14	3.97	3.96	3.96	−10.3
Germany	4.14	4.27	4.05	4.11	3.87	4.07	3.87	3.89	3.95	−4.6
Slovenia	3.67	3.66	3.65	3.86	3.47	3.54	3.55	3.40	3.34	−9.0
European Union (28 countries)	3.69	3.69	3.62	3.60	3.38	3.50	3.37	3.33	3.29	−10.8
Denmark	3.61	3.88	3.77	3.59	3.43	3.62	3.35	3.22	3.23	−10.6
Slovakia	3.54	3.51	3.32	3.40	3.12	3.31	3.23	3.09	3.19	−9.9
United Kingdom	3.89	3.80	3.64	3.56	3.33	3.40	3.14	3.20	3.15	−19.1
Ireland	3.71	3.71	3.67	3.52	3.29	3.34	3.04	3.01	2.99	−19.4
Italy	3.24	3.19	3.15	3.08	2.86	2.95	2.90	2.80	2.68	−17.2
Poland	2.42	2.54	2.54	2.57	2.48	2.65	2.65	2.57	2.58	6.7
Spain	3.33	3.28	3.27	3.10	2.82	2.80	2.75	2.73	2.54	−23.7
Cyprus	3.46	3.54	3.63	3.73	3.54	3.34	3.20	2.92	2.53	−27.0
Bulgaria	2.57	2.67	2.65	2.65	2.34	2.39	2.59	2.49	2.30	−10.4
Hungary	2.73	2.73	2.66	2.65	2.51	2.58	2.51	2.37	2.30	−16.1
Lithuania	2.60	2.60	2.86	2.89	2.66	2.16	2.30	2.36	2.25	−13.3
Greece	2.84	2.84	2.83	2.85	2.72	2.57	2.50	2.49	2.22	−21.9
Latvia	2.04	2.14	2.21	2.14	2.08	2.18	2.11	2.22	2.21	8.1

[2] The table ends in 2013 because this is the last year for which data for all selected countries were published.

Country/TOE (tons of oil equivalent) *per capita*	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**Diff. 2005–2013 in %**
Portugal	2.62	2.49	2.49	2.41	2.37	2.30	2.23	2.13	2.16	−17.6
Malta	2.41	2.25	2.39	2.37	2.12	2.23	2.22	2.33	1.99	−17.5
Croatia	2.06	2.07	2.16	2.10	2.02	1.99	1.99	1.90	1.84	−10.9
Romania	1.83	1.91	1.91	1.95	1.74	1.76	1.81	1.76	1.62	−11.9

Source: Own elaboration based on datasets from [Eurostat 2015a,b].

Comparing the energy intensity data (Table 1) and total energy spending data (Table 3), we can make the following observations:

– The countries with low energy intensity tend to have high or average energy consumption. Almost all countries with lower-than-average energy intensity (Ireland, Denmark, the United Kingdom, Italy, Austria, Luxembourg, and Germany) have either higher-than-average or close-to-average energy consumption. The exception is Spain, which had a *per capita* consumption of only 2.54 tons of oil equivalent in 2013. The country with the highest per capita energy consumption, Luxembourg, is considered one of the most energy efficient countries, even if its *per capita* consumption is more than four times higher than that of Romania.
– The countries with the highest energy intensity (such as Bulgaria, Estonia, Romania, Poland, Latvia, Slovakia, and the Czech Republic) tend to have either very low or average energy consumption *per capita*.

The low energy intensity of Western and Northern European countries is based on a higher GDP that strongly reduces the indicator (Eurostat 2015), not lower the energy spending. This analysis does not support energy intensity as a suitable indicator for energy efficiency relevant to climate change mitigation. On the contrary, we can clearly see that at both global and national levels, indicators based on the GDP–energy spending relationship are counterproductive and even deceptive.

4. Structure of energy spending

One argument supporting GDP adjustment is that the higher energy spending in economies with higher GDPs is completely justified because more energy is required for the production of goods and services that are essential for the global economy. A country with a fully developed heavy industry clearly has relatively higher corresponding energy needs. However, the question as to what extent the GDP justifies energy consumption arises. Examining the structure of energy spending is also valuable in the broader context of sustainable development. Different types of energy sources vary in their specifics and externalities; they are also disproportionally relevant for different sectors of the economy.

We will focus on statistics for member states of the EU. Information using the same methodology and enforced by EU standards has already been gathered, evaluated, and published by Eurostat and the European Environment Organization. On a global level, even studies that target wide coverage rely on data published by national statistical organizations that may feature more significant deviations in their methodologies.

Analyzing the structure of energy spending and the flows of goods and services is valuable. Arguments that higher energy spending results from added value to the global economy emphasize the role of the industrial and agricultural sectors. The distribution of energy spending over sectors and over time is illustrated in Figure 5.

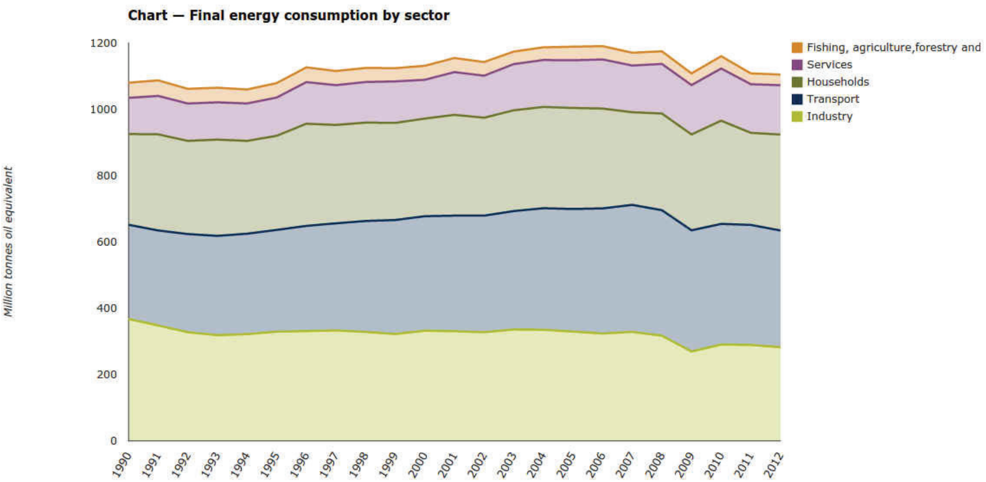

Fig. 5. Final energy consumption in EU28 by sectors of the economy for the years 1990–2012[3]
Source: (European Environment Agency 2015) (Figs. 5–9).

When considering the dataset for final energy consumption, as distributed by sector of the economy (Figure 5), by Eurostat for a longer time period, we can observe the following important features:

- As pointed out in the previous section, the overall energy consumption decreased between 2005 and 2012 and was preceded by an increase between 1990 and 2005. The level of energy spending in 2012 was very close to the level 23 years earlier.
- Fishing, agriculture, and forestry are the sectors with the strongest decrease in energy consumption between 2005 and 2012 at 22% (European Environment Agency 2015: 11). Their share in overall consumption is very low.
- Absolute spending and the relative industry share in energy spending have been continuously decreasing. Energy consumption in this sector decreased by 14% between 2005 and 2012 (*ibidem*).

3 The chart originates from the latest report in 2015. The numbers for the following year are not yet published.

– The largest amount of energy is consumed by transportation. The relative share of this sector was lower than that the industry share in 1990, but has since been increasing steadily.
– Housing is another very large sector. Its share has remained relatively stable over the years.

This information contradicts the hypothesis that higher levels of energy consumption, mostly in some Western European states, are caused by industrial and agricultural production. Contrary to this assumption, housing and transportation account for more than 50% of energy expenditures, and their relative shares are increasing.

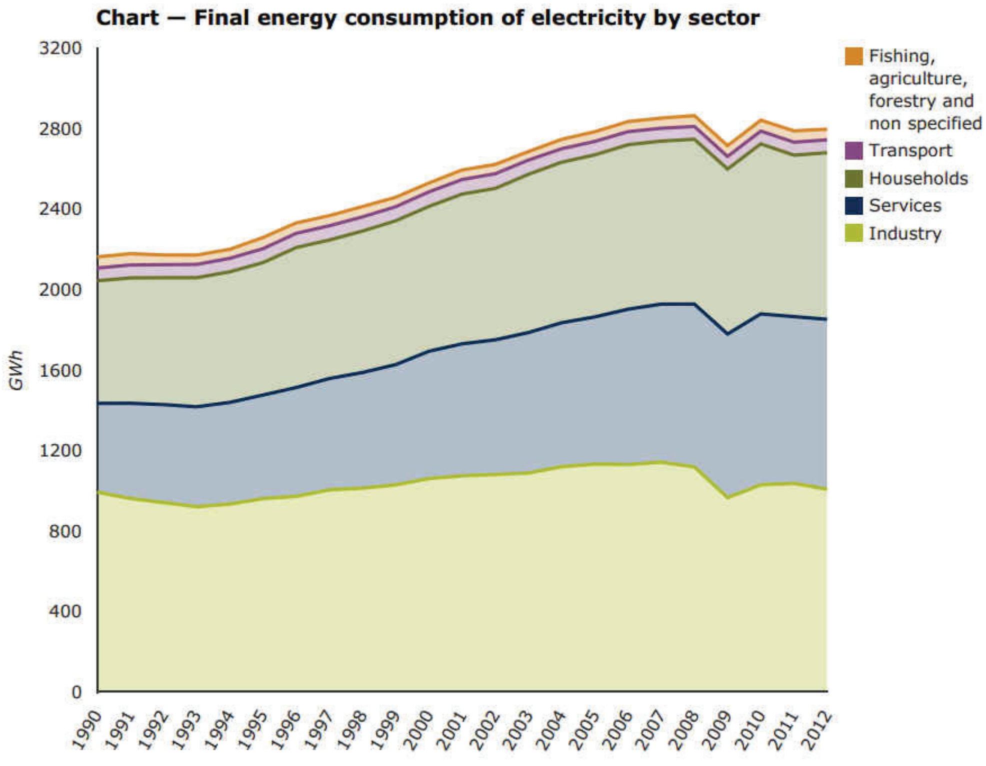

Fig. 6. Final energy consumption of electricity in EU28 by sector in the years 1990–2012[4]

The household and transport sectors have been the leaders in increases in electricity consumption in the last two decades (Figure 6). A positive aspect of consuming electricity instead of fossil fuels, such as oil and coal, is that renewable energy sources can be used to substitute for conventional sources of electricity. Notably, the data (Fig. 6) published by the European Environment Agency define

4 The report (2015) shows the structure of consumption until 2012.

one category for electricity. The data do not distinguish between different methods of electricity generation, which include renewable energy sources, nuclear power, or fossil fuels. Thus, the category "solid fuel" does not cover the whole consumption of fossil fuel, but only the share that is directly consumed.

Examining the consumption of petroleum products (Figure 7), one can observe that this type of consumption has been increasing for a long period and has decreased only since 2005, with the strongest decrease in consumption coinciding with the most active phase of the economic crisis (2007–2009).

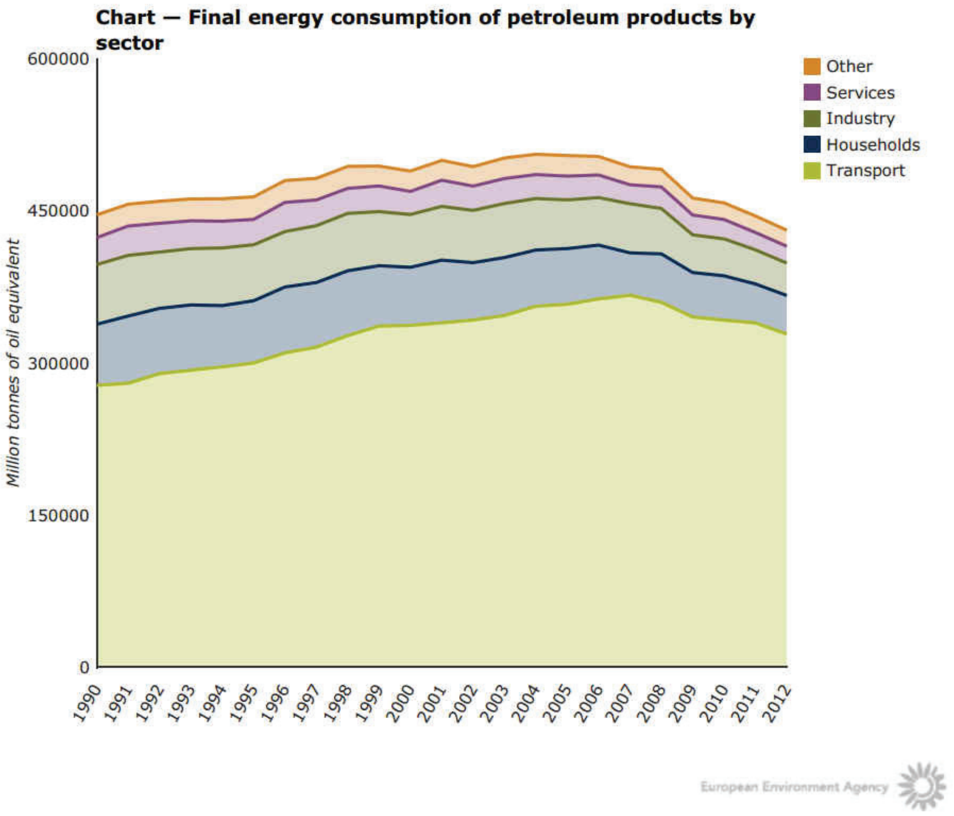

Fig. 7. Final energy consumption of petroleum products in EU28 by sector in the years 1990–2012[5]

One positive trend is the drop in the consumption of solid fuel, which has been steadily decreasing for the last two decades (Figure 8). This trend is especially positive because solid fuel is associated with severe negative externalities. As stated earlier, this metric does not cover the complete amount of solid fuel, a very large share of which is used for electricity generation.

5 The latest report from 2015 includes data until 2012.

The share of solid fuel directly consumed by market players represents only a relatively small share of the total energy mix (Figure 9). While its direct consumption in industry and households has been decreasing since 1990, an increased demand for other energy sources overcompensated for it until 2005.

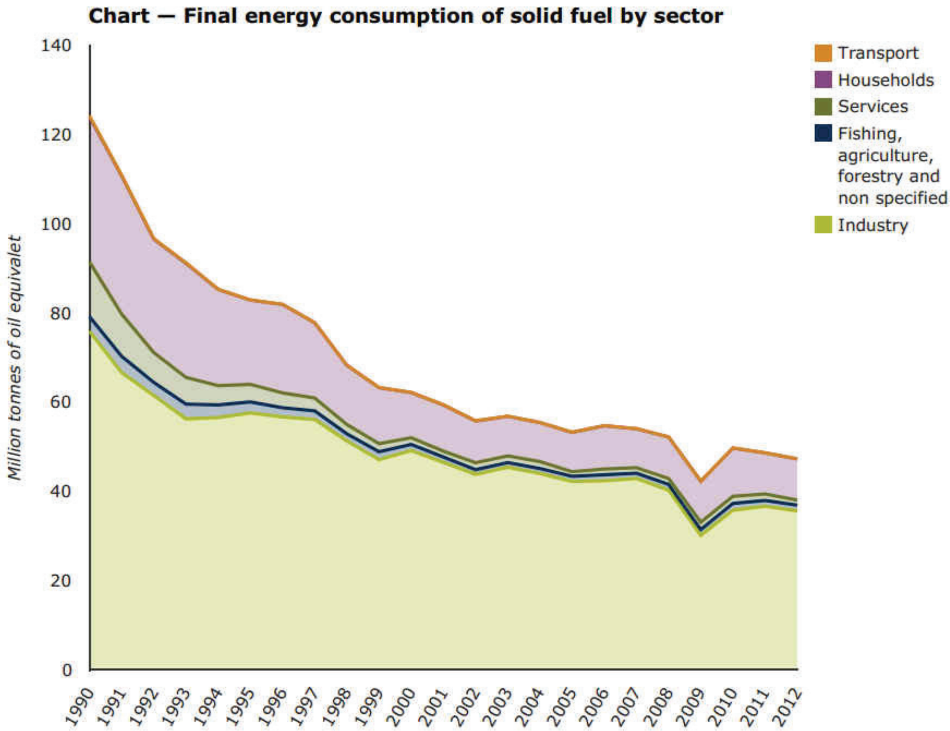

Fig. 8. Final energy consumption of solid fuel in EU28 by sector in the years 1990–2012[6]

The datasets on the structure of final energy consumption discussed so far in this section illustrates its structure at the EU level; however, we are also interested in examining its structure at the national level.

To do so, we have selected three countries: Poland, Germany, and Romania. Poland and Germany have similar climate parameters, and their economies are large enough to avoid the high volatilities possible for very small economies, in which the operation of a single large facility can strongly influence the statistics at the national level. Romania is an interesting example because it is a country with a medium-sized population and has a very low consumption of energy *per capita*, compared with other EU states (Table 3).

The data on energy spending in the selected countries (Figure 10, Figure 11, Figure 12) show a similar distribution across sectors. The notions of *tertiary sector*

[6] The latest report from 2015 includes data until 2012.

and *service sector* are used as synonyms. Household consumption and transport-related consumption have the largest share in each of these economies. The fact that energy consumption *per capita* in Germany is more than two times higher than that in Romania is not caused by energy expenditures in the industrial sector. A similar distribution can be observed in other EU countries. Private consumption based on higher consumption power, not on industry, in Western and Northern Europe is the main reason for higher energy spending.

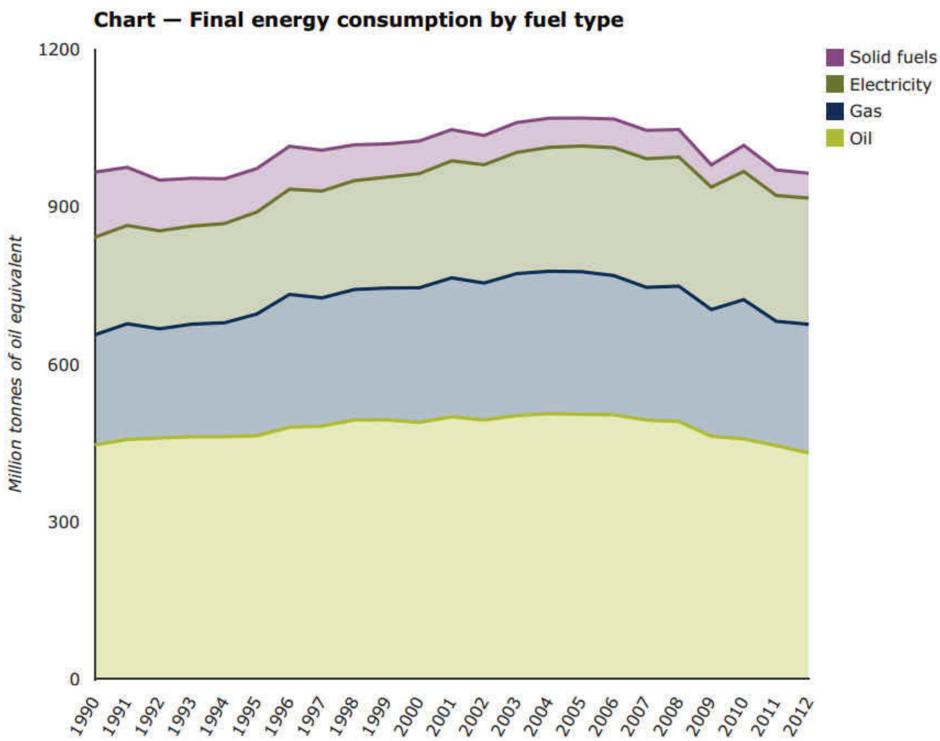

Fig. 9. Final energy consumption by type in EU28 by sector in the years 1990–2012[7]

This observation confirms our finding from the previous section that energy intensity, which is used as the main indicator of energy efficiency in the EU, does not appear to be an appropriate vehicle for comparing the energy efficiency of countries with respect to climate change mitigation.

[7] The latest report from 2015 includes time numbers until 2012.

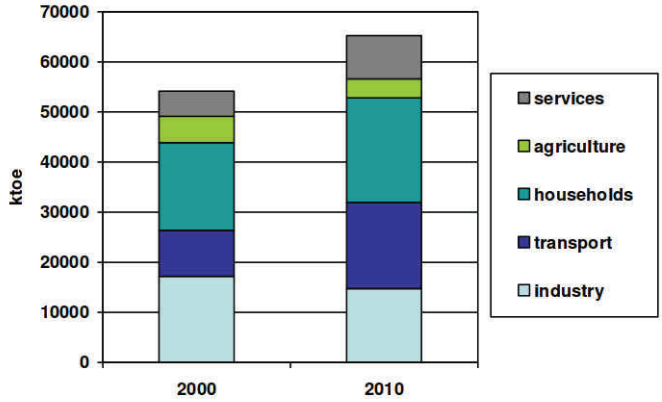

Fig. 10. Final energy consumption by sector in Poland in 2000 and 2010
Source: (Central Statistic Office 2012: 7).[8]

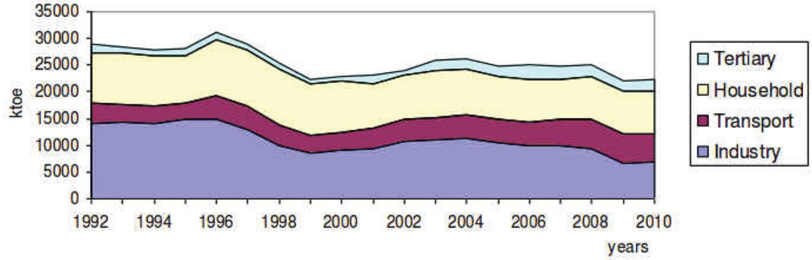

Fig. 11. Final energy consumption by sector in Romania in the years 1992–2010[9]
Source: (Energy Research… 2012: 11)

8 This time period is selected to guarantee consistency. Not all required information for recent years for the selected countries is available.

9 This time period is selected to guarantee consistency. Not all required information for recent years for the selected countries is available.

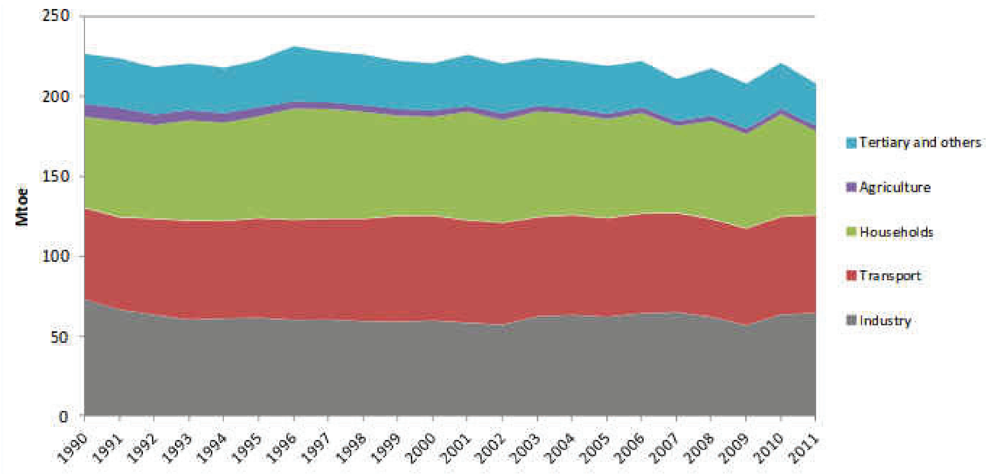

Fig. 12. Final energy consumption by sector in Germany in the years 1990–2011[10]
Source: (Eichhammer 2012: 9).

5. International trade and energy efficiency

Regional specifics such as transit traffic and tanking tourism can have a very large impact on energy consumption statistics, especially for smaller economies. There is evidence that such factors play a very important role for countries such as Luxembourg, resulting in very large petroleum product consumption (Fraunhofer ISI 2012: 5). Fuel price differences, geographic location, transport infrastructure, and traffic intensity are factors that can trigger this phenomenon. Depending on the size of the economy and the intensity of traffic, the bias can be significant. Differentiating between domestic consumption and tanking tourism can be difficult without dedicated studies. In the case of Luxembourg, 70% of energy demand is accounted for by transport, and this share is rapidly increasing (Figure 13).

Analyzing the flow of energy-intensive products with respect to international trade is also important. Some countries have a higher share of energy-intensive production in their economies. Extraction of raw materials, agriculture, or the production of metal or other specific products can consume much energy and simultaneously have a moderate price in the international market. A dominant share of the added value is attributable to high-technology or know-how-dominated activities, such as design and marketing, with low energy costs. Wealthier countries tend to have a higher share of high-technology products, income from intellectual properties, and financial services in their economies.

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10 This time period is selected to guarantee consistency. Not all required information for recent years for the selected countries is available.

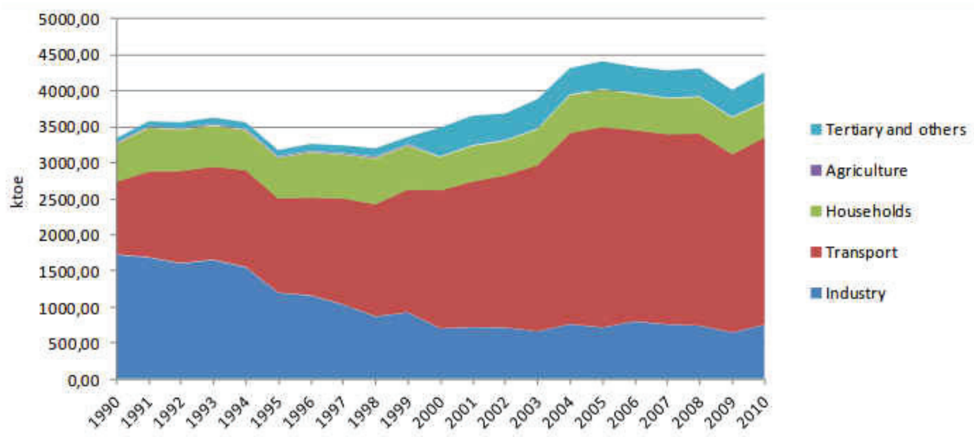

Fig. 13. Final energy consumption by sector in Luxembourg in the years 1990–2010[11]
Source: (Fraunhofer ISI 2012: 6).

We can consider the example of the production of a device designed and marketed by company A in Europe, produced by sub-contractor B in China, and sold primarily in the European and US markets. Assume that the whole physical production cycle takes place in China, including raw materials and the production of assembly parts. The largest share of profit flows to the company that has designed and is selling the product. According to the methodology used by Eurostat or the World Bank, China would be responsible for all energy costs associated with the physical production of the product. The energy efficiency of the European country where company A is situated would be improved because the profit would flow into the GDP of this country, whereas the energy costs for design would be minimal compared with the production costs. Most importantly, the countries in Europe and the USA where the end-consumers of the product are based are not "punished" by reduced efficiency because the production takes place abroad.

Using energy intensity shifts the responsibility for energy spending for goods toward producing countries, not consuming countries. The citizens of a country with an economy focused on financial or information technology services may consume many energy-intensive products that are imported and not accounted for in the energy balance of the country.

Consumption and production should be distinguished when assessing energy efficiency. Consumers should carry the energy costs of the products they purchase. International flows of energy-intensive products and services should be acknowledged and considered.

[11] This time period is selected to guarantee consistency. Not all required information for recent years for the selected countries is available.

6. Problems in measuring energy efficiency using an adjustment to the GDP

Improvements in energy efficiency and energy conservation are a crucial aspect of sustainable development. Our analysis leads us to the conclusion that the main energy efficiency indicators used today by the EU, the World Bank, and multiple other national and international institutions are inadequate and counterproductive. As the indicators are often used for calibrating energy strategies, deficits in energy policies result.

The main implication of using the indicator discussed in this article as the principal indicator for energy efficiency is that it has been incorporated in major energy reports issued at the national level, and its improvement has been targeted by decision makers. Energy efficiency is estimated as the ratio of the amount of energy spent per unit of the GDP. This ratio is relevant for the stability of an economy in cases of price volatilities of energy. However, it is counterproductive and deceptive for tracking energy efficiency with respect to sustainable development because of the following reasons:

- Countries with high GDPs are green labeled as sustainable regardless of their very high consumption of energy *per capita*, which is largely based on private consumption rather than production.
- All emerging economies striving to increase their energy efficiency are motivated to maximize their GDP rather than to keep their consumption moderate.
- The fact that the indicator is adjusted to the GDP, which is increasing exponentially in the long term, leads to an exponential increase in efficiency as a result of GDP growth, even with a stable level of energy consumption.
- The indicator encourages outsourcing of responsibility. It sanctions countries producing and exporting energy-intensive goods and services, and frees importers of energy-intensive products from responsibility.

Indeed, we can observe that emerging economies, such as China and India, have experienced a considerable increase in energy spending *per capita* while improving their official energy efficiency (Figure 14).

The increase in energy consumption is especially large in the case of China (Figure 14). While developing countries are the source of increased global energy consumption, considering them as the only ones responsible for subsequent problems would be wrong. Furthermore, they are following a path established by high-GDP countries, and energy efficiency indicators are among the beacons guiding them along this path.

The energy intensity of an economy is useful as an indicator relevant to the energy balance of a country and the dependency of its economy on volatilities in energy prices. Its properties do not justify being used as the main indicator to measure energy efficiency in support of sustainable development.

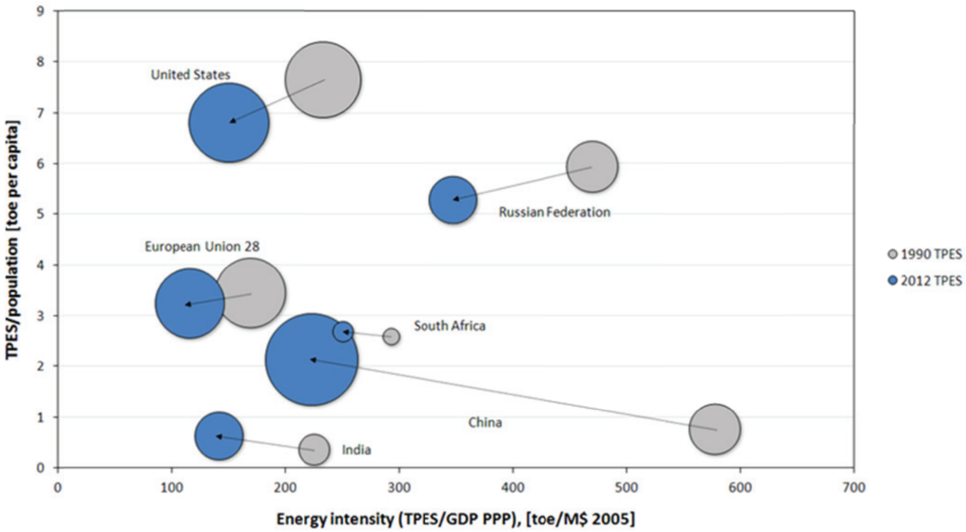

Fig. 14. Energy intensity and energy consumption *per capita* for selected countries in the years 1990–2012[12]
Source: (International Energy Agency n.d.).

7. An alternative – real energy efficiency

In this section we consider Real Energy Efficiency (REE) – an alternative to the GDP-based measurement of efficiencies. REE is an algorithm for evaluation of the energy efficiency of whole economies, individual companies, and economic sectors, proposed in "Economic Aspects of Energy Policies Supporting Sustainable Development" (Koralov 2017: 94–117). In the next paragraphs we will briefly outline the main characteristics of the approach and reasons why it has multiple advantages for supporting decision making and policy making processes.

REE is based on physical values and avoids the deficits of GDP-based calculations. It also offers numerous advantages compared to "Economy-wide Energy Intensity Index" (EEII) and "Total-factor energy efficiency" (TFEE). In addition to calculating energy efficiencies, it delivers valuable additional results, such as the aggregated energy consumption of an entity or a branch, which can support the identification of areas with high potential for energy conservation (Figure 15).

12 This time period is selected to guarantee consistency. Not all required information for recent years for the selected countries is available.

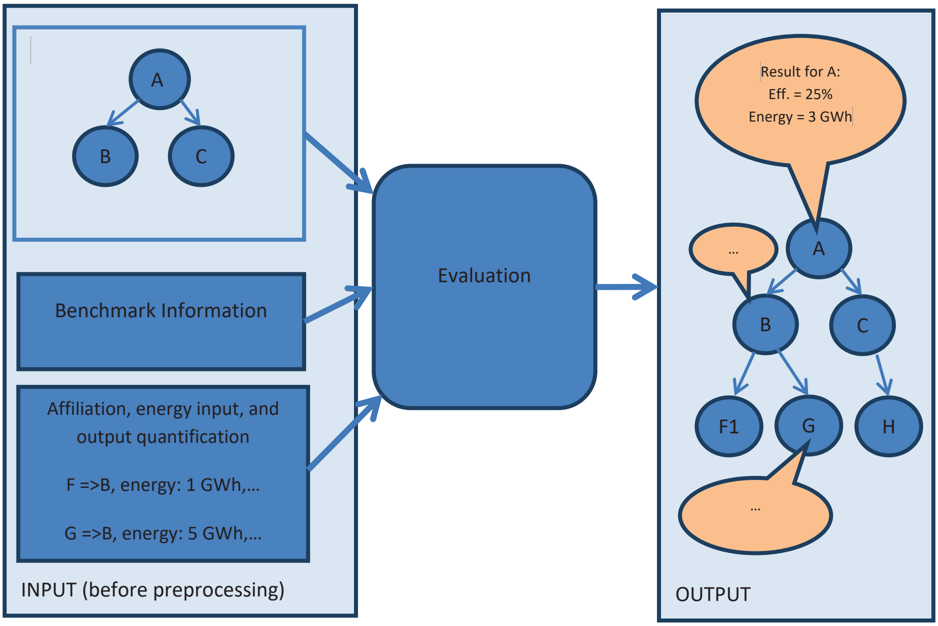

Fig. 15. Algorithm overview—inputs and outputs (General Form)
Source: (Kolarov 2017: 100).

REE algorithm describes a process for the hierarchical evaluation of energy efficiencies. It is based on the energy required to produce products and services.

The approach has the following multiple advantages:

- Energy efficiency is calculated as the efficiency of covering a concrete demand with a given amount of energy. It is not dependent on the GDP or other monetary evaluations.
- The focus is on the environmental impacts of an activity. Physical parameters, rather than financial ones, are considered. Energy spending is hierarchically organized.
- Energy benchmarks are defined for end units and incorporate sector-specific knowledge.
- Efficiencies are initially calculated for low-level units and are hierarchically aggregated in subsequent steps. The bottom-up aggregation of efficiencies is based on an energy-weighted calculation and is defined recursively for higher levels.
- The process is extensible to optimally support policy and decision-making processes.
- In addition to offering an adequate measure for energy efficiency, it calculates a set of additional outputs that support energy conservation.

The Real Energy Efficiency Algorithm (REEA) and the "Economy-wide Energy Intensity Index" (EEII) by the US Energy Information Administration (US EIA)

(153), described in section Measuring Energy Efficiency, have multiple similarities (154):

- Both approaches consider the energy required for measuring a specific demand or function.
- Both approaches are based on hierarchical structuring.
- Both indicators are computed using bottom-up aggregation of the results.

However, there are important differences between the solutions:

- The EEII registers changes in energy efficiency between different time periods. At the component level, it evaluates the relationship of energy intensity for generating a unit of output (EERE n.d.). The REEA, on the other hand, evaluates efficiencies based on energy benchmarks. Thus, the primary output of the EEII is the relative change in energy efficiency over a period of time, while the REEA calculates the overall efficiency without the requirement of a reference to previous periods.
- Due to the aforementioned property, the REEA can be effectively used for identifying areas with low energy efficiency and triggering improvements by designing custom policies. The EEII registers changes only when they take place and does not give a quality indication of which sectors should be improved in the future.
- The EEII has a fixed, predefined hierarchical structure and is focused on the computation of an economy-wide index (EERE n.d.), (154). The REEA defines a general process that can be applied to multiple hierarchical structures.
- The REEA supports the evaluation of multiple custom hierarchies based on the same set of end units. This enables multiple ways of viewing an economy or a smaller subset of an economy from different perspectives. The EEII does not offer a similar possibility.
- The secondary outputs of the REEA, which are generated for each node of the graph structure, indicate the total amount of energy and the total output at the corresponding part of the hierarchy. They are especially valuable for backtracking areas where improvements in efficiency would have a maximal result in terms of total energy savings as well as giving important information about possible energy conservation due to changes in behavioral patterns.

The EEII is a valuable tool for tracking relative changes in the overall energy efficiency of an economy from a historical standpoint. It can give a good relative indication about the overall improvement or decline of the energy efficiency of an economy. The REE indicator is optimal for supporting forward thinking: the identification of areas that allow maximal energy saving both in relative and absolute terms. It delivers a set of outputs that can support both improvements in energy efficiency and energy conservation.

REE differs significantly from Total-factor energy efficiency (TFEE), described in section Measuring Energy Efficiency:

- TFEE is partly based on economic values such as GDP or capital stock, while REE focuses on physical energy spending and process efficiency.
- Both methods compare the actual energy consumption with reference energy consumption level. However, TFEE considers the reference to be the efficiency

frontier calculated with data envelopment analysis of the decision making units, while REE relies on low-level reference benchmarks and bottom-up aggregation of the energy efficiencies and secondary outputs.

- If TFEE is computed for a set of countries or regions, the results will indicate relative differences between their top level efficiencies. However, it will not identify inefficiencies which are common for all of them.
- REE delivers a complete data structure including relative efficiencies and absolute consumption values for all substructures including sectors of the economy, production processes, and consumption patterns. It supports the decision maker in identifying concrete sectors or processes which can be improved and indicates the possible total gains from their relative implement.
- REE offer multidimensional picture of the energy spending and energy efficiency of an economy or low-level structure. It can also be extended for aggregation of multiple additional outputs including material expenditure and chemical pollution.

The Real Energy Efficiency represents a valuable tool for policy making and the optimization of energy consumption. It is a tool that can be used for the improvement of both energy efficiency and energy conservation since it delivers a set of additional outputs, such as a hierarchical structure of aggregated energy outputs. The proposed method also supports the creation of multiple views of an economy in order to gain additional knowledge about the structure of energy consumption. The REE can be especially valuable for decision making and calibrating of policies at the national and regional levels because it enables fine-tuned custom views of different economic segments.

The GDP-based major indicators for energy efficiency used currently by many major institutions deliver a distorted view on the energy efficiency. They are inadequate and counterproductive in the context of sustainable development. Indicators based on physical values such as the Real Energy Efficiency have significantly better properties for supporting policy making and decision making.

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To cite the article:
Kolarov Y. (2016) Inadequacy of energy efficiency measurements based on GDP. *Studia Regionalia* 48: 25–52. doi: 10.12657/studreg-48-02