ENERGY EFFICIENCY AND THE GROSS DOMESTIC PRODUCT

by

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Improving energy efficiency can be powerful tool for achieving sustainable economic development and most important for reducing energy consumption and environmental pollution on national level. Unfortunately, energy efficiency is difficult to conceptualize and there is no single commonly accepted definition. Because of that, measurement of achieved energy efficiency and its impact on national or regional economy is very complicated. Gross domestic product is often used to assess financial effects of applied energy efficiency measures at the national and regional levels. The growth in energy consumption per capita leads to a similar growth in gross domestic product, but it is desirable to provide for the fall of these values. The paper analyzes some standard indicators and the analysis has been applied to a very large sample ensuring reliability for conclusion purposes. National parameters for 128 countries in the world in 2007 were analyzed. In addition to that, parameters were analyzed in the last years for global regions and Serbia.

Key words: *energy efficiency, energy consumption, gross domestic product*

Introduction

In the seventies of the last century, there was abrupt rise of energy raw materials prices and short stagnation in the volume of their use but some dozen years later, the prices became relatively stable again and the growing trends of consumption continued all over again. Ever since, these events have been causing war turmoil because energy requirements of the most developed and military the most powerful countries are very high and, as a rule, the deposits are outside their territories in underdeveloped and military weak countries. There is fairly accurate correlation between overall economic progress of a country and its energy consumption growth.

Growth related economic indicators are true "driving force" for special care of energy. It can be said with certainty that the energy sector of a country occupied between 10 and 20% of the national product before the oil prices rise (which was reflected in the growth of prices for other energy carriers) in the seventies of the last century. Nowadays, this is probably between 25 and 50%. The extent to which certain country is developed and has (by laws, norms, technical standards ...) regulated economy affects financial proportion of energy in the national income.

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There are no doubts that the introduction of energy efficiency measures should slow down this growth. Energy price in the last few decades has substantially grown in both relative and absolute sense. Almost all countries in the world design measures in the area of energy efficiency as well as in order to reduce the share of energy in the gross domestic product (GDP).

In the most recent literature dealing with energy economics, it is discussed more and more about the relation between economic growth and energy consumption [1-6]. International Energy Agency (IEA) has been gathering and statistically processing data which affect energy sector at the national level. The Agency has energy data for numerous countries at the annual level. The IEA synthesizes gathered data into following indicators: TPES/population (toe/capita), TPES/GDP, TPES/GDP(ppp), EE consumption/population, CO_2/TPES, CO_2/population, and CO_2/GDP. This database has been used for analyses and calculations in this paper.

The paper [1] deals with relations between energy and GDP and analyzes integration, co-integration and causality of the relationship between energy output and consumption by comparing data of six countries included in the Gulf Co-operation Council (GCC). The obtained results are slightly in favor of the hypothesis: since oil exporters enjoy cheap energy resources then, energy consumption is the source of GDP growth in these countries. Empirical results obtained in this paper can be, thus, compared with some other groups of countries or with single countries. Among other things, this hypothesis has also been proved in this paper but on a much larger sample .

Very comprehensive study [2, 7, 8] defines all types of energy indicators and elaborates basic methods for their decomposition and analysis. The aim of the research work is to investigate issues related to development, utilization and interpretation of energy indicators. The discussion concerns the importance of energy indicators as a tool for the development of energy policy.

In the last three decades, energy indicators and related environmental indicators have growingly become more numerous and more complex enabling more reliable information to policymakers to address national and global energy, environmental, and resource depletion problems. The analysis of available indicators and their overview is provided in [9-12].

Energy efficiency is lower in the countries of Western Balkans than in developed countries. This can be proved by analyzing energy indicators. Papers [13-17] provide an overview of what has been done and accomplished in this field so far.

In addition to the significant growth of energy costs, which set off the introduction of new technologies, the global warming caused by the combustion of fossil fuels has largely intensified works related to the measures for increasing energy efficiency. After the ratification of the Kyoto Protocol, the key element of the strategy for reducing Green house gasses (GHG) for the majority of countries is the increase of energy efficiency in all sectors.

There is no doubt that for the assessment of effects generated by energy efficiency measures at the national level the most important is energy intensity and it will be dealt with in more details in this paper. In addition to history, this paper will provide growths perspectives of primary energy supply and energy intensity not only for the world regions but also for the Serbia.

Energy indicators

Energy consumption is defined in various ways and used with the indicator of energy intensity. The problem occurs relevant to the choice of measuring energy quantities since they differ depending on special requirements of the study and analysis or depend on the politics and expectations. Types of energy consumption generally involve the end use, useful energy, final energy, purchased energy (the most easily measured and most often used), net available energy and primary energy demand needed to provide final energy expressed for every sector. The basic factor which affects the source of energy consumption classification refers to available data, complexity of measurement, as well as measurement of potentials for reducing CO_2 emissions, level of data breakdown.

Since unmistakable quantification of energy efficiency measurement does not exist, there is a trend of relying on energy indicators which are typically composed of quantified indices with an aim to express energy efficiency approximately. According to the synthesis of this idea [8], there are three resulting types of energy indicators which can be used for monitoring energy efficiency such as: thermo-dynamical, physical, and economical.

When we talk about the concept of energy efficiency, we must say that although this is a very simple concept, it is very complex for measurement in particular on the large scale as in the case of a whole country. Since there is no unique measurement of the contribution of energy devices to the country's economy, there is also no way of measuring their overall efficiency.

In the absence of adequate ways for measuring energy efficiency trends, as we have already mentioned in the previous sections, the gross domestic product is used as the basis.

Indicators of energy efficiency provide the connection between the consumption of energy and certain relevant economic and physical indicators. They can be defined at various levels of aggregation in respect of energy requirements (energy-wide, sector, sub-sector, end users, technology, process, or particular equipment).

Economic energy indicators are often used when energy efficiency is measured at higher level of aggregation, for example, at the national level, because it is not possible to make the analysis otherwise. Economic indicators provide relations between energy consumption expressed in the energy unit of economic activities expressed in monetary units. Nevertheless, numerous examples have shown and this paper also, that energy intensity should not be observed separately from other energy and economic parameters.

In this paper, the technical concept of energy efficiency is used:

– *Energy efficiency* is the ratio between the useful output of energy conversion machine and energy input. The useful output may be electric power, mechanical work, or heat. Energy conversion efficiency is not defined uniquely but instead, it depends on the usefulness of output. All or part of the heat produced from burning fuel may become rejected waste heat if, for example, work is the desired output from the thermodynamic cycle. Using this concept energy efficiency is:

$$\eta \quad \frac{P_{\mathrm{out}}}{P_{\mathrm{in}}} \tag{1}$$

where P_{out} is the energy output and P_{in} the energy input.

When this technical definition is applied to national or regional levels, it implies total primary energy supply (TPES) as P_{in} and total final energy consumption (TFC).

Now, primary and final energy should be defined.

– *Primary energy* is energy that has not been subjected to any conversion or transformation process. Thus, primary energy does not include electricity or refined petroleum products.
– *Final energy* are forms and fuels as sold to or as used by final consumers (households, industries, commercial buildings, transport, *etc.*) or, simpler, energy supplied that is

available to the consumer to be converted into useful energy (*e. g.*, electricity at the wall outlet).

Final energy forms and fuels are generated involving various steps of conversion from primary energy to final.

The TFC is often found in national statistics for economic sectors, for example, industry, transport, and other sectors. Other sectors assumes: residential, commercial and public services, agriculture and forestry, fishing, and non-specified, and as a special item, there is non-energy use. Since primary energy supply is always an integral part of such national statistics, it is possible to define one indicator of energy efficiency by the relation between TFC and TPES. But, energy efficiency defined in this manner does not take into account energy transformation of final energy into useful service which is the original reason for the use of energy. This means, we have delivered *final* energy to a certain factory, the factory has paid for this energy, used it in the production and made certain products and delivered them to the market. The energy efficiency in the use of delivered final energy is contained only in the price of the product. Unfortunately, this can only be indirectly expressed through the energy efficiency effect of the factory itself.

National energy efficiency measurements and monitoring have become important components of energy strategy in many countries, especially energy deficient ones. With substantial increases oil prices in the world, many countries have recognized the need to understand whether energy is consumed effectively in their economies and to increase energy efficiency. To serve these purposes, appropriate energy efficiency indicators have been developed and applied so that any efficiency changes that have taken place can be quantitatively expressed. These indicators are also used in cross-country comparisons to explain differences in energy performance between countries and for international benchmarking. We have already defined one of such indicators as the relation between TFC and TPES. But, there are many mutually independent factors affecting energy efficiency at national or regional levels and, it is not possible to assess energy efficiency correctly only on the basis of one indicator.

When energy efficiency at the national or regional level is concerned, energy intensity indicator is frequently used. This indicator is based on the GDP, which should be defined:

– GDP is the total value of goods and services produced by the nation's economy before deduction of depreciation charges and other allowances for capital consumption, labor, and property located in the country. It includes the total output of goods and services by private consumers and government, gross private domestic capital investment, and net foreign trade.

The World Bank has recommended the methodology which should be used in all countries. Unfortunately, very often, due to political reasons, there are some deviations in methodologies for the calculation of GDP in some countries which later cause confusion when this indicator is used in practice.

Energy intensity connects energy efficiency and some other economic indicator. It can generally be defined as the ratio between energy consumption and the measure of demand for services (number of buildings, total floor space, number of employees, or value of GDP for services, *etc*.). For the purpose of this paper, the energy intensity will imply the ratio between consumed energy and relevant GDP. It is assumed that PRIMARY ENERGY is used in the creation of the GDP. Why primary energy? It is because this is the only way in which the GDP is consistently associated with energy consumed for its creation. For the purpose of more realistic evaluation of national economies, this paper uses GDP in dollars for estimates derived from purchasing power parity calculations of GDP (ppp).

Energy indicators for 128 countries

Only data from 2007 will be analyzed as the most recent ones are not available. However, *ad hoc* checks have shown that in the last decade relative relations of data for some countries were very stable.

Figure 1 shows dependency of energy intensity from GDP(ppp) per capita for 128 countries in the world. Such a large sample covers around 95% of the world's population. All countries form the sample are grouped into those which import or export energy. There are 43 exporting countries and 85 importing ones. Some 25% of population on the planet lives in energy exporting countries. The GDP(ppp) span per capita is enormous and moves from 657 (Democratic Republic of the Congo) up to 65000 (Luxemburg). The span of energy intensity varies form 0.0563 (Hong Kong) to 1.1602 (Iraq).

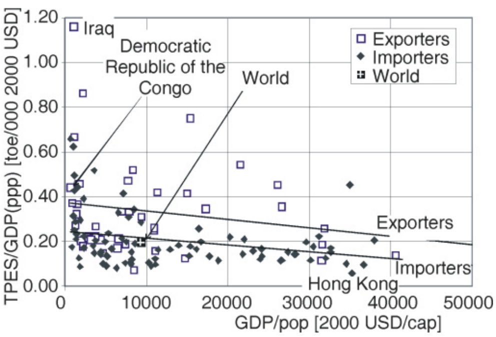

Figure 1. Energy intensity *vs.* GDP per population for 128 countries

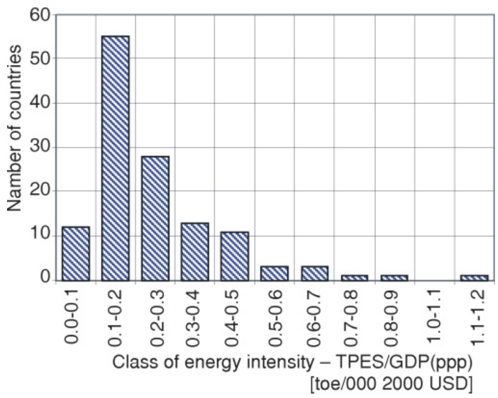

Figure 2. Number of countries distribution *vs.* class of energy intensity

Figure 2 shows classes of energy intensity and the number of countries in certain classes. There are few countries with exceptionally high energy intensity (Bahrain, Iraq, Jamaica, Kazakhstan, Nigeria, Tanzania, Trinidad and Tobago, Uzbekistan, and Zimbabwe). They are all energy exporting and three of them (Jamaica, Tanzania, and Zimbabwe) have low GDP per capita.

It should be emphasized that higher GDP(ppp) per capita is obvious for the same energy intensity in energy exporting countries than in energy importing ones. The strength of the energy sector is evident.

Figure 3 presents distributions of the number of countries in the world *vs*. GDP(ppp) per capita. Unfortunately, dominant are countries with low GDP(ppp) per capita. Both distributions significantly diverge from normal Gaussian distribution which best describes great majority of occurrences in nature. Presented distributions correspond well to the Weibull

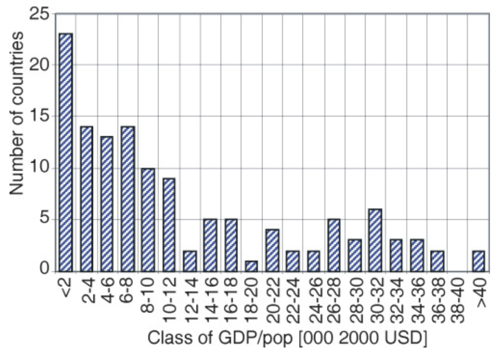

Figure 3. Number of countries distribution *vs.* class of energy intensity

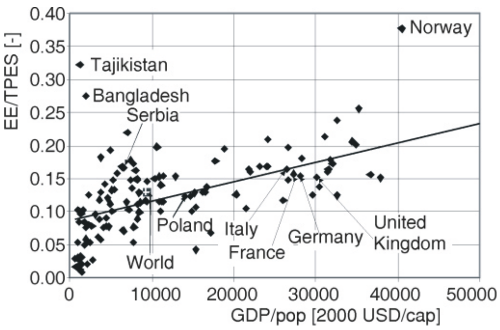

Figure 4. Ratio of electrical energy consumption and TPES *vs.* GDP per capita

distribution. In this paper, we are not going to go beyond these statements connected to mention distributions and explanation of the distribution forms touches historic, social, cultural, climatic, and many other factors.

One indicator which is not often used is shown in fig. 4. This is the relation between electricity consumption against total primary energy supply. Unequivocally, it can be concluded from the figure that countries with higher GDP per capita use much more electricity than those with low GDP. The exceptions are Tajikistan and Bangladesh. The former generates almost all electrical energy from enormous available hydro potential and the latter uses own resources of natural gas for generating electricity. It is typical for both countries that they import part of the energy and economic activities there are at a very low level. Unfortunately, there are many counties in which the proportion of electricity consumption in total TPES is very small and they also have low GDP per capita. Those are poor countries with respect to all possible criteria. Norway (fig. 4) stands on the other end since the portion of electricity in the total primary energy supply is as much as 0.38, and the GDP per capita is one of the highest in the world. The explanation lies in enormous production of electricity from hydro energy, and Norway is also energy exporter. Five developed European countries (UK, Germany, France, Italy, and Poland) which have advanced electric energy systems but use different fuels for running them (France mostly uses nuclear power, Poland coal, Italy natural gas and coal, UK coal, natural gas, and nuclear power, and Germany coal and nuclear power), show very constant relation between indicators EE/TPES and GDP per capita. This also indicates without any doubts approximately the same level of energy efficiency in these countries. At the same time, this relation in Serbia is much higher which can be attributed to the lower level of energy efficiency. In Serbia, electricity is mostly generated from coal and hydro power.

The fig. 5 shows the relation between TFC and TPES *vs*. GDP per capita. This is the indicator of energy transformation efficiency at the national (or regional) level which involves all possible transformations up to final energy supply. Non-energy use of final energy is exempt from the analysis. It is immediately noticeable that there is high scatter around trend line. The world average is 62.5%. Extremes refer to Nepal, Ethiopia, Trinidad and Tobago, and Singapore. Explanation can be found in energy systems of these countries. When Nepal is concerned, it should be said that relatively small production of electricity is achieved only from hydro power and other primary energy is directly used as final without any transformations. Similar situation is in Ethiopia where around 90% of electricity is produced from hydro power, and the rest from petroleum products. Trinidad and Tobago generate only 37% of electricity by using natural gas and the rest is

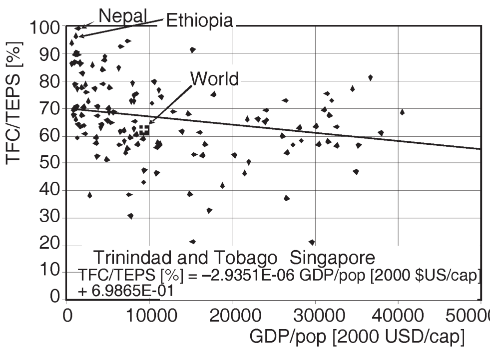

Figure 5. TFC/TPES *vs.* GDP per capita

imported electricity. As far as Singapore is concerned, it uses around 70% of own electrical energy produced from natural gas and petroleum products and the rest is imported. However, there is also huge export of petroleum products. This means that in Singapore as well, there is large consumption of primary energy and that part of products is exported and in case of Trinidad and Tobago, there is small consumption of primary energy and relatively high import of electrical energy.

These analyses explicitly point out to large dependence of national or regional energy system structure on basic energy indicators.

History of energy intensity

Figure 6 shows TPES in million tons of oil equivalent [mtoe] for seven regions in the world, as well as for the whole world from 1980 to 2006.

The projection of TPES growth until 2030 is expected to decline from the initial 2.4% in 2009 to 1.3% in 2030 [4]. It is estimated that the population number will grow slightly slower (around 1%) whereas the GDP will grow at the rate of around 2.6% per annum [18].

It is particularly important to highlight that the energy intensity is expected to fall at the rate of around 0.8% per annum [18] and that final consumption of electrical energy is expected to grow by around 2.4%. In the same period (from 2010 to 2030), it is expected to have the fall of oil production from 1.44% at the beginning of the period to 0.81% at the end of the period and constant and substantial growth of coal production by around 2.2%. The highest growth is expected in the use of nuclear power from 0.51% in 2010 to 1.7% in 2030.

Figure 7 shows the history of energy intensity in regions of the world, for the whole world, and for Serbia.

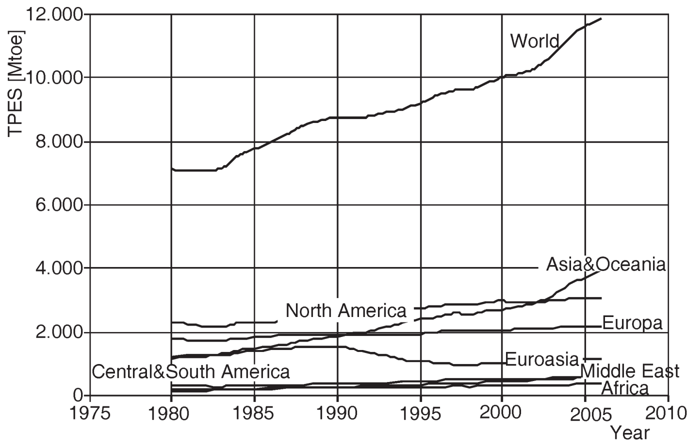

Figure 6. Total primary energy supply *vs.* time for the regions

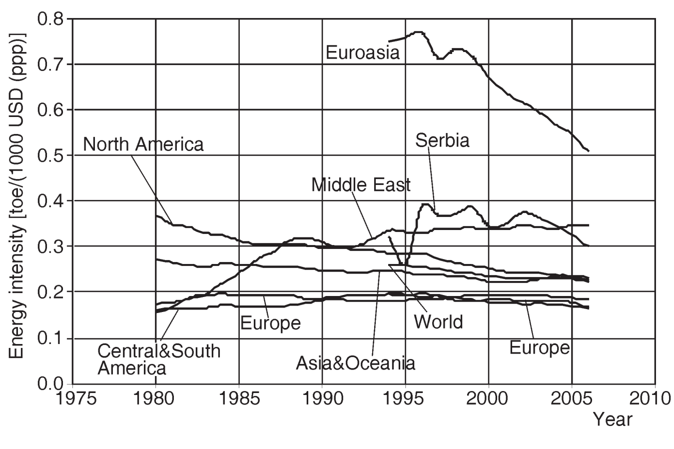

Figure 7. History of energy intensity for different regions

Discussion

The relation between overall primary energy consumption and the GDP, or energy – GDP ratio, is one of the most frequently used economic indicators for energy efficiency. This relation is the measure of the economy's energy intensity at the highest level of aggregation. Calculated at the annual level, energy-GDP ratio can show short term and long term trends. The decline of this ratio shows on the average reduced necessary energy for the generation of national output units. This comparison can provide satisfactory results only if single indicators are carefully determined in the same way. Therefore, we have precisely defined terms such as TPES, GDP, *etc*., at the beginning of the paper. Also, for all our analyses, we have used the same sources which are more or less relied on International Energy Agency.

The assessment of the saving policy effects on the economic development is made by testing the direction of this causal relation between the two variables. This relation is the topic of numerous disputes. The direction of causality is very important because it reveals the credibility of the energy saving policy and achievement of conservation goals in the economy without substantially impeding its growth.

The elusive causative connection between the energy consumption and the GDP makes it difficult to create adequate energy saving policy. Empirical investigations of the relationship between energy and GDP have given mixed results of analyses in oil importing countries. This has raised questions regarding effects which occur due to the application of the energy saving policy on the economic development not only in developed countries but in developing countries as well. It is believed that this difference has occurred as a consequence of various methodologies and origins of data. Therefore, the agreement on the causality between the energy consumption and the GDP has failed [1].

Several separated measures for energy consumption per the GDP unit in the analysis enable deeper revealing of effects on the change of economic structure and behavior as well as better assessment of basic trends associated with movements and development of energy efficiency. It is crucial for the characteristics of energy indicators that every parameter is grouped around specific sector, *i. e*., user.

Some authors have supposed that there is direct connection between energy consumption and the GDP and they have further proceeded with estimating their values by means of various methods [19, 20]. Other authors have used various methods for estimates in order to study both the direction and the amount of this sub-relation [8].

Methodologically, empirical conclusions related to the nature of the relation between energy consumption and the GDP have shown that they change depending on econometric method used and on the way in which data have been collected. Standard tests based on causality techniques have been widely used. However, such methods are criticized as yielding inconsistent results. Instead, co-integration and error-correction models are being increasingly applied [1].

Indicators which reflect changes in energy intensity have been used for the last ten years to follow the progress of efficiency and to identify opportunities for improving this efficiency. Governments make documents routinely in order to present these trends and make comparisons with energy intensity in various countries and do not take into account specificities of these countries.

Trends of energy intensity indicators serve not only as a monitoring tool but also for the preparation of energy efficiency policy and regulations aimed at accomplishing higher energy savings. Although maintenance of economic development is the main objective of all governments, the focus of politics has been slightly changed and oriented towards benefits which concern joint improvements of the environment and better utilization of energy and not as much economic benefits created by energy savings.

In other words, policy-makers are becoming increasingly concerned with the physical rather than with economic repercussions of energy use [2].

However, there are issues which concern interpretation of trends described by energy indicators as different trends appear in case of physical and in case of economic energy indicators.

Conclusions

The research about causality between energy consumption and GDP in developed countries is of a more recent date. By employing different methodologies, many authors have come to opposite results when the question concerns effects that can be accomplished in the countries in transition. The investigation results in developed countries are not much more convincing than results obtained in the transition economies.

This paper has addressed the need to analyze energy intensity concurrently with other indicators of energy and economy. In the contrary, very unreliable conclusions can be made. Also, it is necessary to use only verified data obtained by means of well-known methodologies. Such analysis can be very useful to the energy policy makers.

Serbia is a candidate for becoming an EU member in the future and preparation for this integration requires stabile economy. In that respect, it will be necessary to analyze the energy situation in Serbia in correlation with economic indicators.

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Nomenclature

GDP – gross domestic product, [USD]
GDP(ppp) – GDP dollar estimates derived from purchasing power parity (ppp) calculations; purchasing powe parity (ppp) is a theory of long-term equilibrium exchange rates based on relative price levels of two countries, [USD]
TPES – total primary energy supply (indigenous production + imports – exports – international marine bunkers ± stock changes), [ktoe]
TFC – total final consumption, [ktoe]

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