

ENERGY CONSUMPTION AND CO₂ EMISSIONS ON A GLOBAL LEVEL

Ntanos S.^{1*}, Arabatzis G.², Milioris K.³, Chalikias M.^{4**}, Lalou P.⁵

^{1,2}Democritus University of Thrace, Department of Forestry and Management of the Environment and Natural Resources,
Orestiada, 68200, Greece

³University of Piraeus, Department of Informatics, 18534, Piraeus, Greece

^{4,5}Technological Educational Institute of Piraeus, Department of Business Administration,
Aigaleo, 122 44, Greece *sdanos@mycosmos.gr, **mchalik@teipir.gr

ABSTRACT

Analysis of the relation between economic development, energy consumption and carbon dioxide emissions is considered to be important for environmental planning on a national and international level. Several studies have focused on this issue and the results lead to a positive relation between these variables. For the purpose of this study, a database was created including variables such as gross domestic product (GDP), population, total primary energy supply and carbon dioxide emissions per energy sector. Data derives for the International Energy Agency including over 140 countries. The purpose of this study is to test the hypothesis that there is a statistical correlation between economic growth and a) energy consumption, b) carbon emissions from each energy sector. Countries classification according to GDP per capita is performed and then the One-way ANOVA command is used to test the hypotheses. The results verify existence of relation between GDP and energy consumption and also between GDP and carbon emissions from the electricity sector and the transportation sector. These results are compatible with other studies reviewed in this article.

Keywords: Primary energy supply, income levels, one-way ANOVA, carbon dioxide.

1. Introduction

Scientists dealing with climate change, observed that concentrations of carbon dioxide in the atmosphere (hereinafter CO₂) have increased considerably over the last century, compared to the rather stable level of the pre - industrial era. In recent decades, global economic growth has caused various side effects including climate change due to global warming. Accordingly, international interest in carbon dioxide increases. Since the late 1970s there are a number of scientific publications concerning controlling of CO₂ emissions in the atmosphere.

Dyson calculated that fossil fuel combustion adds an annually of 5x10⁹ tons of CO₂ of which approximately half remains in the atmosphere. As a way of resolving, he proposes, the implementation of afforestation programs and energy crops that are able to save carbon dioxide. The need for a shift from fossil fuels to other more environmentally friendly fuel forms is emphasized, with fuels including the nuclear energy [6].

Bach notes that increasing population rate, energy consumption and economic development contribute to climate change. He estimates a temperature increase of around 1.5 °C to 3 °C by 2050 due to an increase of anthropogenic CO₂ emissions. Among the possible solutions he proposes an energy mix based on new carbon based technologies (gasification and liquefaction), nuclear energy, solar energy and also refers to an implementation of a global agreement to control the rate of energy use in combination with energy saving measures [3]. According to Garret, global temperature will rise by an average of 2 °C (optimistic scenario) to 4°C (pessimistic scenario) by the year 2100 compared to the average temperature of the Industrial Revolution era, referring to estimates by the IPCC Working Group 1 [7].

In 1997, the United Nations Convention on Climate Change (UNFCCC) adopted the Kyoto Protocol and countries have committed in an effort to reduce carbon emissions.

During 2013, the concentration of CO₂ (396 parts per million by volume ppmv) was approximately 40% higher than in mid-1800 (around 280 ppmv), with an average increase of 2 ppmv / year for the last ten years [9].

Anthropogenic CO₂ emissions result from the combustion of fossil fuels as a result of energy production and fuel consumption. The main areas where fossil fuels are used are the following:

- Electricity
- Industry
- Transport
- Agricultural sector
- The residential sector
- Tertiary sector

It must be noted that carbon emissions data are estimates, as there is no way for real measurement to all emission sources. Total energy consumption is allocated to sectors and then carbon emissions are calculated indirectly by using the revised emission factors according to the Intergovernmental Panel Guidelines on Climate Change [12]. Emission factors indicate carbon content per unit of energy produced or consumed. The International Energy Agency (IEA), records energy consumption on a global scale. The calculation of carbon emissions is done with two different approaches. The first approach (Reference method) refers to a uniform emission factor applied after the conversion of the total energy consumed in tonnes of oil equivalent (hereinafter TOE). The second approach calculates CO₂ emissions per energy sector, using different emission factors. IEA provides calculated carbon emissions at a global and country level [10].

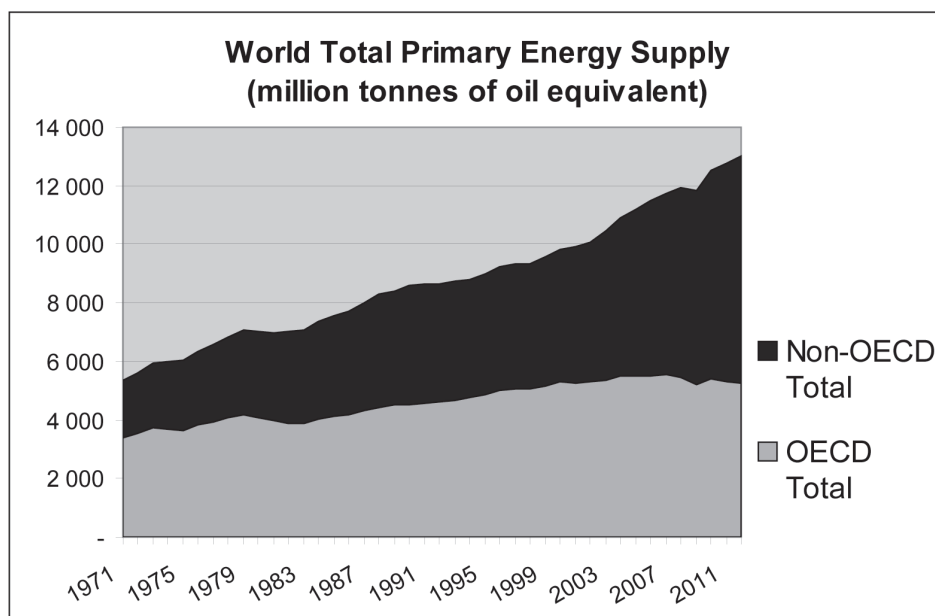
For cross-countries energy comparisons, the index of total primary energy supply (hereinafter TPES) is used:

TPES = energy production + imports - exports - international marine bunkers - International Aviation stock changes.

According to IEA estimates [11], global primary energy consumption rose from 5.5 GTOE in 1971 to 13.3 for 2012, an increase of 140%, as can be seen in Figure 1.

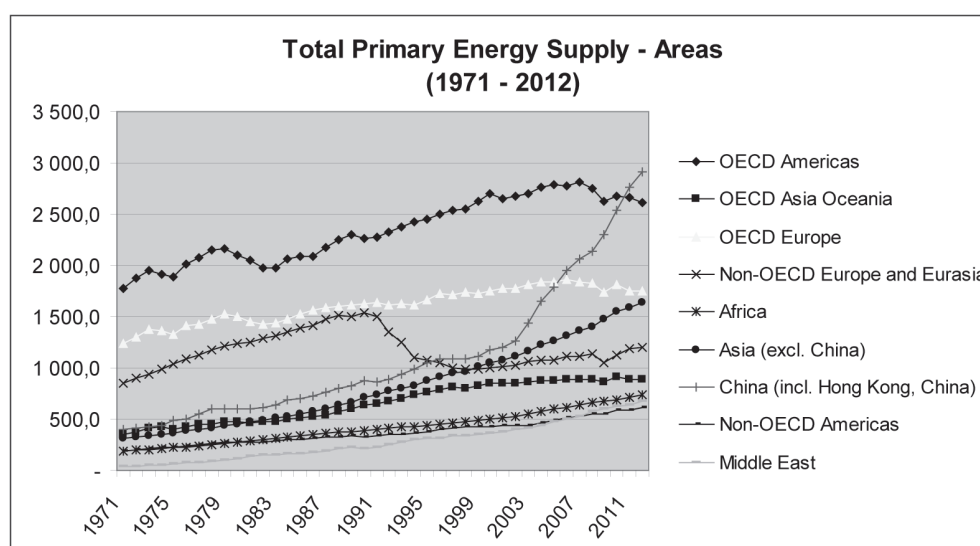
Analyzing further in OECD and non-OECD countries, we observe the following: OECD Countries, consumed 3.4 GTOE in 1971 and 5.2 in 2012, with an overall increase in energy consumption by 54%. The non-OECD countries demanded 2 GTOE in 1971 and 7.8 in 2012, which is 4 times more energy. We must note that energy consumption represents OECD countries after the 2000 consolidation, and is between 5-5,5 GTOE while energy consumption of non-OECD countries experienced rapid growth rate of about 300 MTOE per year for the past 10 years.

Figure 1: TPES, historical trend for OECD countries and Non-OECD countries



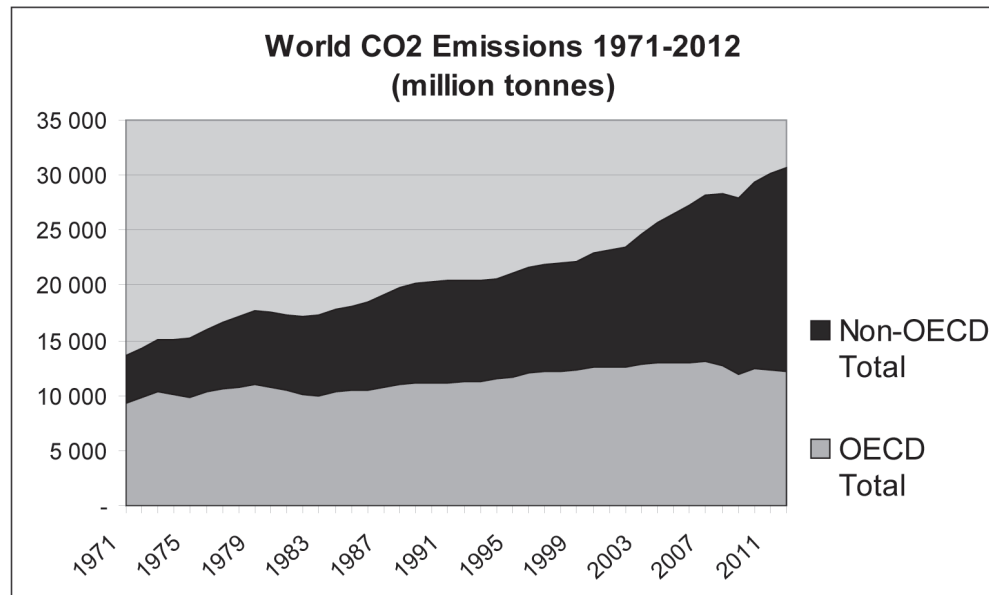
By looking at the historical trend of the annual per capita energy consumption (Figure 2), significant differences are observed between different geographical areas.

Figure 2: TPES, historical trend for World regions



During 2012, North America used about 6.8 toe / person, the EU 3.46 toe / person, while in non-OECD countries energy consumption is calculated to 1.34 toe / person. These important differences confirm that the level of prosperity of the countries associated with energy consumption. A higher standard of living means more energy consumption and hence more CO₂ emissions. For the European Union, energy consumption in 1997 was estimated at 3.74 toe / person while in 2012 was 3.46, which equates to a reduction of 8% (due to environmental stabilization trend of Kyoto Protocol commitments). China on the other hand shows an impressive TPES increase, due to intense industrialization.

Figure 3: CO₂ emissions, historical trend for OECD countries and Non-OECD countries



Based on IEA estimates, CO₂ emissions reached 31734 million tons in 2012, from 14085 in 1971, which means increase 125%. Analyzing further in OECD and Non-OECD countries, we deduce that emissions increase in Non-OECD countries is significant higher. Specifically, in OECD countries we have a 30% CO₂ emissions increase between 1971 and 2012 (from 9370 million tons to 12146), while increase in Non-OECD countries is 340% (from 4202 million tons to 18508 million tons).

2. Literature Review

The relation between energy consumption and GDP growth is considered to be of high importance for rationing energy consumption and controlling carbon dioxide emissions. Knowledge of the above relationship together with the knowledge of specific economy characteristics and inefficiencies allows improvement of the energy security of a country and control of carbon emissions into the atmosphere. According to literature, energy is important for motivating productivity, especially for the case of developing countries [2],[15],[16],[17]. Chontanawat provides causality tests between energy consumption and Gross Domestic Product (GDP) for over 100 countries [5]. Martínez and Moranco investigated the emissions and income relationship in 22 OECD countries [13]. Using data for six Central American states, Apergis and Payne investigated the relation between economic growth, energy consumption and emissions. Their findings showed that short run unidirectional causality runs from economic growth and energy use to emissions and in long run, bidirectional causality exists between energy consumption and emissions [1]. Similar results were found by Soytaş et al. stating that energy consumption had a long run causal relationship with emission in the United States [19]. In Greece, Hatzigeorgiou et al. found that GDP per capita, energy intensity had a positive causal relationship with CO₂ emissions [8].

In a comprehensive review about the relation between energy intensity and GDP growth, four scenarios were formed according to relevant literature. First, the growth hypothesis where energy saving policies may have an adverse impact on real GDP was examined, since the economic growth is very energy dependent. Second, the conservation hypothesis suggests that energy consumption can decrease without necessarily a negative effect on economic growth. Third, the neutrality hypothesis suggests that energy consumption has little or no impact on g. Fourth, the feedback hypothesis suggests that energy consumption and real GDP are interrelated, because there is bi-directional causality and hence they complement to each other [14].

The relation between GDP, electricity energy consumption and CO₂ emissions by using data for 22 OECD countries was examined by Bella et al. [4]. Three clusters were formed, showing different patterns. For countries belonging to the first cluster it was found that increase in the per capita income over the point of around 20,000 USD (in 2000 prices) leads to gradual reduction of per capita CO₂ emissions and per capita electricity consumption (Austria, Belgium, Denmark, Finland, Greece, Italy, Japan, Norway, Sweden and Turkey). For countries belonging to the second cluster it was found that growing GDP lead to an increase in per capital

electricity consumption with a parallel decrease in per capita CO₂ emissions. It is not surprising to find heavily nuclear energy countries in this group, where it appears reasonable to expect that an increasing-in-GDP energy consumption goes along with decreasing patterns of per capita CO₂ emissions (France, Portugal, Spain and Switzerland). For countries belonging to the third cluster we note that with growing GDP there is a decrease in per capital electricity consumption with a parallel increase in per capita CO₂ emissions. There may be several reasons why electricity consumption does not cause CO₂ emissions in the long-run. As confirmed by the international statistics, the most extant one can be referred to the fact that, in this group of countries, CO₂ emissions are largely misaligned from electrical consumption, because of the heavy role of other emitting sectors, among which transportation is the leading source (Australia, Canada, Ireland, the Netherlands, New Zealand, UK and USA).

In an interesting study on capital formation, energy consumption and real GDP in G7 countries, cointegration was found. In the long-run, capital formation and energy consumption had a positive effect on real GDP in the G7 countries. The results in this study are consistent with the energy-dependent hypothesis, suggesting that energy consumption is a major factor influencing economic growth. The findings suggest that cutting carbon dioxide emissions under the Kyoto Protocol will have a negative effect on economic growth for the G7 economies under a holistic perspective [15].

During a comparative work concerning the relation between (1) economic growth, fossil fuel consumption, renewable energy consumption and real output, and (2) economic growth, fossil fuel and renewable energy for 20 OECD countries from 1980 to 2010, it was found that fossil fuels are a key factor in driving economic growth and also renewable energy consumption. Also R&D was found to have a crucial role in promoting economic growth. The effects of renewable energy consumption on economic growth were considered sizable and significant specifically to countries without oil reserves. In addition it was found that countries without oil reserves, as compared to countries with oil reserves, tend to have their real output to be responsive to renewable energy consumption [18].

In a study examining the impact of nuclear energy consumption on GDP growth and CO₂ emission in 30 developed and developing countries for the time period 1990-2010, the results demonstrated that fossil fuel energy production is more significant in increasing GDP growth than nuclear energy production. In addition, GDP growth and fossil fuel energy consumption are mentioned as major sources of CO₂ emission while nuclear energy consumption and urbanization are not. Moreover and most important findings were that a) there is a bi-directional negative short run causal relationship between fossil fuel and nuclear energy consumption b) nuclear energy consumption has a negative short run causal relationship with CO₂ emission while fossil fuel energy consumption has a positive short run causal relationship with CO₂ emissions [20].

There is a wide spread assumption among a growing literature that examines the relation between energy consumption and real GDP. This assumption is that the relation between energy consumption and real GDP is positive in testing for causality. In a comparative review, the main goal was to verify the truth of the above assumption for 93 countries and seven panels (Western Europe, Asia, Latin America, Middle East, Africa, and globally). It has been found that the assumption is only partially true. From the results it occurs a) that in around 59% of the countries, energy consumption had a statistically significant positive effect on real GDP in the long-run and b) on the other hand in around 61% of the countries, real GDP had a statistically significant positive effect on energy consumption in the long-run [15].

In a study examining the causal relation between GDP, energy intensity (EI) and CO₂ emissions in Greece, for the time period 1977–2007, the results show that there is a unidirectional causality between GDP, EI, GDP and CO₂, running from GDP to EI and to from GDP to CO₂ emissions, as well as a bi-directional relationship between CO₂ emissions and EI. So it can be understood that the possibility of separating CO₂ emissions and economic growth in Greek economy seems to be extremely questionable. Regarding the bi-directional causal relationship between CO₂ emissions and energy intensity, this signifies an obvious connection, meaning that a more efficient energy system structure will result to reduced emissions [8].

3. Methodology

The purpose of this study is to verify the relation between energy consumption, economic growth and carbon dioxide emissions. By using data from IEA (2014), we created a database including data for 140 countries concerning the year 2012. The database includes variables for each country, such as population, gross domestic product (GDP), total primary energy supply (TPES) and total CO₂ emissions in detail for each energy sector. By calculating GDP per capita, we created an income classification variable for the 140 countries involved (categorical). For the purpose of this analysis, according to the World Bank Atlas method, as low income countries

are classified those of \$1,045 or less in 2012; middle-income economies are those with a GDP per capita of more than \$1,045 but less than \$12,746; high-income economies are those with a GDP per capita of \$12,746 or more. Lower-middle-income and upper-middle-income economies are separated at a GDP per capita of \$4,125 (see table 1).

The correlation between energy consumption per capita and income per capita is then tested by using one way ANOVA.

4. Results

The 140 countries used in this study, were classified according to income per capita by using the method presented in the methodology section.

Table 1: CO₂ emissions and TPES per capita in 2012, shown per country income level

Calculated CO ₂ Emissions, Energy Consumption and GDP (2012)				
COUNTRIES CLASSIFICATION (WORLD BANK)		CO ₂ emissions per capita (in kgr)	Total Primary Energy Supply per capita (in Toe)	GDP per capita (in USD - 2010 fixed)
LOW INCOME	(3)	289,00	,48	517,19
LOW-MIDDLE INCOME	(25)	559,40	,45	2.380,51
HIGH-MIDDLE INCOME	(47)	3.421,70	1,48	8.315,28
HIGH INCOME	(65)	9.313,75	4,45	30078,88
TOTAL	(140)	5.579,04	2,65	17.192,92

Figures 5 and 6 represent carbon emissions and TPES per capita for different incomes per capita and reveal a positive relation between GDP, energy consumption and CO₂ emissions, respectively. Fig 5 reveals that level of carbon emissions increases with a rise in per capita GDP. We can observe that this positive relation is non-linear. In high incomes, energy consumption and CO₂ emissions presents rapid growth rate.

Figure 5: Change in CO₂ emissions / capita by GDP / capita

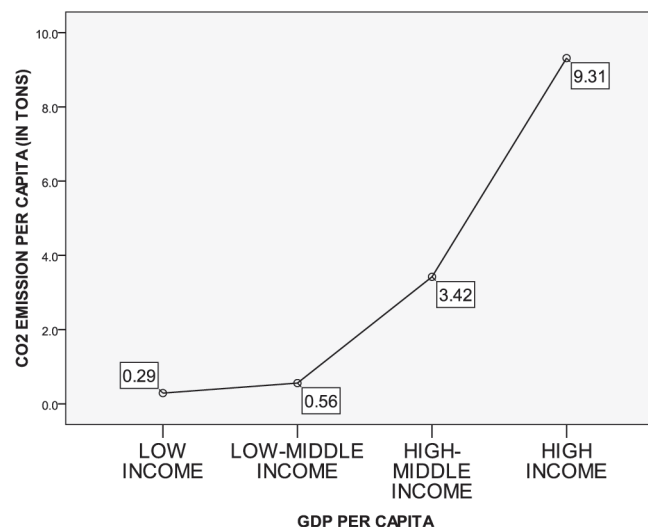


Figure 6: Change in TPES / capita by GDP / capita

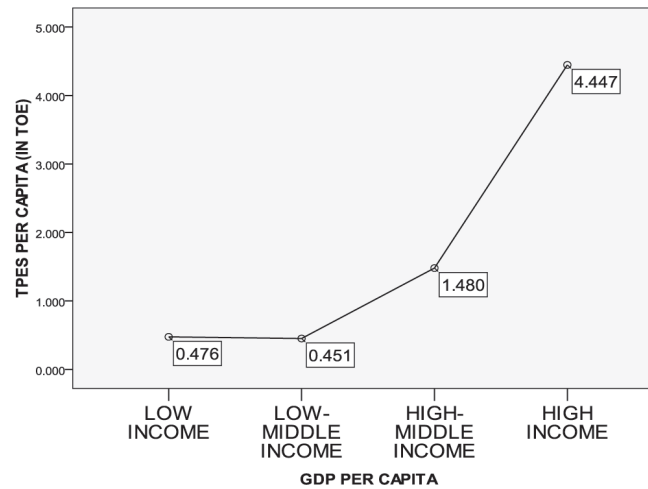


Table 2: Highest and lowest values on CO₂ emissions and Energy consumption per capita for every income level

Highest and lowest values on CO ₂ emissions and Energy consumption per capita	LOW INCOME		LOW-MIDDLE INCOME		HIGH-MIDDLE INCOME		HIGH INCOME	
	lowest	highest	lowest	highest	lowest	highest	lowest	highest
CO ₂ per cap	Dem. Rep. of Congo	Zimbabwe	Ethiopia	Republic of Moldova	Nigeria	Netherlands Antilles	Gabon	Qatar
			Eritrea	Syrian Arab Republic	Congo	Turkmenistan	Botswana	Kuwait
			Nepal	Kyrgyzstan	Guatemala	South Africa	Uruguay	Trinidad and Tobago
			United Rep. of Tanzania	Honduras	Paraguay	Libya	Panama	Bahrain
			Haiti	Yemen	Sri Lanka	Ukraine	Mauritius	Oman
Energy per cap	Dem. Rep. of Congo	Zimbabwe	Eritrea	Republic of Moldova	Congo	Netherlands Antilles	Mauritius	Iceland
			Bangladesh	Kyrgyzstan	Philippines	Turkmenistan	Botswana	Qatar
			Tajikistan	Syrian Arab Republic	Sri Lanka	Libya	Panama	Trinidad and Tobago
			Yemen	Honduras	DPR of Korea	Ukraine	Uruguay	Kuwait
			Myanmar	Zambia	Morocco	South Africa	Gabon	Brunei Darussalam

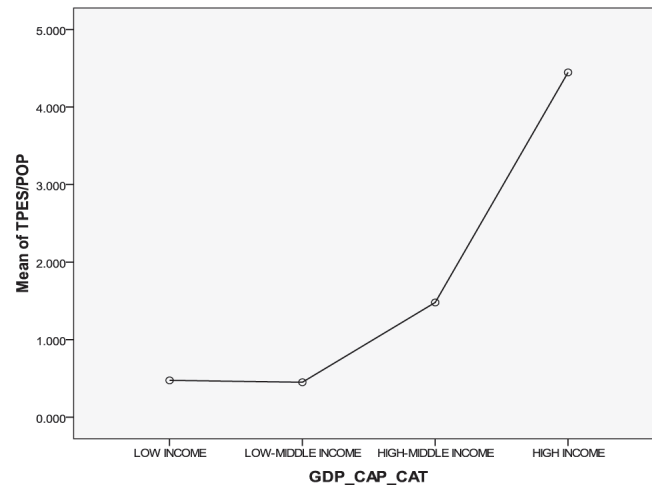
Table 3 includes the results of the one-way ANOVA between income and energy supply and indicates (by looking at the sig.) that there is a correlation between energy consumption per capita and GDP per capita.

Economical growth leads to an increase of TPES per capita. Figure 8 describes how the mean of TPES is affected by income increase.

Table 3: Results of ANOVA Test between variables TPES /cap and GDP /cap

ANOVA					
Mean energy supply cap and GDP/cap					
	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	409.184	3	136.395	19.215	.000
Within Groups	965.378	136	7.098		
Total	1374.563	139			

Figure 8: Change in TPES /capita by GDP /capita



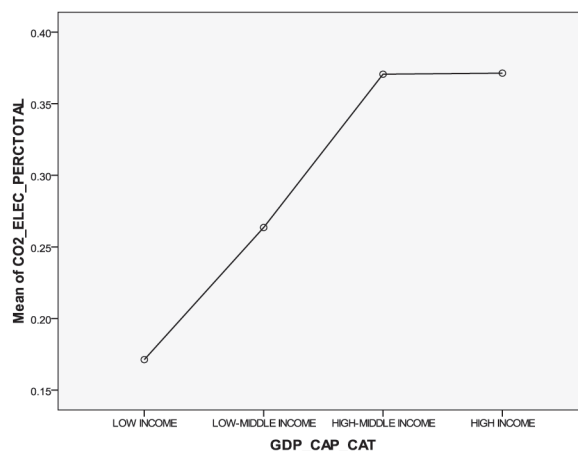
As shown in table 4, according to one-way ANOVA test, there is a correlation between GDP and CO₂ emissions as a result of energy production and consumption in the areas: Electricity and Transport. Economical growth, mainly in developing countries, allows increasing energy productivity; therefore we have CO₂ emissions increase. On the other hand, the results (look .sig) show that there is no correlation between GDP and CO₂ emissions deriving from residential and industrial sectors. An interpretation of this result is the Kyoto Protocol's commitment of industrialized countries, to reduce emissions from fossil fuel combustion that has lead to energy saving measures for home and industrial applications.

Table 4: Results of one-way ANOVA Test between variable GDP/cap and variables CO₂ emissions from electricity sector, transportation sector, residential sector, industrial sector and other sectors (in% of total emissions)

ANOVA						
		Sum of Squares	df	Mean Square	F	Sig.
CO2_ELEC_PERCTOTAL	Between Groups	.284	3	.095	3.040	.031
	Within Groups	4.085	131	.031		
	Total	4.370	134			
CO2_TRANS_PERCTOTAL	Between Groups	.609	3	.203	7.975	.000
	Within Groups	3.461	136	.025		
	Total	4.070	139			
CO2_RESIDENCE_PERCTOTAL	Between Groups	.012	3	.004	1.381	.252
	Within Groups	.392	130	.003		
	Total	.404	133			
CO2_INDUSTRY_PERCTOTAL	Between Groups	.006	3	.002	.196	.899
	Within Groups	1.453	135	.011		
	Total	1.460	138			
CO2_OTHER_PERCTOTAL	Between Groups	.083	3	.028	5.022	.003
	Within Groups	.694	126	.006		
	Total	.777	129			

According to Figure 10, there is a positive relation between GDP and carbon emissions from the Electricity sector. We observe that in low and middle incomes, this relation is almost linear. In high incomes, emissions are stabilized and are not affected by the income increase. This can be explained by the rapid expansion of Renewable energy sources for electricity in the case of developed, high income countries.

Figure 10: Change in CO₂ emissions from Electricity by GDP / capita



As we see in the following Figures 11 and 12, there is a negative relation between GDP and CO₂ emissions by Transport. It seems that economic growth is associated with reduction in levels of CO₂ emissions per capita for the transportation sector, implying a shift to “cleaner” transportation means. The graph shows that transportation emissions are only a small percentage of the total per capita emissions in the case of developed countries while in low income and low-middle income countries this percentage is 60% and 40% respectively

Figure 11: Change in CO₂ emissions from transport by GDP / capita

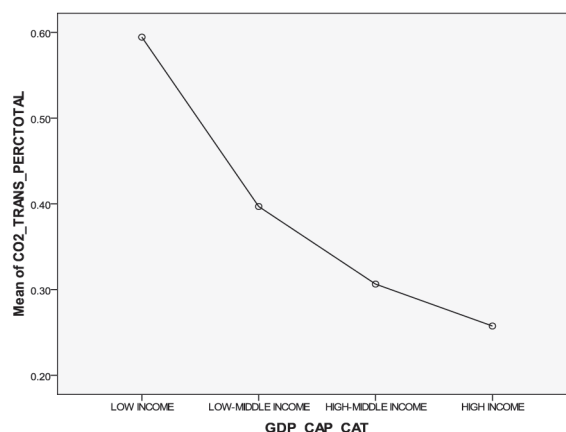
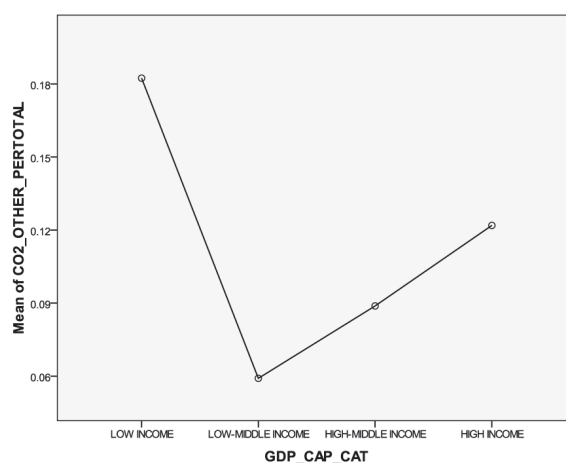


Figure 12: Change in CO₂ emissions from other energy use, GDP / capita



5. Conclusions

By using data covering 140 countries for the year 2012, this work investigates the relation between GDP, energy consumption and CO₂ emissions. Using one-way analysis of variance (abbreviated one-way ANOVA), we indicate that there is a connection between GDP, per capita and energy consumption. Furthermore we found that GDP per capita had a positive causal relationship to CO₂ emissions. Particularly, we investigated the correlation between energy sectors, CO₂ emissions and GDP per capita. Our results indicate that there is correlation between GDP and CO₂ emissions from electricity and transform, but there is no correlation between GDP and CO₂ emissions from industry and residence. These results are compatible with results from various reviewed studies concerning the causal relationship between energy consumption and economic growth.

Finally, as further research, it is interesting to study the case of Greece, and more specific the variation of energy consumption and CO₂ emissions for different regions of the country.

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