Reduction of CO₂ Emissions Due to Energy Use in Crete-Greece

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Abstract

Use of fossil fuels in modern societies results in CO_2 emissions which, together with other greenhouse gases in the atmosphere, increase environmental degradation and climate changes. Carbon dioxide emissions in a society are strongly related with energy consumption and economic growth, being influenced also from energy intensity, population growth, crude oil and CO_2 prices as well as the composition of energy mix and the percentage of renewable energies in it. The last years in Greece, the severe economic crisis has affected all sectors of the economy, has reduced the available income of the citizens and has changed the consumers' behavior including the consumption of energy in all the activities. Analysis of the available data in the region of Crete over the period 2007-2013 has shown a significant decrease of energy consumption and CO_2 emissions due to energy use by 25.90% compared with the reduction of national G.D.P. per capita over the same period by 25.45% indicating the coupling of those emissions with the negative growth of the economy. Carbon dioxide emissions per capita in Crete in 2013 are estimated at 4.96 tons. Main contributors of those emissions in the same year were electricity generation from fuel and heating oil by 64.85%, heating sector by 3.23% and transportation by 31.92%.

Keywords: CO₂ emissions, Crete-Greece, economic crisis, energy use, fossil fuels, renewable energies

1.Introduction

1.1 Purpose of the Work

Various studies related with the interconnection of economic growth with energy consumption and CO_2 emissions in many countries including Greece have been implemented so far. However the most of them have correlated the increase of G.D.P. per capita with the increase of energy consumption. In accordance to this, current long economic crisis in Greece has decreased significantly the national G.D.P. per capita and has reduced the energy consumption in the country affecting all the parameters of economic and social life. Purpose of current work is to investigate in the island of Crete-Greece the changes of CO_2 emissions over the period 2007-2013 as a result to the decrease of energy consumption and G.D.P. per capita due to economic crisis.

1.2 Overview of the Past Research

A preliminary attempt to address the effects of the current economic crisis on the Greek environment has been presented (Lekakis & Kousis, 2013). Some environmental benefits due to lower emission loads from reduced economic activity have been reported, but the authors comment that there is the danger of wealth diminishing over years and the environment will be part of it. CO_2 emissions due to energy use in Greece have been studied (Christodoulakis et al., 2000). It has been found that energy related CO_2 emissions are increasing with higher annual rate than world forecasts. It has been predicted that annual growth rate of CO_2 emissions until 2012 will be in the range of 1.8-2.2 % which is higher than the E.U. and world average. The authors propose measures which should be taken to limit the increase of CO_2 emissions, like promotion of energy efficiency and increasing use of renewable energies in all sectors of the economy, combined with the introduction of an energy tax. The effect of energy taxes on reducing environmental pollution in Greece are the same as in other E.U. countries, then the annual increase of CO_2 emissions would be 6%, but higher energy taxes will result in lower increases. Although the obligation of Greece is to reduce CO_2 emissions until 2010 by 25% compared to 1990, they have estimated using mathematical models that they will be 25% higher compared with 1990 level.

consumption, fossil fuels demand and CO₂ emissions in Greece during 1990-2006 has been studied (Papathanashopoulou, 2010). The author found that changes in household consumption by 44% influences fossil fuels demand by 67% and CO_2 emissions by 60%. This is due to energy supply side and not to consumers demand. The author concluded that the government must change citizen's behavior towards sustainable consumption. The determinants of CO_2 emissions in high income countries have been studied (Sharma, 2011). Sharma has found that for the period 1985-2005 growth of G.P.D. per capita increased the energy consumption per capita having positive effects on CO₂ emissions. G.D.P. growth, energy intensity and CO₂ emissions in Greece during 1997-2007 has been studied (Hatzigeorgiou et al., 2011). According to the findings, decoupling of CO₂ emissions and economic growth in Greece seems unlike and it is necessary to promote energy efficiency and the use of renewable energies in all sectors of the economy reducing the use of fossil fuels. The determinants of CO₂ emissions in a small open economy like Austria have been investigated (Friedl & Getzner, 2003). The authors have found that before 1973, CO₂ emissions were coupled with economic growth but after the first oil crisis CO₂ emissions were decoupled from economic growth, due to improvements in energy efficiency and the increased use of renewable energies. However, they concluded that still in Austria the driving force for CO₂ emissions remains the economic growth. Influence of the energy consumption and the income in CO₂ emissions in USA has been studied (Soytas et al., 2007). The authors concluded that reducing energy consumption is the most effective way in order to cope with environmental degradation. CO₂ emissions in Turkey during 1980-2003 have been investigated (Lise, 2006). Considering that annual increase of G.D.P. in Turkey will be at 7%, the author concluded that CO₂ emissions will increase by 600% during the period 1990-2025. Largest contributor in CO₂ emissions is the expansion of the economy. Carbon intensity and change in the composition of the economy in Turkey contribute to higher CO₂ emissions, but it is expected that decrease of energy intensity will reduce them. Energy consumption and CO₂ emissions in Turkey have been also investigated (Say & Yucel, 2006). During the period 2000-2015 the authors foresee an increase of 6.7% in G.D.P., increase of 8.4% in energy consumption and 9.9% in CO_2 emissions. The relation of economic growth and energy consumption with CO_2 emissions in Turkey has been investigated (Soytas et al., 2009). The authors did not find a long run link between CO₂ emissions and growth and they proposed that policies should focus in the reduction of energy consumption without much concern for long run economic growth. The impacts of economic recession to CO₂ emissions due to power generation in Europe during 2008-2009 have been studied (Declercq et al., 2011). The authors investigated the influence of electricity demand, CO_2 prices and fuel prices in power sector emissions. They concluded that there is a big impact on CO_2 emissions due to fuel and CO_2 prices. A report related with energy efficiencies policies and measures in Greece has been presented (CRES, 2010). According to this study the energy efficiency index for all sectors of the Greek economy decreased by 32% between 1990 and 2010. Taking into account that various energy efficiency measures started to apply since 2008 combined with the economic crisis, the total energy efficiency index is gradually decreasing after 2008. The report concludes that the impacts of the economic recession are visible in all sectors of the economy resulting in lower energy consumption in Greece. The increase of CO₂ emissions in Greece during 1990-2002 using Laspeyres model has been investigated (Diakoulaki et al., 2006). The authors found that CO_2 emissions are strongly coupled with energy consumption and economic growth. However, there are some encouraging signs against this general trend, related with improvements of the energy mix in electricity generation as well as in using less polluting vehicles resulting in the decrease of energy intensity in the transportation sector. CO₂ emissions in Greece during 1990-2002 have been investigated (Hatzigeorgiou et al., 2008). Emissions were decomposed in four factors, income effect, energy intensity effect, fuel share effect and population effect. The results have shown that the most important factor increasing CO₂ emissions is the income effect but also the population factor contributed positively. Energy intensity effect was the most important factor reducing CO₂ emissions and fuel share effect has also a small negative contribution since 1997 onwards.

2. The Energy System of Crete

Crete is highly depended on oil for energy production (81%) compared with the Greek average (61%) (Zografakis, 2005). The area of Crete is 8335 km² compared with 131 960 km² of Greece and its population in 2011 was 623 065 inhabitants compared with 10 816 286 inhabitants in the country.

The energy system of Crete is based on the use of a mixture of fossil fuels and renewable energy sources including:

- Diesel oil
- Fuel oil
- Heating oil
- Gasoline

- LPG
- Solar energy
- Wind energy
- Solid biomass
- Biogas
- Hydroelectricity
- 2.1 Electricity Generation

In Crete, electricity is mainly generated in three thermoelectric plants located in different parts of the island which use fuel oil and heating oil as primary energy sources. Renewable energy sources currently contribute annually up to 23 % to the total electricity generation in the island. Among renewable energies, solar PV and wind energy dominate contributing significantly to the total electricity generation, however small amounts are additionally generated with two small biogas units and two small hydroelectric plants. Currently there are in Crete over thirty operating wind farms with nominal capacity 0,5-6 MW each and over a thousand solar-PV units with nominal power 5-100 KWp each. Fuel oil and heating oil are used for power generation in Crete with steam turbines, gas turbines, diesel engines and a combined cycle plant. Natural gas or solid fuels are not used for electricity generation in the island.

2.2 Heat Generation

Energy sources currently used for heat generation in Crete include

- Electricity
- Fuel oil and heating oil
- Solar-thermal energy
- Solid biomass mainly locally produced
- Small quantities of LPG
- Low enthalpy geothermal energy with heat pumps

The last years due to the severe economic crisis many people have either heat less their homes, since the climate in Crete is rather mild during the winter, or they have changed the fuel which they use in their buildings and, instead of heating oil, they use locally produced solid biomass which is significantly cheaper in Crete compared with heating oil. The same has happened in small and medium size enterprises which have replaced the previously used fuel and heating oil with solid biomass. The most popular solid biomass fuels used are olive Kernel wood with a total production in Crete of 110 000 tons year⁻¹ (Vourdoubas, 2015) as well as olive tree firewoods. Solar thermal energy is extensively used for hot water production in buildings and it is estimated that more than 250 000 m² of solar thermal collectors are installed currently in Crete (Zografakis, 2005).

2.3 Transportation

Energy fuels used for transportation in Crete include

- Gasoline
- Diesel oil
- Small quantities of LPG in some cars.
- Electric vehicles are not used currently in Crete.

3. Energy Consumption in Crete

Electricity consumption in Crete is mainly based on fuel and heating oil and its consumption during 2007-2013 is presented in table 1 (www.statistics.gr).

| Year | Electricity consumption (MWh) |
|------------------|-------------------------------|
| 2007 | 2 703 443 |
| 2008 | 2 700 125 |
| 2009 | 2 743 490 |
| 2010 | 2 776 715 |
| 2011 | 2 652 918 |
| 2012 | 2 691 527 |
| 2013 | 2 682 423 |
| Change 2007-2013 | -0.78% |

Table 1. Electricity consumption in Crete during 2007-2013

Electricity consumption in Crete has been slightly reduced during the period 2007-2013 by 0.78 %.

For heating purposes among fossil fuels, fuel oil and heating oil are mainly used in Crete. The consumption of fuel oil and heating oil for heat generation during 2007-2013 in Crete is presented in table 2 (www.statistics.gr).

Table2. Fuel oil and heating oil consumption for heat generation in Crete during 2007-2013

| Year | Fuel oil (tons) | Heating oil (tons) |
|------------------|-----------------|--------------------|
| 2007 | 10 119 | 127 008 |
| 2008 | 10 197 | 110 552 |
| 2009 | 9501 | 110 785 |
| 2010 | 7884 | 86 897 |
| 2011 | 6694 | 99 814 |
| 2012 | 5192 | 69 493 |
| 2013 | 5661 | 25 123 |
| Change 2007-2013 | -44.06% | -80.22% |

Use of fuel and heating oil for heat generation is affected from the weather conditions each winter. The decrease of fuel oil and heating oil consumption in Crete during 2007-2013 was 80.22 % and 44.06 % correspondingly.

In transportation sector the fuels used in Crete are gasoline and diesel oil. Their consumption during 2007-2013 is presented in table 3 (www.statistics.gr).

| Year | Gasoline (tons) | Diesel oil (tons) | | |
|------------------|-----------------|-------------------|--|--|
| 2007 | 245 007 | 187 752 | | |
| 2008 | 241 619 | 204 260 | | |
| 2009 | 233 894 | 174 349 | | |
| 2010 | 211 436 | 163 520 | | |
| 2011 | 195 462 | 139 013 | | |
| 2012 | 173 658 | 127 129 | | |
| 2013 | 164 549 | 138 666 | | |
| Change 2007-2013 | -32.84 % | -26.14 % | | |

Table 3. Gasoline and diesel oil consumption for transportation in Crete during 2007-2013

The decrease of gasoline and diesel oil consumption in Crete during 2007-2013 was 32.84 % and 26.14 % correspondingly. The percentage reduction of fossil fuels used for heating during this period is higher than in transportation. However, the decrease in electricity consumption is much lower than the decrease of fossil fuels used in heating and in transportation.

4. Economic Recession in Greece

Since 2007 Greece has entered in a long and deep economic recession period with a sharp decrease of the Gross domestic product per capita as is presented in figure 1 (Greece G.D.P. per capita 1960-2015, 2015). This recession had severe impacts on the income of the households since G.D.P. per capita during 2007-2013 had been reduced by 25.45 % and had affected seriously the economic behavior of the citizens. The Cretan G.D.P. per capita is almost equal with the national average (www.crete.gov.gr), and probably its reduction should be similar with it. Regarding energy consumption less income is available to citizens in order to buy the necessary fuels and electrical energy which they need. At the same time households have shifted to cheaper fuels which are more affordable for them in order to meet their energy requirements. Therefore, a consequence of the economic recession is the increase of energy poverty in the society. Many households and enterprises are not able to pay their electricity bills and the national power company disconnects the buildings from the electric grid. The decrease of the available income lowers also fuels consumption in transportation since consumers either limit the use of their vehicles or replace their old vehicles with new, having lower fuel consumption per km. In many blocks of flats and houses the owners cannot afford to buy the necessary heating oil and either they stop heating them, heat them less or they use locally produced solid biomass like firewoods which are cheaper.



Figure 1. Change of G.D.P. of Greece during 2007-2013

5. Changes in Oil Prices

Energy consumption depends adversely on energy prices. Although taxes on final oil products are high in Greece, changes of crude oil prices have slightly affected the prices of electricity and various oil based fuels during the period 2007-2013. Crude oil prices in this period have been temporarily decreased after the global economic crisis of 2007-2008 and are shown in table 4 (www.eia.gov).

Table 4. Changes in crude oil prices during 2007-2013

| Year | Oil price (US dollars) |
|------|------------------------|
| 2007 | 77.16 |
| 2008 | 102.41 |
| 2009 | 65.52 |
| 2010 | 82.79 |
| 2011 | 108.59 |
| 2012 | 104.84 |
| 2013 | 100.29 |

6. Increase of Energy Efficiency

The last years, an increase of energy efficiency has been obtained in Greece in various sectors of the economy as a consequence of the following factors:

- Changes in the legal framework concerning energy efficiency in buildings and the obligation of regular energy inspection in them (Greek law 3661/2008).
- Governmental financial support concerning investments promoting energy efficiency in various enterprises. Financial support is also offered through European Structural Funds in energy renovation of public and private buildings.
- Improvements and innovations in energy technologies result in more reliable and economical attractive energy saving technologies, techniques and systems.
- Due to governmental incentives like tax reliefs, old vehicles have been replaced with new having lower fuel consumption.
- More efficient plants and technologies are currently used for energy generation and distribution.

The combined effect of the abovementioned factors resulted in the increase of the energy efficiency in buildings as well as in other sectors of the economy. The increase of energy efficiency results in lower demand of electricity and of various energy fuels from the consumers. New legislation also came in force in Greece in order to comply with the E.U. directives (2006/32, 2012/27) concerning promotion of energy efficiency in member states.

Recent studies until 2014 (CRES, 2010) have shown a significant reduction in primary energy intensity (ratio of

primary energy consumption to gross domestic product) and in final energy intensity (ratio of final energy consumption to gross domestic product) in Greece particularly in the period 2008-2010. It has pointed out that this is due mainly to economic crisis but also to the successful energy saving policies applied after 2008 in Greece.

7. Change of the Energy Mix for Power Generation in Crete

The last fifteen years a significant change in the energy mix for electricity generation in Crete has taken place. Although in the beginning of the 21^{st} century the main fuels used for power generation in Crete were fuel and heating oil, gradually solar and wind energy have penetrated in the energy mix and today approx. 22-23 % of the annual generated electricity in the island is provided from wind farms and solar PV plants. The contribution of two very small hydroelectricity plants and two small biogas plants in total power generation is rather negligible. If the electricity grid of Crete had been interconnected with the grid of continental Greece or if pump storage systems had been created, then the contribution of solar PV and wind energy in power generation in Crete would have been much higher. The increasing use of the abovementioned renewable energies in power generation in Crete existing thermoelectric power stations. A big shift in fuels used for heat generation has also taken place and diesel and fuel oil have been replaced in buildings and in small enterprises with locally produced solid biomass which is cheaper.

8. Population Changes

According to the recent census, population of Crete has increased by 3.65 % during the period 2001-2011 from 601 131 to 623 065 inhabitants. On the contrary the population of Greece has slightly decreased over the same period by 0.88% from 10 964 020 to 10 816 286 inhabitants (www.statistics.gr).

9. CO₂Prices

European carbon dioxide emission trading system allows the reduction of greenhouse gas emissions by sending a price positive signal to low carbon technologies. The price of CO_2 has been reduced significantly from 2008 to 2013, from over 30 dollars per ton to less than 5 dollars per ton (What's needed to fix the EU's carbon market). The collapse in the prices is due to the inbalance between the supply and demand of carbon permits and discourages the use of sustainable energies.

10. CO₂Emissions Due to EnergyUse in Crete

 CO_2 emissions due to fossil fuels used for electricity generation heating and transportation in Crete have been estimated using emissions coefficients as follows:

| Fuel oil | 3.65 | kgCO ₂ Kg ⁻¹ |
|-------------|------|------------------------------------|
| Heating oil | 3.15 | kgCO ₂ Kg ⁻¹ |
| Diesel oil | 3.20 | kgCO ₂ Kg ⁻¹ |
| Gasoline | 3.30 | kgCO ₂ Kg ⁻¹ |

The existing thermoelectric plants in Crete use mainly fuel oil and heating oil for electricity generation in a proportion 3:1. For the estimations it has been assumed that electricity generation from renewable energies in Crete has been increased steadily during the period 2007-2013. During 2007, 90 % of primary energy sources used for electricity generation were fossil fuels (the rest were renewable energies), and since then they have been gradually reduced to 78 % by 2013 (the remaining 22% are renewable energies). CO_2 emissions in electricity generation, in heating and in transportation in Crete are presented in table 5.

Table 5. CO₂ emissions in Crete due to electricity generation, heating and transportation (tons/year).

| | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 |
|------------------------|----------|----------|-----------|-----------|----------|----------|----------|
| Electricity generation | 2323 000 | 2266 000 | 2 252 000 | 2 224 000 | 2076 000 | 2054 000 | 2005 000 |
| Heating | 440 009 | 385 458 | 383 652 | 302 503 | 338 847 | 237 854 | 99 800 |
| Transportation | 1409 329 | 1450 975 | 1 329 767 | 1 221 003 | 1103 768 | 979 884 | 986 743 |
| TOTAL | 4172 338 | 4102 433 | 3 965 419 | 3 747 506 | 3518 615 | 3271 738 | 3091 543 |

Assuming that the population of Crete in 2013 was 623 065 inhabitants , CO_2 emissions per capita this year were 4.96 tons CO_2 .

11. Discussion and Conclusions

Economic recession in Greece since 2008 which affected all the regions in the country resulted in significant reduction of energy consumption and CO2 emissions in Crete during 2007-2013. The decrease of energy consumption and CO₂ emissions has been influenced from economic recession, changes of the population, changes of the energy mix used and in energy efficiency as well as from changes in crude oil and CO₂ prices. Data from current crisis, confirm the hypothesis that "emissions are coupled with growth", simply now we observe negative growth that results to decrease in emissions, the relationship has not changed. Reduction of G.D.P. per capita has decreased the available income resulting in lower energy consumption and CO_2 emissions due to energy use. The reduction is sharper in the heating and transportation sector since people heat less their houses and use less their vehicles. At the same time, commercial transportation of goods has been reduced. Weather conditions and mild winters in Crete allow less heating of the buildings without serious consequences. Many people have also changed the fuel used for heating their homes and instead of heating oil they are turning to solid biomass which is cheap and locally produced in Crete mainly from olive trees. This explains the sharp decrease at 80.22 % of heating oil used in Crete at this period. During 2007-2013 reduction of CO₂ emissions in Crete (25.90 %) is almost the same with the decrease of Greek G.D.P. per capita (25.45 %). Since the G.D.P. per capita in Crete does not differ significantly to the national average, this indicates the coupling of expansion or shrinking of the economy with CO₂ emissions. Population increase results in higher energy consumption and during this period a slight increase of Cretan population has been occurred although in the country the opposite has happened. Energy mix and the percentage of fossil fuels in it also affect CO₂ emissions. The increasing use of renewable energies in Crete during this period has resulted in lower CO₂ emissions. Solar and wind energy are extensively used for power generation and solar thermal energy and solid biomass for heat generation. Increases in energy efficiency and energy productivity result in lower CO_2 emissions. After 2008 new policies and various measures were adopted in Greece which resulted in the improvement of energy efficiency, both in supply and demand side, in power generation and transmission as well as in heating and in transportation. The contribution of the heating sector in CO₂ emissions during 2007-2013 has been reduced significantly those years and the contribution of electricity generation has been increased. The obligation of energy inspection in buildings has improved their energy efficiency and various incentives offered for more efficient vehicles, resulted in energy efficiency improvements in the transportation sector. During 2007-2013 energy efficiency has increased in Crete as well as in Greece. Oil prices affect energy consumption and during this period oil prices were varying from 65 to 109 U.S. dollars barrel⁻¹. Finally CO_2 prices influence energy and fossil fuels consumption and during this period CO₂ prices were sharply decreased from $30 \in \text{ton}^{-1}$ to $5 \in \text{ton}^{-1}$. Carbon dioxide emissions per capita in Crete in 2013 are relatively low, slightly less than 5 tons, due to the absence of heavy industries as well as power stations using coal in the island.

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