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ECONOMIC EFFICIENCY, ENERGY CONSUMPTION AND SUSTAINABLE DEVELOPMENT

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Abstract. This paper analyzes structural indicators of economic efficiency and energy intensity consumption as determinants of sustainable economic development for the selected 33 European countries. The correlation, regression and multivariate factor analyses are applied to test the associations between the selected structural variables of energy intensity consumption, economic efficiency, and the main driving forces behind these developments. Economic efficiency is positively associated with expenditures on research and development (R&D) and a greater technological intensity of exports, while at the same time the economic efficiency of R&D expenditures and technological intensity of exports reduce the energy intensity consumption of the economy. The results suggest that management strategies and policies directed towards R&D expenditures, human capital investments, and technologically intensive export oriented products are improving economic efficiency performance and contributing to energy saving sustainable economic development. The technological intensity of products reduces energy consumption, which is related to restructuring of energy intensive industries into more advanced and energy saving ones with higher value added per unit of product, but with lower energy consumption per unit of product.

Keywords: economic efficiency, energy consumption, research and development, technological intensity, sustainable development, Europe.

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1. Introduction

The issue of sustainable development and sustainability has been analyzed in theory and application from different perspectives (Pearce, Warford 1993; Dasgupta 2007; Tvaronavicius, Tvaronaviciene 2008; Sobotka, Rolak 2009). Zavadska and Antucheviciene (2006) defined a set of indicators in the multicriteria analysis for a rational redevelopment of derelict immovable property from the perspective of sustainable development that includes environmental, social and economic aspects of sustainability. Wegscheider and Sabolovic (2006) underlined the importance of a bio-based economy with non-food bio-based products. Kryk (2009) evaluated the implementation of the sustainable development concept and effectiveness of environmental protection policy during the economic transformation, European Union (EU) membership and globalization process of the Polish economy. Ighodaro (2010) found the existence of a long-run relationship between energy consumption and economic growth using the Johansen co-integration technique, but the causality depends on the variables used. Electricity consumption and gas utilization are found to determine economic growth, while economic growth determines domestic crude oil production. Chen (2009) investigated causalities between price competition, investment in clean production technologies in the presence of environmental concerns, and consumers' willingness to pay an extra premium for green eco-labelling products and systems in the market to reduce environmental impacts of consumption due to the environmental attributes of green products.

Economic efficiency, efficient energy consumption, and sustainable economic development are objectives which can be in a collision of different interests. The business interests of energy suppliers can be in a conflict with efficient energy consumption and with development of an alternative energy production and use, particularly from renewable sources of energy, which have impacts on the environment and competitiveness (Nordhaus 1994; Filbeck, Gorman 2004; Stern 2007; Wagner *et al.* 2007).

Burinskienė and Rudzkienė (2007) provide a literature review dealing with economic, ecological and social components of sustainable development with analysis focusing on the aggregated indicators on air pollution variation, income, energy consumption and selected social indicators of national residents. In the literature there exists a recognition of the need for environmental management and sustainable development (Roome 2001; Schaltegger, Synnestvedt 2002; Li *et al.* 2009), which is beyond the narrow boundaries of an enterprise (Sinding 2000), by considering the sustainable component in economic growth (Priemus 1994; Ginevičius *et al.* 2008). In this development process there are important positive effects from technological changes and the development of sustainable technologies (Weaver *et al.* 2000), strategies and management of economic-ecological sustainable development of industries with negative impacts on the environment and sustainable development (Frosch, Gallopoulos 1989).

Moreover, the implications of the global warming and climate change have become one of the most crucial and challenging questions for sustainable economic and environmental development. Due to this, these subject areas have become important for research and policy questions in different sciences (e.g. European Commission 2003, 2008; Eydeland, Wolyniec 2003). The economics and management of climate change (e.g. Nordhaus 1994; Stern 2007; Wagner *et al.* 2007) and sustainable economic development have become a constituent part of different documents, global, regional and national policy agendas. These subject areas of the global warming and climate change and their different implications are also causing changes in energy consumption, changing economic efficiency and sustainability, which motivated our research. We focus on the analysis of the causalities between the intensity in energy consumption and economic efficiency and their implications for long-term sustainable economic development.

The global warming and climate change have several implications for the economic developments with associated significant implications for energy demands, efficient supply and consumption of energy, and for sustainable economic development. Energy demand is increasing, which is determined by growth of incomes and by more extreme weather conditions (e.g. Papler, Bojnec 2007). With the global warming and climate changes, and changing economic structures of the developed and some emerging developing economies there are also changes in the seasonal consumption patterns of energy. In the continental northern hemisphere the consumption energy peak is no longer concentrated only on the colder winter season, but also on the hotter summer season.

One of the priorities of sustainable economic development is reduction of the impact of major economic activities on the environment. Burinskienė and Rudzkienė (2007) have explained the association between increase in the economic efficiency and decrease in the environmental impact. One of the key indicators that reveal economic efficiency is the amount of energy consumed for production. The previous studies confirmed the causality between energy consumption and changes in socio-economic structures (Berndt 1978; GiamPietro, Pimentel 1991; Beckerman 1992; Suri, Chapman 1998; Schategger, Synnestvedt 2002; Rutkauskas 2008). Hall *et al.* (1986) with cross-country analysis confirmed the strong correlation between the gross domestic product (GDP) and the fuel consumed. This correlation association could vary by different countries and by different periods. However, the significant positive association between energy consumption and economic growth has important implications for further development of the economy's efficiency and energy consumption in its close connection to problems of sustainable development (GiamPietro, Pimentel 1991; Spangenberg 2004; Blok 2005).

The object and goal of our research is the analyses of the causalities and relations between economic efficiency and energy intensity consumption in the 33 European countries: EU-27 countries[1], four European Free Trade Agreement (EFTA-4) countries (Iceland, Liechtenstein, Norway, and Switzerland), and two EU candidate countries (Croatia and Turkey). We analyze structural indicators of economic efficiency and energy intensity consumption as determinants of sustainable economic development. Restructuring and transformation of the economies from energy intensive industries towards more technologically advanced products and services might lead to higher value added per unit of product, thus higher labour productivity, and energy saving sectors with lower energy consumption per unit of output. This might improve economic performance and lead to higher technological intensity of products, but might at the same time reduce energy intensity consumption and also reduce negative environmental pressures as an important factor of sustainable economic development considering possible (non-renewable) resources needed for energy production and environmental implications.

[1] The EU-27 countries can be divided into three groups: (i) EU-15 (Austria, Belgium, Denmark, Germany, Greece, Finland, France, Ireland, Italy, Luxembourg, the Netherlands, Portugal, Spain, Sweden, and the United Kingdom); (ii) EU-25, which is defined as EU-15 plus the ten new member states from 2004 (Czech Republic, Cyprus, Estonia, Hungary, Latvia, Lithuania, Malta, Poland, Slovakia, and Slovenia), and (iii) EU-27, which is defined as EU-25 plus the two new member states from 2007 (Bulgaria and Romania). In further analyses we compare the old EU-15 countries and the new EU-12 countries, which jointly represent the enlarged EU-27 countries.

The method applied is the statistical multivariate analysis (Kachigan 1991; Hair *et al.* 1995). We test the hypothesis that economic efficiency and energy intensity consumption are associated with expenditures on research and development (R&D) and with the share of technologically intensive products in exports by underlying the importance of new challenges in investments in R&D resources and industrial experiences in energy consumption and economic efficiency. We analyze structural indicators of economic efficiency and energy intensity consumption as determinants of sustainable economic development for the selected 33 European countries. Economic efficiency and energy intensity consumption in the selected 33 European countries are investigated in order to establish associations between the level of economic efficiency on the one hand, and the expenditures on R&D and the share of technologically intensive products in exports on the other. With the cross-country correlation, regression and multivariate factor analyses, we identify signs and intensities of the associations of energy intensity consumption with the human capital and technologically intensive products in exports and the economic efficiency of investments in R&D, which provide important policy implications for economic efficiency, energy intensity consumption and sustainable economic development.

The paper is organized as follows. In the next, the second section, we present the methodology and data used. In the third section, the empirical results are presented and explained. The final, fourth section derives main conclusions in order to increase economic efficiency and to rationalize energy intensity consumption, which are important for sustainable long-term economic development.

2. Methodology and data used

Different methodological approaches have been used to investigate the relationship between economic efficiency, energy consumption and sustainable economic development. Ighodaro (2010) employed the Johansen co-integration technique and causality relationship between different proxies of energy consumption, government activities, monetary policy, and economic growth using time-series data for Nigeria. We apply correlation analysis, regression analysis and multivariate factor analysis (e.g. Kachigan 1991; Hair *et al.* 1995) on the 33 European cross-country datasets to test the sign and statistical significance of the associations between selected structural indicators' variables of energy intensity consumption and the economic efficiency, and the main driving forces behind these developments across the selected 33 European countries. Sustainable economic development considers both efficient economy and efficient energy consumption in order to assure the quality of life also for future generations.

Efficient economic development across the selected 33 European countries is measured by the labour productivity per person employed relative to the average for the EU-25 (LAB_P_E), where the EU-25 = 100. The energy intensity consumption of the economy (EN_INT) is defined as the gross inland consumption of energy divided by GDP at constant prices (1995 = 100) or as kilogram of oil equivalent (kgoe) per 1000 Euro.

The set of associations is tested by two hypotheses with two pertaining regression equations. Each of the regression equations is explained by two explanatory variables: (1) gross domestic expenditures on research and development activities (R&D) and (2) with the share of technologically intensive products in total exports (HTECH):

$$LAB\_P\_E = f(R\&D, HTECH) \quad (1)$$

and

$$EN\_INT = f(R\&D, HTECH). \quad (2)$$

From (1) and (2) we specify the following empirical cross-section regression models:

$$LAB\_P\_E = \alpha_0 + \alpha_1 R\&D + \alpha_2 HTECH + u \quad (3)$$

and

$$EN\_INT = \beta_0 + \beta_1 R\&D + \beta_2 HTECH + v. \quad (4)$$

where α_0 and β_0 are regression constants, α_1, α_2, β_1, and β_2 are regression coefficients pertaining to the explanatory variables, and u and v are the stochastic error terms. We expect positive associations of the LAB_P_E with the R&D and the HTECH, respectively, but negative associations between the EN_INT with the R&D and the HTECH, respectively.

In addition to correlation and regression analysis, we employ multivariate factor analysis to test the reliability of our regression results with a greater number of included explanatory variables. In the multivariate factor analysis, in addition to the LAB_P_E, EN_INT, R&D and HTECH variables, we include also the additional four explanatory variables: the GDP per capita in purchasing power parity (GDP_PPP), the emissions of CO_2 (GHGEMISS), the share of renewable sources of energy (RE_SH), and the number of graduates in the field of science and technology (H_ED). With the multivariate factor analysis we aim to identify a smaller number of common factors with the highest weights of variables inside them.

The data source for the selected 33 European cross-country analysis for the years 2003 and 2005 focusing on the factors of economic efficiency, efficiency in energy consumption, and determinants of sustainable economic development, is the Statistical Office of the European Communities (Eurostat 2006 and 2008).

3. Empirical results and findings

3.1. Summary statistics for the selected European countries

We first provide the summary statistics on the analyzed structural indicators' variables. Prior to interpreting the empirical results, it is worth mentioning that some missing data for some analyzed variables by the analyzed countries are found (e.g. in 2005 for Liechtenstein and Switzerland in the group of EFTA-4 countries) as a reason that the total number of observations (N) is not matched with the number of the analyzed selected 33 European countries. As can be seen from Tables from 1 to 6, the sample includes those

European countries which on average are somewhat less developed than the average for the EU-25 countries. Among the least developed countries outside the EU-25 are the candidate countries for EU membership, particularly Turkey. This finding is even more considerable and clearly confirmed in the case of labour productivity. Similarly, as in the case of GDP per capita and labour productivity, there is considerable variation across the analyzed 33 European countries for the gross domestic expenditure on R&D activities as percentage of GDP. This is confirmed by a large gap between the minimum and maximum values across the analyzed countries and by the standard deviation. The total number of graduates in science and technology per 1000 of population aged 20–29 years increased from 10 to 11.4 graduates, but again with considerable differential across the analyzed 33 European countries and over time. The index of greenhouse gas emissions on average for the analyzed 33 European countries increased over time, but remained below its level in the base year in 1990. As an important finding, the economic growth for the analyzed countries between 2003 and 2005 was achieved by the reduced energy intensity consumption in the analyzed 33 European economies. Moreover, the share of electricity from renewable sources energy to gross electricity consumption increased, which can be again considered as a positive outcome for sustainable economic development. Again, there are large variations across the analyzed 33 European countries, as a finding which has important policy implications by the countries and for regional European development, with implications for efficiency in energy intensity consumption and economic efficiency and sustainable economic development.

Due to large variations in the analyzed variables across the analyzed 33 European countries, we explain the descriptive summary statistics by the more homogeneous groups of the analyzed European countries to exclude possible outliers' biases. Tables from 2 to 4 present the results for the groups of EU countries (for old EU-15, new EU-12, and total EU-27 jointly for the old EU-15 and the new EU-12), while Tables 5 and 6 present similar results for the EFTA-4 countries, and for the candidate EU countries Croatia and Turkey in the years 2003 and 2005, respectively (Table 1).

As expected, GDP per capita, labour productivity, exports of high technology products as a share of total exports, the share of electricity from renewable energy to gross electricity consumption, and total number of tertiary graduates in science and technology per 1000 of population aged 20–29 increased in each of the EU groups of countries with considerable gaps between the higher level of the indicators for the old EU-15 countries than for the new EU-12 countries. Moreover, the energy intensity consumption of the economy has declined in both the old EU-15 and the new EU-12 countries, but the energy intensity of consumption in the old EU-15 countries is lower than in the new EU-12 countries. Mixed results are seen for the gross domestic expenditure for R&D activities as a percentage of GDP and the index of greenhouse gas emissions with declines in the old EU-15 countries, but increases in the new EU-12 countries. On average the index of greenhouse gas emissions is higher in the old EU-15 countries than in the new EU-12 countries, giving the latter an opportunity to be successful in sustainable economic development.

Table 1. Descriptive statistics of the analyzed structural indicators' variables for the selected 33 European countries in 2003 and 2005

	N	Minimum	Maximum	Mean	Std. Deviation
	2003				
GDP per capita (GDP_PPP)	32	26.50	233.90	90.36	44.08
labour productivity per person employed (LAB_P_E)	31	32.00	156.80	85.27	32.64
expenditure for research and development (R&D)	30	0.27	3.98	1.44	0.97
graduates in science and technology (H_ED)	31	3.10	24.20	9.99	5.36
exports of high technology products (HTECH)	30	1.80	55.50	12.35	11.71
greenhouse gas emissions (GHGEMISS)	31	33.80	152.80	94.51	30.04
energy intensity consumption (EN_INT)	31	128.19	1756.21	479.15	421.72
share of electricity from renewable energy (RE_SH)	31	0.00	99.90	19.80	24.64
	2005				
GDP per capita (GDP_PPP)	32	35.40	264.60	99.01	47.53
labour productivity per person employed (LAB_P_E)	32	34.40	176.00	93.54	33.72
expenditure for research and development (R&D)	30	0.40	3.80	1.42	0.92
graduates in science and technology (H_ED)	32	3.40	24.50	11.41	4.97
exports of high technology products (HTECH)	32	1.40	50.80	13.44	11.60
greenhouse gas emissions (GHGEMISS)	31	42.00	184.00	98.47	35.74
energy intensity consumption (EN_INT)	31	32.50	1582.40	421.14	364.65
share of electricity from renewable energy (RE_SH)	31	0.00	108.40	22.30	26.99

Note: GDP_PPP = GDP per capita in Purchasing Power Standards (PPS), (EU-25 = 100); LAB_P_E = labour productivity per person employed, expressed as GDP in PPP standards per labour active population, relative to EU-25 (EU-25 = 100); R&D = gross domestic expenditure for research and development (R&D) activities as percentage of GDP; H_ED = total number of tertiary graduates in science and technology per 1000 of population aged 20-29; HTECH = exports of high technology products as a share of total exports; GHGEMISS = index of greenhouse gas emissions; percentage change since 1990 = 100, based on CO_2 equivalents and Kyoto Targets in CO_2 equivalents (actual base year = 100); EN_INT = energy intensity consumption of the economy defined as gross inland (domestic) consumption of energy divided by GDP (at constant prices, 1995 = 100) in kilogram of oil equivalent per 1000 Euro in constant prices, 1995 = 100; and RE_SH = share of electricity from renewable energy to gross electricity consumption.

*Source***:** Authors' calculations from Eurostat (2006 and 2008).

Table 2. Descriptive statistics of the analyzed structural indicators' variables for the old EU-15 countries in 2003 and 2005

	N	Minimum	Maximum	Mean	Std. Deviation
	2003				
GDP per capita (GDP_PPP)	15	72.90	233.90	118.360	35.726
labour productivity per person employed (LAB_P_E)	15	66.00	156.80	109.780	19.501
expenditure for research and development (R&D)	15	0.62	3.98	1.935	0.949
graduates in science and technology (H_ED)	13	7.30	24.20	13.531	5.850
exports of high technology products (HTECH)	15	5.90	29.90	15.727	8.094
greenhouse gas emissions (GHGEMISS)	15	81.50	140.60	109.033	17.965
energy intensity consumption (EN_INT)	15	128.19	280.70	203.653	41.617
share of electricity from renewable energy (RE_SH)	15	1.80	53.40	17.127	15.648
	2005				
GDP per capita (GDP_PPP)	15	75.50	264.60	125.533	41.783
labour productivity per person employed (LAB_P_E)	15	68.70	176.00	115.873	22.446
expenditure for research and development (R&D)	15	0.50	3.80	1.627	1.069
graduates in science and technology (H_ED)	14	8.60	24.50	13.914	5.065
exports of high technology products (HTECH)	15	5.70	38.00	15.980	9.412
greenhouse gas emissions (GHGEMISS)	15	81.30	152.30	107.787	20.616
energy intensity consumption (EN_INT)	15	114.10	241.50	191.813	37.372
share of electricity from renewable energy (RE_SH)	15	2.80	57.40	17.887	17.155

Source: Authors' calculations from Eurostat (2006 and 2008).

Table 3. Descriptive statistics of the analyzed structural indicators' variables for the new EU-12 countries in 2003 and 2005

	N	Minimum	Maximum	Mean	Std. Deviation
	2003				
GDP per capita (GDP_PPP)	12	29.80	79.90	54.050	17.116
labour productivity per person employed (LAB_P_E)	12	32.00	85.60	56.517	16.355
expenditure for research and development (R&D)	11	0.27	1.54	0.717	0.398
graduates in science and technology (H_ED)	12	3.10	16.30	7.433	3.643
exports of high technology products (HTECH)	11	2.70	55.50	11.246	15.814
greenhouse gas emissions (GHGEMISS)	12	33.80	152.80	74.325	35.894
energy intensity consumption (EN_INT)	12	268.95	1756.21	852.036	467.200
share of electricity from renewable energy (RE_SH)	12	0.00	35.40	9.175	11.838
	2005				
GDP per capita (GDP_PPP)	12	35.40	92.70	62.267	18.530
labour productivity per person employed (LAB_P_E)	12	34.40	90.20	63.908	17.978
expenditure for research and development (R&D)	11	0.40	2.40	1.036	0.625
graduates in science and technology (H_ED)	12	3.40	18.90	9.258	4.180
exports of high technology products (HTECH)	12	2.90	50.80	12.533	14.874
greenhouse gas emissions (GHGEMISS)	12	42.00	163.70	78.092	41.015
energy intensity consumption (EN_INT)	12	32.50	1582.40	723.142	430.847
share of electricity from renewable energy (RE_SH)	12	0.00	48.40	12.808	15.722

Source: Authors' calculations from Eurostat (2006 and 2008).

Table 4. Descriptive statistics of the analyzed structural indicators' variables for the EU-27 countries in 2003 and 2005

	N	Minimum	Maximum	Mean	Std. Deviation
	2003				
GDP per capita (GDP_PPP)	27	29.80	233.90	89.778	43.263
labour productivity per person employed (LAB_P_E)	27	32.00	156.80	86.107	32.332
expenditure for research and development (R&D)	26	0.27	3.98	1.420	0.971
graduates in science and technology (H_ED)	25	3.10	24.20	10.604	5.733
exports of high technology products (HTECH)	26	2.70	55.50	13.831	11.909
greenhouse gas emissions (GHGEMISS)	27	33.80	152.80	93.607	32.059
energy intensity consumption (EN_INT)	27	128.19	1756.21	491.823	448.414
share of electricity from renewable energy (RE_SH)	27	0.00	53.40	13.593	14.400
	2005				
GDP per capita (GDP_PPP)	27	35.40	264.60	97.415	45.953
labour productivity per person employed (LAB_P_E)	27	34.40	176.00	92.778	33.173
expenditure for research and development (R&D)	26	0.40	3.80	1.377	0.941
graduates in science and technology (H_ED)	26	3.40	24.50	11.766	5.161
exports of high technology products (HTECH)	27	2.90	50.80	14.448	12.014
greenhouse gas emissions (GHGEMISS)	27	42.00	163.70	94.589	34.157
energy intensity consumption (EN_INT)	27	32.50	1582.40	427.959	389.454
share of electricity from renewable energy (RE_SH)	27	0.00	57.40	15.630	16.421

*Source***:** Authors' calculations from Eurostat (2006 and 2008).

In comparison with the EU-27 countries, the EFTA-4 countries experience similar tendencies, except having the increase in the energy intensity use. On average the EFTA-4 countries vis-à-vis the EU-27 countries have higher GDP per capita, labour productivity, the gross domestic expenditure for R&D activities as percentage of GDP, the index of greenhouse gas emissions, the energy intensity consumption of the economy, and the share of electricity from renewable energy to gross electricity consumption, and vice versa the EFTA-4 countries have a lower total number of tertiary graduates in science and technology per 1000 of population aged 20–29 and lower exports of high technology products as a share of total exports than the EU-27 countries.

Table 5. Descriptive statistics of the analyzed structural indicators' variables for the EFTA-4 countries in 2003 and 2005

	N	Minimum	Maximum	Mean	Std. Deviation
	2003				
GDP per capita (GDP_PPP)	3	118.40	146.20	131.700	13.939
labour productivity per person employed (LAB_P_E)	2	95.20	126.80	111.000	22.345
expenditure for research and development (R&D)	2	1.75	2.97	2.345	0.863
graduates in science and technology (H_ED)	4	5.20	9.50	7.400	2.317
exports of high technology products (HTECH)	3	1.80	3.70	2.500	1.044
greenhouse gas emissions (GHGEMISS)	3	93.90	109.30	102.833	7.991
energy intensity consumption (EN_INT)	2	159.20	482.57	320.885	228.657
share of electricity from renewable energy (RE_SH)	2	92.20	99.90	96.050	5.445
	2005				
GDP per capita (GDP_PPP)	3	134.20	180.00	149.633	26.299
labour productivity per person employed (LAB_P_E)	3	105.60	155.70	123.333	28.073
expenditure for research and development (R&D)	2	1.50	2.80	2.150	0.919
graduates in science and technology (H_ED)	4	9.00	16.10	11.975	3.157
exports of high technology products (HTECH)	3	2.90	21.20	10.233	9.676
greenhouse gas emissions (GHGEMISS)	2	108.80	110.50	109.650	1.202
energy intensity consumption (EN_INT)	2	211.60	433.80	322.700	157.119
share of electricity from renewable energy (RE_SH)	2	99.90	108.40	104.150	6.010

*Source***:** Authors' calculations from Eurostat (2006 and 2008).

The EU candidate countries Croatia and Turkey in comparison with the EU-27 countries experience lower GDP per capita, labour productivity, the gross domestic expenditure for R&D activities as a percentage of GDP, total number of tertiary graduates in science and technology per 1000 of population aged 20-29, exports of high technology products as a share of total exports, and the energy intensity consumption of the economy, but higher is the index of greenhouse gas emissions and the share of electricity from renewable energy to gross electricity consumption. Croatia and Turkey, except for the total number of tertiary graduates in science and technology per 1000 of population aged 20–29, and the energy intensity use, have experienced an increase in the analyzed indicators of economic efficiency, energy consumption and sustainable development as a positive sign for future sustainable economic development.

Table 6. Descriptive statistics of the analyzed structural indicators' variables for the EU candidate countries (Croatia and Turkey) in 2003 and 2005

	N	Minimum	Maximum	Mean	Std. Deviation
	2003				
GDP per capita (GDP_PPP)	2	26.50	46.00	36.250	13.789
labour productivity per person employed (LAB_P_E)	2	38.60	57.80	48.200	134577
expenditure for research and development (R&D)	2	0.40	1.14	0.770	0.523
graduates in science and technology (H_ED)	2	5.60	9.40	7.500	2.687
exports of high technology products (HTECH)	1	3.30	3.30	3.300	0
greenhouse gas emissions (GHGEMISS)	1	94.00	94.00	94.000	0
energy intensity consumption (EN_INT)	2	452.64	479.98	466.310	19.332
share of electricity from renewable energy (RE_SH)	2	25.20	29.40	27.300	2.970
	2005				
GDP per capita (GDP_PPP)	2	39.20	50.00	44.600	7.637
labour productivity per person employed (LAB_P_E)	2	56.20	62.20	59.200	4.243
expenditure for research and development (R&D)	2	0.80	1.80	1.300	0.707
graduates in science and technology (H_ED)	2	5.70	5.70	5.700	0.000
exports of high technology products (HTECH)	2	1.40	8.00	4.700	4.667
greenhouse gas emissions (GHGEMISS)	2	95.50	184.00	139.750	62.579
energy intensity consumption (EN_INT)	2	416.60	438.30	427.450	15.344
Share of electricity from renewable energy (RE_SH)	2	24.70	36.20	30.450	8.132

Source: Authors' calculations from Eurostat (2006 and 2008).

3.2. Correlation analysis

The correlation analysis is used to establish the signs, intensity of associations, and statistical significance of the associations between the pairs of the variables that are used later in the regression and in the multivariate factor analyses. The correlation matrix between the analyzed variables for the 33 European countries indicates positive correlations between the analyzed variables: labour productivity (LAB_P_E) measured as GDP in PPP per labour active person, gross domestic expenditures for research and development activities (R&D), and the share of technologically intensive products in total exports (HTECH) (Table 7). The intensity of the associations is found stronger

Table 7. Correlation matrix of Pearson correlations between the variables for the selected 33 European countries

		2003			2005		
		Labour productivity (LAB_P_E)	Expenditures in R&D	High-tech exports (HTECH)	Labour productivity (LAB_P_E)	Expenditures in R&D	High-tech exports (HTECH)
Labour productivity (LAB_P_E)	Pearson Correlation	1	.589(**)	.474(*)	1	.252	.439(*)
	Sig. (2-tailed)	.	.001	.011	.	.179	.012
	N	31	28	28	32	30	32
Expenditures in R&D	Pearson Correlation	.589(**)	1	.113	.252	1	–.022
	Sig. (2-tailed)	.001	.	.560	.179	.	.908
	N	28	30	29	30	30	30
High-tech exports (HTECH)	Pearson Correlation	.474(*)	.113	1	.439(*)	–.022	1
	Sig. (2-tailed)	.011	.560	.	.012	.908	.
	N	28	29	30	32	30	32
		2003			2005		
		Energy intensity consumption (EN_INT)	Expenditures in R&D	High-tech exports (HTECH)	Energy intensity use (EN_INT)	Expenditures in R&D	High-tech exports (HTECH)
Energy intensity consumption (EN_INT)	Pearson Correlation	1	–.474(*)	–.383(*)	1	.235	.371(*)
	Sig. (2-tailed)	.	.001	.044	.	.211	.040
	N	31	28	28	31	30	31

Notes: * Correlation coefficient is significant at the 5% level (2-tailed), ** Correlation coefficient is significant at the 1% level (2-tailed).

in 2003 than in 2005. This could be explained by the EU enlargement in 2004, which seems – in combination with developments in energy markets – to have broadened the scope for the economic efficiency, energy consumption and sustainable economic development. The estimated Pearson correlation coefficient between the R&D and the HTECH is relatively low (0.113 in 2003 and negative in 2005) and modest to low between the LAB_P_E and the R&D (0.589 in 2003 and 0.252 in 2005), and between the LAB_P_E and the HTECH (0.474 in 2003 and 0.439 in 2005). On the other hand, less clear associations are found between the energy intensity consumption (EN_INT), the R&D, and the HTECH, respectively: negative in 2003 and vice versa positive in 2005. These correlation results suggest shifts from energy saving towards energy using technologies, which can be explained by the growth in world oil and energy real prices, which has caused the increase of the share of gross domestic consumption of energy in the unit of product or in GDP.

3.3. Regression analysis

The regression analysis is used to identify the signs, intensity of the associations, and statistical significance for the associations of economic efficiency and energy intensity consumption, respectively, as the dependent variables, with the expenditures on R&D and technologically intensive products in exports as the explanatory variables. These two explanatory variables are used as proxy determinants for sustainable economic development.

Both cross-section regression equations for economic efficiency and energy consumption, respectively, are estimated for the years 2003 and 2005, respectively. As can be seen from Table 8, the regression analysis confirmed: first, positive and significant associations of labour productivity (LAB_P_E) with the expenditures on R&D and with the share of technologically intensive products in exports (HTECH), respectively. Second, energy intensity is negatively and significantly associated with expenditures on R&D and with the share of technologically intensive products in exports (HTECH), respectively. Third, the comparison between the cross-section regressions for the years 2003 and 2005, respectively, shows an increase in the regression constant for autonomous labour productivity, and vice versa a decline of autonomous energy intensity consumption. These findings for the regression constants are consistent with the theoretical expectations and objectives of sustainable economic development to assure higher labour productivity with lower energy intensity consumption. The regression coefficients pertaining to the expenditures in R&D decline, implying a slight deterioration of the transmission of the expenditures in R&D on labour productivity on the one hand, but its efficiency improvements in energy intensity consumption on the other. The regression coefficients pertaining to the high-tech exports are of the theoretically expected sign and are significant: the greater share of the high-tech exports increases labour productivity on the one hand, but decreases energy intensity of consumption on the other.

These regression results suggest that management strategies and economic policies directed towards investments in R&D, and particularly in technologically intensive exports oriented products, are significant for the macro-economic efficiency performances and for the energy saving sustainable economic developments in the analyzed 33 Eu-

Table 8. Regression analyses of labour productivity and energy intensity consumption in the selected 33 European economies in 2003 and 2005

Dependent variable	Constant	Expenditures in R&D	High-tech exports (HTECH)	Adjusted R^2	F
	2003				
labour productivity (LAB_P_E)	48.4*** (5.39)	16.98*** (3.50)	1.07** (2.69)	0.46	12.0
energy intensity consumption (EN_INT)	924.1*** (6.67)	–197.27*** (–2.78)	–12.44** (–2.09)	0.29	6.8
	2005				
labour productivity (LAB_P_E)	64.67*** (5.23)	9.57* (1.56)	1.21** (2.50)	0.18	4.26
energy intensity consumption (EN_INT)	707.0*** (5.08)	–97.22* (–1.40)	–11.46** (–2.11)	0.13	3.14

Notes:*, **, *** denote level of significance at 10, 5, and 1% respectively.

ropean countries. The higher technological intensity of exported products is associated negatively with the energy consumption per unit of a product, which is related to the restructuring of production processes from the energy intensive industries towards industries with the higher value added per unit of the product with lower energy consumption per unit of the product.

3.4. Multivariate factor analysis

The multivariate factor analysis is used to investigate common factors and main weights of variables in associations between various analyzed variables, in order to find a smaller number of joint variables that represent common factors of the analyzed variables explaining economic efficiency, energy intensity consumption, and sustainable economic development. The following eight variables are included into the multivariate factor analysis: gross domestic product per capita in purchasing power parity (GDP_PPP), labour productivity (LAB_P_E) measured as GDP in PPP per labour active person, gross domestic expenditures on research and development activities (R&D), graduates in the field of science and technology (H_ED), the share of technologically intensive products in total exports (HTECH), energy intensity consumption of the economy (EN_INT), emissions of CO_2 (GHGEMISS), and the share of renewable resources of energy (RE_SH).

The Kaiser-Meyer-Olkin (KMO) measure of sampling adequacy and Barlett's test of sphericity are used as measures of appropriateness of factor analysis. Bartlett's test of sphericity shows the significance of the data for the year 2003 (approx. Chi-Square 133.25, Sig. 0.000) and for the year 2005 (approx. Chi-Square 141.13, Sig. 0.000). The KMO measure of sampling adequacy is 0.77 for the 2003 sample and 0.60 for the 2005 sample. In spite of the relatively smaller sample sizes, Bartlett's test and the KMO measure imply suitability of data for factor analysis. The multivariate factor analysis was conducted in four steps employing the extraction methods of the principle axis factoring and three different methods of maximum likelihoods for the years 2003 and 2005, respectively (Table 9). To assess the reliability of an underlying construct, Cronbach's alpha of the internal consistency indices of reliability is used. Cronbach's alpha coefficient for the first summated scale is –0.673 for the 2003 sample and –0.776 for the 2005 sample, close to or above the 0.70 criteria (Nunnelly 1978). Cronbach's alpha coefficient for the second summated scale is 0.713 for the 2003 sample and 0.684 for the 2005 sample, which is close to the 0.70 criteria.

The extraction method of the principle axis factoring confirmed the model for the total sample of eight variables with the two common factors that explain 59.5 and 54.2 percent of variance for 2003 and 2005, respectively. The first common factor explained 49.4 percent in 2003 (39.1 in 2005), and the second one an additional 10.1 (15.1) percent of variance. The first common factor of the economic efficiency of expenditures in R&D and energy intensity consumption has the highest weights for variables that are greater than $|0.5|$ in variables GDP_PPP, LAB_P_E, R&D, GHGEMIS, and EN_INT. The second common factor of the human capital and expenditures in R&D has the highest weights in the variables R&D and GHGEMISS.

The extraction method of the maximum likelihood confirmed the two common most significant factors, which in 2003 explained 59.8 percent of variance: the first one 49.1 percent and the second one an additional 10.7 percent. The highest weights for variables in the first common factor of the economic efficiency and expenditures in R&D are for GDP_PPP, LAB_P_E, R&D (but not in 2005), GHGEMIS and EN_INT (with negative sign). In the second common factor of the human capital and knowledge with expenditures in R&D the highest weights are found for GHGEMIS (with negative sign) and only in 2005 for GDP_PPP and LAB_P_E.

The extraction method of the maximum likelihood with the rotation method of Oblimin with Kaiser Normalization does not change communalities considerably, but has improved the obtained results on the common factors. The first common factor of the economic efficiency and expenditures in R&D underlined the importance of ecological factors, whereas the second common factor of the human capital and knowledge with expenditures in R&D underlined the importance of energy intensity consumption. The highest weights in the first common factor are found for variables GHGEMIS, EN_INT (with negative sign), GDP_PPP, and LAB_P_E. In the second common factor the highest weights for variables are found for GDP_PPP, LAB_P_E, R&D, H_ED, and in 2005 to a lesser extent also for GHGEMIS (with negative sign).

The extraction method of the maximum likelihood with the rotation method of Varimax with Kaiser Normalization confirmed also the two common and most significant factors of economic efficiency and expenditures in R&D on the one hand, and the human

Table 9. Multivariate factor analysis and matrices of five different extraction methods (two components extracted) in 2003 and 2005

	Principal Axis Factoring		Maximum Likelihood		Maximum Likelihood. Rotation Method: Oblimin with Kaiser Normalization				Maximum Likelihood. Rotation Method: Varimax with Kaiser Normalization.	
	Component matrix		Factor Matrix		Pattern Matrix		Structure Matrix		Rotated Factor Matrix	
	Factor[a]		Factor[b]		Factor[c]		Factor		Factor[d]	
	1	2	1	2	1	2	1	2	1	2
	2003									
GDP_PPP	.983	.095	.994	.034	.636	.543	.863	.809	.700	.706
LAB_P_E	.956	.026	.967	.006	.642	.502	.853	.771	.700	.667
R&D	.679	.525	.688	.339	.165	.683	.451	.752	.268	.718
H_ED	.403	.358	.460	.438	–.075	.662	.203	.631	.035	.634
HTECH	.382	–.231	.382	–.174	.408	.026	.419	.197	.397	.135
GHGEMISS	.672	–.492	.640	–.624	.975	–.280	.858	.128	.894	–.016
EN_INT	–.890	.267	–.849	.345	–.871	–.099	–.912	–.464	–.855	–.331
RE_SH	.242	.158	.213	–.070	.204	.041	.221	.127	.203	.095
	2005									
GDP_PPP	.953	.234	.755	.598	.540	.693	.685	.806	.611	.745
LAB_P_E	.977	.147	.818	.574	.608	.676	.750	.803	.677	.735
R&D	.342	.413	.099	.471	–.056	.490	.047	.478	–.003	.481
H_ED	.250	.368	.069	.490	–.091	.505	.015	.486	–.037	.493
HTECH	.292	–.268	.368	–.024	.364	.017	.368	.093	.364	.055
GHGEMISS	.463	–.803	.806	–.591	.973	–.510	.866	–.307	.913	–.406
EN_INT	–.830	.258	–.848	–.133	–.780	–.231	–.829	–.394	–.800	–.311
RE_SH	.309	.209	.272	.221	.193	.255	.246	.296	.219	.274

Notes: [a]13 (30 for 2005) iterations required, [b]17 (55) iterations required, [c]Rotation converged in 8 (18) iterations, [d]Rotation converged in 3 iterations.
GDP per capita in purchasing power parity (GDP_PPP), labour productivity (LAB_P_E) measured as GDP in PPP per labour active person, gross domestic expenditures for R&D activities, graduates in the field of science and technology (H_ED), the share of technologically intensive products in total exports (HTECH), energy intensity consumption of the economy (EN_INT), emissions of CO_2 (GHGEMISS), and the share of renewable resources of energy (RE_SH).

capital and knowledge with expenditures in R&D on the other. In the first common factor, the highest weights are found for variables GHGEMIS, GDP_PPP, LAB_P_E, and EN_INT. In the second common factor, human capital and knowledge with expenditures in R&D underlined the impact on the number of graduates in the areas of science and technology, where the highest weights are confirmed for variables R&D, GDP_PPP, LAB_P_E, and for H_ED. The economic efficiency in the analyzed European countries depends on the expenditures in R&D, energy intensity consumption, and human capital and knowledge investments in R&D.

4. Conclusion

Energy consumption in the European economies has increased, but greater efforts have been made towards reducing energy intensity consumption of the economy production. In order to achieve stabilities and efficiencies in the energy markets, both efficient energy supply and efficient energy use are important. The energy market stabilities with rational energy consumption can contribute to energy friendly sustainable economic development with the aim of achieving a higher level of living standard of the population. The promotion of economic efficiency in sustainable economic development with competitive energy supply and efficient energy use could be an effective strategy providing benefits to energy producers, energy consumers, and society's environmental concerns to treat the environment in a sustainable way. According to our empirical results, it is less likely that conservation policy regarding energy consumption would harm economic growth. On the contrary, our results clearly confirm that sustainable economic development can be achieved by a combination of higher economic efficiency with at the same time more efficient energy consumption.

Our results also confirm that there are significant differences in economic efficiency, efficiency in energy consumption and in sustainable economic development between the analyzed 33 European countries. This finding has been a reason for presenting and explaining the summary statistics results between more homogenous groups of countries in order to derive similarities and differences between them. The strengthening of the importance of economic efficiency and sustainable energy projects is an objective of the EU policies and one of the possibilities for using EU structural funds to assist in developing sustainable energy projects to ensure environmental safety and efficient usage of energy resources towards sustainability (Grundey 2008). Energy consumption can also be biased towards extra energy losses (Oke, Oyedokun 2007) associated with production facilities that occur in energy transfer as a result of inefficiencies in equipment and operations. Therefore, more in-depth analysis by countries is an issue for future research.

The EU strategy for smart, sustainable and inclusive growth "Europe 2020" (e.g. Balkytė, Tvaronavičienė 2010; Balkytė, Peleckis 2010) underlines the deeper relationship between sustainable development and competitiveness suggesting different concepts, models of competitiveness, evaluation criteria, challenges and opportunities in the context of international globalisation, economic growth, sustainable competitiveness and sustainable development. Consistently with changing policy context, growing role of sustainable development and the transition to a green economy, our present analysis has been geared towards achieving economic efficiency, effective and efficient energy consumption, and sustainable development by researching causalities between structural indicators of economic efficiency and energy intensity consumption as determinants of sustainable economic development.

The correlation, regression and multivariate factor analyses results consistently show the feasibility of the applied procedure and the contribution of the results in analyzing structural indicators of economic efficiency and energy intensity consumption as determinants of sustainable long-term economic development. With the cross-country correlation, regression and multivariate factor analysis of the economic efficiency and energy intensity use variables, we have found a significant association between the energy intensity consumption with two groups of factors: the economic efficiency of expenditures in R&D and the intensity in energy consumption on the one hand, and the human capital and knowledge investments in R&D and energy intensity consumption on the other.

These results and findings suggest that management strategies and policies directed towards economic efficiency of expenditures in R&D with human capital knowledge and investments into technologically intensive export- oriented products are significant for the economic efficiency performance and for energy intensity saving technologies as the important determinants for long-term sustainable economic development. Restructuring and transformation of the European economies from energy-intensive industries towards energy-saving service and more technologically intensive and advanced industries with export-oriented products leads to higher economic efficiency with higher value added per unit of product and to higher efficiency in reducing energy consumption by energy saving - technologies with a lower energy use per unit of product. These restructuring and transformation processes towards a higher technological intensity, with higher value added per unit of product and with lower energy consumption per unit of product and their export orientation, are the potential to improve economic performance by reducing energy intensity consumption with implications for reduction in environmental pressures and with greater sustainability in long-term economic development in the direction of smart, sustainable and inclusive growth.

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EKONOMINIS EFEKTYVUMAS, ENERGIJOS VARTOJIMAS IR SUBALANSUOTA PLĖTRA

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Santrauka

Autoriai analizuoja struktūrinius ekonominio efektyvumo ir energijos vartojimo intensyvumo, kaip vienų iš pagrindinių subalansuotos plėtros kintamųjų, rodiklius. Tirti buvo pasirinktos 33 Europos valstybės. Autoriai, siekdami pagrįsti iškeltus teiginius, naudojo koreliacinę, regresinę analizę bei daugiakriterinius metodus galimoms ekonominio efektyvumo bei energijos vartojimo laipsnio (ir kitų, ne mažiau svarbių elementų) variacijoms nustatyti. Ekonominis efektyvumas labai dažnai asocijuojasi su tyrimais ir plėtra (R&D), eksportuojamomis aukštosiomis technologijomis. Remdamiesi atliktų tyrimų rezultatais autoriai siūlo nukreipti tiek politinius sprendimus, tiek valdymo strategijas į tyrimų ir plėtros (R&D) veiklas, investicijas į žmogiškuosius išteklius, technologinius sprendimus, nes visa tai galima susieti su subalansuotos plėtros koncepcija.

Reikšminiai žodžiai: ekonominis efektyvumas, energijos vartojimas, tyrimai ir plėtra, technologinis intensyvumas, subalansuota plėtra, Europa.

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