MODELING THE RELATIONSHIP AMONG ENERGY DEMAND, CO₂ EMISSIONS AND ECONOMIC DEVELOPMENT: A SURVEY FOR THE CASE OF GREECE

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ABSTRACT
The purpose of this paper is to offer an initial presentation and classification of the methodological approaches used to analyzing energy demand, related CO₂ emissions and economic development for countries, regions and subsequently to provide for an extended survey of related articles for the case-study of Greece that identified 48 scientific publications. It was found that all three main existent methodological analytical schemes, namely 'Top-down' models, Econometric methods and Decomposition Analysis methods, have been applied to model energy, environmental and macro-economic variables for Greece. Specific application areas included sectoral (industrial, transport, tourism, manufacturing, residential and electricity) energy demand and related CO₂ emissions, energy prices and energy taxation. The paper culminates to a comprehensive comparison of employed methods and obtained results for Greece and conclusions.

KEYWORDS: Energy demand, CO₂ emissions, Economic development, Survey, Greece.

INTRODUCTION
As a fundamentally empirical activity, the practice of modeling of the relationship among energy use, CO₂ emissions and economic development is necessarily a synthesis of data and methods (Greening et al., 2007). To this end, particular quantitative methodological tools and models appeared in the scientific literature in the late 70s, early 80s.

The objective of this article is to provide for an initiatory overview and categorization of the methodologies used in this area, and a survey and a first round comparison of relevant studies for the case of Greece. There is a multi-dimensional need for this review paper:

- There emerges an urgent need for current economic recession to be analyzed and accordingly tackled in order for Greece to be back on track towards a sustainable state form an economic, energy and environmental point of view.
- Greece has ratified the Kyoto Protocol and is in the process of assessing its course regarding greenhouse gas emissions under the post-Kyoto procedures.
- According to the Ministry of Development of Greece, at the end of 2020 CO₂ emissions will surpass the 1990 level by 68% leading the country to an unsustainable state from an environmental point of view (YPAN, 2004). Nevertheless, recent severe economic recession has significantly affected energy consumption and it would be expected that new scenarios for CO₂ emissions will be set at lower levels.
- Energy intensity has been decreased by 13% for 1980-2005, indicating improvements in energy efficiency and a shift from industry towards services, which are typically less energy intensive (YPAN, 2004).
- Under the 1980–2009 period, structural changes in the Greek energy sector (e.g. the penetration of natural gas in the electricity generation and the building sector) and economic reforms programmes (e.g. Community Support Framework I, II and III) have occurred, whereas the National Strategic Reference Framework is currently under progress.
• Greece could play a strategic role as a gas transit country (Doukas et al., 2010).

The paper is organized as follows. Section 2 provides an overview of the basic methodological approaches; Section 3 presents the surveyed studies in a classified form, a description of their main features and a comparison of methods and results. Finally, in Section 4, the conclusions of the review are summarized.

BASIC METHODOLOGICAL APPROACHES
Figure 1 presents the most common methodologies for investigating the relationship among Energy demand, CO$_2$ emissions and Economic development.

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**‘Top-down’ models**
This category of models/methodologies comprises of Computable General Equilibrium (CGE) models and macro-economic models that utilize econometrically estimated parameters as input data. The main advantage of this approach is the depiction of economy-wide interactions including impacts on sector and total output, employment, consumption, investment, trade, prices and wages (Allan et al., 2007).

**Decomposition Analysis (DA) methods**
Decomposition Analysis (DA) methods constitute a widely accepted analytical tool for policymaking in energy and environmental issues; characteristically the paper by Liu and Ang, 2007 lists a total of 336 related publications up to 2006. Nevertheless, although widely used by a variety of researchers and organizations, no single or standard DA method for has emerged (Tol and Weyant, 2006). DA methods include Index Decomposition Analysis (IDA) and Structural Decomposition Analysis (SDA) and have a long history of independent development, leading to different approaches and techniques. IDA methods can be further divided into two groups: techniques based on the Divisia Index and techniques linked to the Laspeyres Index. For a review of IDA methods one may refer to Ang and Zhang, 2000 and Ang, 2004; an overview of SDA methods is provided by Rose and Casler, 1996.

**Econometric methods**
Econometric methods include single-equation models, simultaneous-equation models and time series models. They can range in complexity from very simple to relatively sophisticated, and can be
applied to data of varying temporal, spatial, and sectoral detail. Since the seminal work of Kraft and Kraft, 1978 different time series techniques such as correlation analysis, simple regressions, bivariate causality, unit root testing, multivariate cointegration, panel cointegration, and Vector Error Correction Modeling (VECM) have been carried out in order to determine the causal relationship between energy use and economic growth. A comprehensive review of this type of literature is presented in Ghali and El-Sakka, 2004. Particularly, the causal relationship between energy use and economic output has been the topic of considerable research in the energy economics literature; characteristically the paper by Chontanawat et al., 2008 provides causality tests between energy consumption and Gross Domestic Product (GDP) for over 100 countries.

It should be noted that other types of models that study energy consumption and related CO\textsubscript{2} emissions also exist, however they fail to account for macro-economic variables in their analysis. Examples of such models are the so called ‘bottom-up’ detailed technological models that are based on disaggregation and the inclusion of a large number of technical parameters. These parameters represent the different end-sectors of an economy or the different end-use energy demand (Jacobsen, 1998). Models based on the bottom-up approach can be either optimization/programming (Mavrotas et al., 2007) or simulation models (Gilen and Taylor, 2007; Oda et al., 2007).

It is evident that there exists a variety of methodological approaches for modeling the relationship among energy consumption, CO\textsubscript{2} emissions and economic output (for an ex post evaluation of European energy models, one may refer to Pilavachi et al., 2008) and that no compendium existed that surveyed the methods used in this area for the case of a particular country or region. We therefore hereinafter gather, present and categorize papers on a range of topics that deal within the general area of energy-economy-environment interactions analysis for the case of Greece.

CLASSIFICATION – MAIN FEATURES OF PAST STUDIES

Presentation of reviewed studies

We have reviewed 48 papers that deal with the modeling of macroeconomic, energy and environmental variables and their linkages for the case of Greece (Table 1).

<table>
<thead>
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<th>No</th>
<th>Publication</th>
<th>Methodological Approach</th>
<th>Application Area</th>
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<td>1</td>
<td>Agoris et al., 2004</td>
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<td>2</td>
<td>Caloghirou et al., 1997</td>
<td>Econometric methods</td>
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<tr>
<td>3</td>
<td>Capros et al., 2001</td>
<td>‘Top-down’ models</td>
<td>Sectoral CO\textsubscript{2} Emissions</td>
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<td>4</td>
<td>Capros and Vouyoukas, 2000</td>
<td>‘Top-down’ models</td>
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<td>5</td>
<td>Capros and Mantzos, 2000a</td>
<td>‘Top-down’ models</td>
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<td>6</td>
<td>Capros and Mantzos, 2000b</td>
<td>‘Top-down’ models</td>
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<tr>
<td>7</td>
<td>Capros and Mantzos, 2000c</td>
<td>‘Top-down’ models</td>
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<td>8</td>
<td>Capros and Mantzos, 1999</td>
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<td>9</td>
<td>Capros et al., 1999a</td>
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<td>10</td>
<td>Capros et al., 1999b</td>
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<td>11</td>
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<td>13</td>
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<td>Energy Efficiency</td>
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<tr>
<td>15</td>
<td>Christodoulakis et al., 2000</td>
<td>Top-down models</td>
<td>Energy Consumption</td>
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</table>
Table 1 (continued). Studies based on 'Top-down' models, DA methods and Econometric methods, for the Greek energy system (presented alphabetically)

<table>
<thead>
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<th>No</th>
<th>Publication</th>
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Methodological Approach

To study possible changes over time, we classified the studies into three time periods: 1980–1990, 1990–2000, and 2000–2011. The total numbers of publications in these three periods are respectively 3, 14, and 31. Figure 2 presents the number of studies during the selected sub-periods, according to the applied methodological approach.

Figure 2. Number of studies according to the applied methodology

From Figure 2 the following remarks can be given:

- For the first sub-period we have identified only 3 studies (Donatos and Mergos, 1989; Mitropoulos et al., 1982; Samouilidis and Mitropoulos, 1984) which have investigated energy demand and its association to output and prices, using conventional econometric techniques. The paper by Samouilidis and Mitropoulos, 1984 is probably the first publication in a recognized scientific journal, in this line.

- Most studies dealing with the application of 'Top-down' models to the Greek economy have appeared in the literature at the beginning of 2000s. The majority of these articles analyzed the impact of certain economic activities or governmental policies on energy consumption and related CO2 emissions using macroeconomic models (e.g. Christodoulakis et al., 2000). It can also be observed that 43% of the selected papers in the 1990-2000 time period adopted econometrics methods. Characteristically, the publication by Donatos and Mergos, 1991 examined the residential electricity consumption over the period 1961-1986, using a single equation model.

- During the last sub-period, IDA has been an area in which extensive research has been conducted; the share taken up by IDA applications is 35%. Examples of such studies include Diakoulaki and Mandaraka, 2007, Diakoulaki et al., 2006, Diakoulaki et al., 2000. In addition, Hatzigeorgiou et al., 2008, investigated the factors that explain the increase of energy-related CO2 emissions in Greece from 1990 to 2002 by means of the Arithmetic Mean Divisia Index (AMDI) and the Logarithmic Mean Divisia Index (LMDI) techniques on a period-wise and on a time-series basis. Recently, Hristou-Varsakelis et al., 2011 have used a SDA analysis to optimize production with CO2 emission constraints in Greece.

- Considering the studies dealing with the econometric methods, in the 2000-2011 time period we have collated 13 published papers which have investigated the relationship between energy demand and economic growth on the basis of modern econometric approaches. An illustrative example of such studies is the article by Hordroyiannis et al., 2002 which has examined the empirical relationship between energy consumption and economic growth (1960-1996) by means of cointegration and Granger causality tests. In addition, Hatzigeorgiou et al., 2011 investigated the causality among GDP, energy intensity and CO2 emissions from 1977 to 2007, in Greece, using, modern techniques of time series analysis.
**Application Area**

In the third column of Table 1 papers are presented by application area. Application area consists of two (2) basic categories: (1) energy-related CO\(_2\) emissions analysis and (2) energy demand analysis.

Particularly, it is found that 50% of the selected studies deal with the analysis of overall (e.g. Hatzigeorgiou et al., 2008; Papadopoulos and Haralambopoulos, 2006) or sectoral energy related CO\(_2\) emissions (e.g. Diakoulaki et al., 2007; Hondroyiannis, 2002; Salta et al., 2009). Further breakdown shows substantial increase in the number of energy related CO\(_2\) emissions studies whose share in total studies raised from nil in 1980-1990 to 58% in 2000–2011. This might be the result of the world-wide concern on global environmental issues and sustainable development. Most of these studies are concerned with historical analysis. However, the study by Hatzigeorgiou et al., 2010 decomposed changes of future energy-related CO\(_2\) emissions, by means of IDA, while Capros and Mantzos, 2000 use the macroeconomic model PRIMES to project CO\(_2\) emissions up to 2030. Energy demand and energy consumption analysis is another popular application area for energy researchers in Greece. Of the 48 selected studies, 19 deal with this area. Until the earlier 2000s most of the publications, focused on energy demand projections, were based on ‘Top-down’ models. In other papers, sectoral energy demand is estimated using econometric methods; see, for example, Hondroyiannis 2004, Polemis, 2006 and Rapanos and Polemis, 2005.

Lastly, and in addition to the two application areas discussed, econometric methods have also been applied to study the impact of the environmental taxation on energy demand (Rapanos and Polemis, 2005; Rapanos, 1995; Vassos and Vlachou, 2005).

**Comparison of methods and results**

Several exercises of modeling energy-economy-environment mechanisms have been made for the case of Greece that started form primitive single equation models in the early 80’ until more cohesive multivariate time series analysis models lately. More particularly and following the classification of Figure 1 we may address the following. ‘Top-down’ models have been employed to estimate and project demand functions by sector of economic activity and type of energy. The work of Christodoulakis et al., 2000 is a representative example of such an approach. The authors found that energy demand follows closely economic output and that the annual growth of CO\(_2\) emissions for the period 1990-2012 would be around 2%. Decomposition Analysis methods disentangle distinct components behind historical energy and/or emissions data in order to identify the factors that might have caused the observed changes. In a characteristically example Diakoulaki et al., 2006 have applied DA methods for Greece and for the time period of 1990-2002 and concluded that economic growth is strongly coupled with energy consumption and related emissions. In particular, they culminated to the fact that the economic activity is responsible for a +150% of total change of CO\(_2\) emissions, while energy intensity is responsible for a -35% of total change. Finally, econometric methods investigate whether economic growth takes precedence over energy consumption or if energy consumption can boost economic growth. Modern econometric techniques focus on exploring the association mechanisms among energy, economic and environmental time series data. Hondroyiannis et al., 2002 uncover that there is a long-run relationship between energy consumption, real GPD and price developments for the studied 1960-1996 time period. More recently Hatzigeorgiou et al., 2011 also concluded that CO\(_2\) emissions and GPD are causally interrelated.

Even though all these methodologies investigate the generic relationship among energy, economic and environmental parameters from different points of view and for different purposes, one may say that for the case-study of Greece most scholars have evidenced that there exists a quite strong bi-directional relationship between energy consumption/CO\(_2\) emissions and economic output. This main common finding might aid potential policy makers to identify, design and promote adequate relevant fiscal measures tailor-made for Greece to boost social welfare.

**CONCLUSIONS**

In contemporary energy planning studies, a broad set of empirical tools has been used to investigate the relationship among energy demand, CO\(_2\) emissions and economic development. The comparison of different methodological approaches and results has significant policy implications for the countries, regions studied. This paper offers an initial presentation and classification of
methodologies for analyzing potential links among energy demand, related CO$_2$ emissions and economic development for countries, regions. An extended survey for the case-study of Greece is subsequently presented that identified 48 relevant publications. Next, these studies have been categorized according to the methodological approach adopted, the application area and time-period. A comprehensive comparison of employed methods and results obtained is also unfolded to aid to the identification of the main features of these studies. It was found that all three main existent methodologies, 'Top-down' models, Econometric methods and Decomposition Analysis methods, widely used in current literature, have been applied to model energy, environmental and macro-economic variables for Greece. Specific application areas included sectoral, i.e. industrial, transport, tourism, manufacturing, residential, electricity energy demand and related CO$_2$ emissions, energy prices and energy taxation. Further research could be directed towards the additional analysis of the results for Greece, and subsequently the integration of current methodological approaches to more advanced platforms that would better model current energy, economic and environmental systems.

REFERENCES


