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Monitoring the sustainability of the Greek energy system

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ABSTRACT

A concise set of energy indicators is proposed to assess the sustainability of the Greek energy system from 1960 onwards. Three generalized indices, each corresponding to one of the three dimensions of sustainable development (social, environmental and economic) are defined, estimated and presented in the form of a ternary plot. Results are used to analyze whether the energy system developed in a sustainable way, and to identify its weaknesses and deficiencies. The analysis further demonstrates the representativeness of the chosen set of indicators, and its ability to describe the most significant changes that occurred during the studied period.

The analysis spans a period of 47 years, during which significant political, social and economic events took place in Greece. Results show that the development of the energy system has been mainly driven by social aspects. Environmental performance improvements are particularly evident during the last decade; however, a lot remains to be done to achieve national and European policy objectives. With regard to the social dimension, accessibility has substantially improved and disparities between low and high income households have narrowed. Nevertheless, energy prices have been continuously increasing at a rate higher than income. On economic terms, the initially observed improvement in productivity is misleading, as it was mostly caused by the increase of the Gross Domestic Product rather than energy efficiency improvements, while energy security has been worsening during the last decade.

Introduction

Greece is at a pivotal point regarding the formulation of energy policies in conjunction with environmental protection. During the next ten years these will have to be harmonized with the European Union Directives, focusing on the reduction of the greenhouse gas (GHG) emissions, penetration of renewable energy sources (RES) and energy saving. At the same time, due to the recent global economic crisis and the country's adverse economic situation, the measures taken should be chosen carefully so as not to further compound the problem.

Proposing energy policies under such restrictions requires monitoring the progress of the energy system towards sustainability, within the overall economic, social and environmental framework. It is also important to know the system's current state, regarding both the achievement of its objectives and its sustainable development and to recognize what improvements are needed and how these can be implemented. Finally, it is critical to assess the impact of possible future actions on the system's behavior. To this end, energy indicators can be a simple and useful tool for monitoring, measuring and evaluating the current and future effects of energy use on the economy, the society and the environment.

The important role that indicators can play in helping policy makers to reach the appropriate decisions for sustainable development was recognized by the 1992 Earth Summit (Vera and Langlois, 2007). The first attempt to create a set of "Indicators for Sustainable Development" (ISD) was made in 1995 by the United Nations' Department of Economic and Social Affairs (UNDESA, 2001). The approach was general and only three of the proposed indicators were energy related (annual energy consumption per capita, energy intensity and share of renewable energy consumption).

The list of energy indicators proposed and used over the last 15 years is extensive (e.g. IAEA et al., 2005; EEA, 2005; DTI, 2006). Large indicator sets have the advantage of covering all aspects of sustainability and providing detailed insight into the energy system. Their complexity, however, renders their interpretation difficult, and they cannot provide a concise general overview of the system's behavior (Hardi and Barg, 1997). Therefore, these sets are not suitable for decision-making purposes, because without any aggregation, they are simple metrics that do not indicate something useful about the progress of the system.

In the present case, i.e. analysis of an energy system, a smaller set with fewer but representative indicators could be more appropriate (Kemmler and Spreng, 2007). However, the formulation of such a set is not an easy task and there is no standardized or commonly

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accepted methodology. Moreover, it is highly dependent on the specific characteristics of the analysis' objectives.

The scope of this paper is to propose a small but representative set of energy indicators in order to assess the economic, social and environmental dimension of an energy system's sustainable development. These indicators will provide an overview of the system, depicting its weaknesses and the required improvements. Furthermore, as they fluctuate over time they will be good markers of progress and underlying changes and may guide energy policy making. The proposed set of indicators is used to analyze the sustainability of the Greek energy system in conjunction with the EU policy requirements.

Greek energy system

A brief overview of the analysis period

In the last 50 years, the period selected for the historical analysis, a number of significant political, social and economic events have taken place in Greece. A very significant event which greatly influenced the economic, social and political life of Greece for many years was the imposition of the Greek military dictatorship from 1967 to 1974. Due to the aggressive policies of the regime, this period is marked by high rates of economic growth, a considerable increase of the country's GDP, low inflation and low unemployment. Many significant infrastructure improvements were realized, including the construction of large scale hydroelectric dams and thermal electric generation plants in the energy sector. The junta was overthrown on July 1974 and the constitution declaring the Third Hellenic Republic was promulgated on 11 June 1975.

In the years following the restoration of democracy, the economic and political situation was stabilized leading to another significant milestone, the admission of Greece as the tenth member of the European Union. Despite this favorable development, Greece suffered from poor macroeconomic performance during the 1980s, due to the expansionary fiscal policies that were adopted, and as a result the country was forced to implement stabilization programs in the late 1980s.

The financial conditions were further aggravated due to political instability caused by the implementation of the electoral law of simple proportionality and the three consecutive elections held in one year (1989). However, Greece gradually managed to improve its financial situation and in 2001 succeeded in meeting the criteria for admission into the Eurozone and adopted euro as its currency. Despite the temporary positive impact of this event on the country, the Greek economy continued to face significant problems, and by the end of 2009 it was characterized by the second highest debt and the second highest budget deficit in Europe, resulting in a severe and ongoing economic crisis.

Another significant but controversial event was the hosting of the 2004 Olympic Games. The advertised positive impact of the Games on the country's economic development is currently being questioned by a large part of the local population, who consider that the Games have led to significant social and environmental degradation. Finally, amongst the international events of the period examined, those with the greatest influence on energy consumption in Greece were the oil crises of 1973 and 1979.

Overview of the Greek energy policies

Greece has very limited domestic fossil resources (mainly lignite). During the first years of the period under study Greece was depending mainly on imported crude oil and petroleum products. The problem became obvious after the first oil crisis (1973–1974) which was followed by a sudden increase in oil prices.

The policies adopted from 1973 onwards have focused on the exploitation of domestic energy resources, such as lignite and hydro, the creation of domestic infrastructure for generating electricity and oil refining, the construction of electrical interconnections to neighboring countries, and finally, the diversification of supply (Agoris et al., 2004). Indigenous lignite gradually became the main source of electricity generation, the refineries tripled their capacity in three years (from 1970 to 1973) and finally natural gas was introduced into the Greek energy system (1996). During the previous decade, further emphasis was placed on environmental protection, RES penetration and increase of energy use efficiency in order to harmonize legislation with the EU Directives.

The year 2020 is a milestone for both Greece and Europe because it marks the deadline for meeting the objectives set within the framework of the European energy policy. The three main objectives are RES penetration in the national energy system, reduction of the GHG emissions and energy savings.

Greece must ensure that the share of energy from renewable sources in the gross final consumption of energy in 2020 will be at least 18% and the respective share in all forms of transport will be at least 10% of the sector's final consumption (Directive 2009/28/EC). Law 3851/2010 follows these guidelines, stating that the Greek government has agreed that RES penetration will reach 20% in gross final consumption and 40% in electricity generation by 2020.

Greece must also limit its 2020 greenhouse gas emissions by at least 4% in relation to 2005 emissions for the sectors included in the greenhouse gas emissions trading scheme and by 21% for all other sectors (Decision 406/2009/EC). Finally, according to the Directive 2006/32/EC, Greece should aim to improve energy services and to adopt other energy efficiency measures in order to achieve an overall national energy savings target of 9% for 2016, compared to the annual energy consumption of the period 2001–2005.

Energy system assessment

The criteria that need to be taken into consideration in order to formulate a representative set of indicators are summarized as follows (Patlitzianas et al., 2008):

- Criterion 1: Appropriateness, including transparency, simplicity and ability of comparison
- Criterion 2: Completeness, including technical and scientific adequacy and international acknowledgment
- Criterion 3: Flexibility, including easy calculation, availability of right quality data and ability of mapping changes.

The set of indicators proposed in the current study is formulated in such a way as to satisfy the above criteria, to reflect all dimensions of sustainable development (economic, environmental and social) and to express the objectives of EU and Greek energy policies. The selected set of indicators used in the analysis is presented in Table 1. It is primarily based on the “Energy Indicators for Sustainable Development” (EISD) set, developed by IAEA et al. (2005), which is the set most commonly used in other related studies (Pereira et al., 2008. Streimikiene et al., 2007; Streimikiene and Šivickas, 2008).

All the data necessary for the estimation of social indicators have been drawn from the annual censuses and the inventory of household amenities, conducted every 5–8 years by the Hellenic Statistical Authority. Both are available at the Authority's digital library (El. Stat, 2009). All data needed for the estimation of economic and environmental indicators have been drawn from the annual energy balance published by the Hellenic Ministry of Development (YPAN, 2009) and the database of Eurostat, the statistical office of the European Union (EUROSTAT, 2009).

Social dimension

The social aspect of the energy system is related to its ability to provide commercial fuels and modern energy services in affordable

Table 1
Proposed set of energy indicators.

Abbr.	Name	Description
Social dimension		
SOC1	Accessibility	Share of households with access to electricity or commercial energy
SOC2	Affordability	Share of household income spent on fuel and electricity
SOC3	Disparities	Share of household expenditure spent on energy for each income group
Economic dimension		
ECO1	Overall use	Final and residential energy consumption per capita
ECO2	Productivity	Total primary energy supply per unit of GDP
ECO3	Dependency	Energy imports per total amount of primary energy supply
Environmental dimension		
ENV1	Climate change	GHG emissions per capita or per unit of GDP
ENV2	RES in FEC	Share of RES in final energy consumption
ENV3	RES in electricity	Share of RES in electricity generation

prices to all people. The issues of accessibility, affordability and social disparities are considered in this analysis.

Lack of access to energy services may have serious effects on consumer health (e.g. burning fuel indoors in open fires, use of inflammable fuels for lighting). Energy should be available to everyone at a fair price and inability to achieve that could lead to marginalization of poor people and social unrest. Table 2 presents the share of households with access to electricity and modern energy services for space heating and cooking, two of the main energy end uses in the residential sector (SOC1). All of them show a continuously increasing trend, starting from the foundation of the Public Power Corporation in 1950, which marked the beginning of the rapid gradual electrification of the whole country. It should be noted that electric cooking appliances are the only reliable indicator for assessing access to commercial energy for cooking. Natural gas was introduced in the domestic sector only in the last decade and its share is still very low and other more traditional appliances have not been recorded overtime by the Statistical Authority.

Table 2 also exhibits the share of household income spent on fuel and electricity (SOC2). The percentage has slightly increased from 4% in 1974 to 6% in the last decade, indicating that fuel prices are increasing at a higher rate than income. As the same data is not available disaggregated for the eight different income categories, the share of household expenditure on energy, disaggregated for the above mentioned groups, is used instead for the calculation of the social disparities indicator (SOC3) (Fig. 1). Lower income groups use a larger share of their budget (14% in 1974, 9% in 2004) to satisfy their basic energy needs compared to the higher income families, who spent 2–3% of their budget during the period under study. However, the difference in allocated income between high and low income families has slightly narrowed over time from 10% to 7%. Although in absolute numbers the high income groups consume more energy, the social inequity and the inability of low income groups to meet other basic needs should be given more attention.

Table 2
Share of households with access to electricity or commercial energy and share of household income spent on fuel and electricity.

Year	SOC1			SOC2
	Electricity access	Electrical cooking appliances	Central heating	Share of household income spent on fuel and electricity
1962	95%	28%	N/A	N/A
1968	98%	46%	N/A	N/A
1974	99%	50%	20%	4.8%
1982	99%	53%	31%	5.1%
1988	99%	64%	37%	4.3%
1994	97%	78%	50%	3.6%
1999	99%	83%	59%	2.9%
2004	100%	86%	68%	3.0%

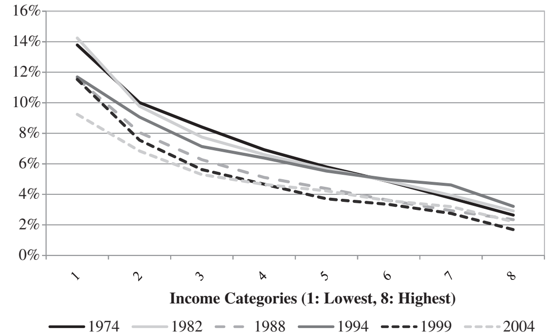

Fig. 1. Share of household expenditure on energy for 8 different income groups (SOC3).

In conclusion, concerning the social dimension of the system, commercial forms of energy are accessible to the majority of the population, disparities between low and high income households have narrowed but not sufficiently enough to alleviate the differences and the energy prices have been increasing at a higher rate than income.

Economic dimension

Modern economies depend on reliable and adequate energy supply, and developing countries need to secure this as a prerequisite for industrialization in order to raise productivity, enable local income generation and improve the standard of living (IAEA et al., 2005). The indicators used to monitor the economic sustainability of the energy system are energy use per capita, productivity and energy dependency.

According to Vera and Langlois (2007) energy consumption per capita is an indicator of the aggregate intensity of a society and, in some cases, can be used as an indicator of economic prosperity. However, a very high value may indicate excessive use of energy with negative impacts to both the society and the environment. Fig. 2 presents the evolution of the final and the residential energy consumption per capita (ECO1). They follow similar increasing trends, almost during the whole period under study, with small but significant differences. Their evolution can be divided into 4 discrete periods (1960–1973, 1974–1995, 1996–2003 and 2004–onwards). During the first period and especially during the dictatorship, a sudden increase is observed. With regard to the final energy consumption, this is mainly a result of

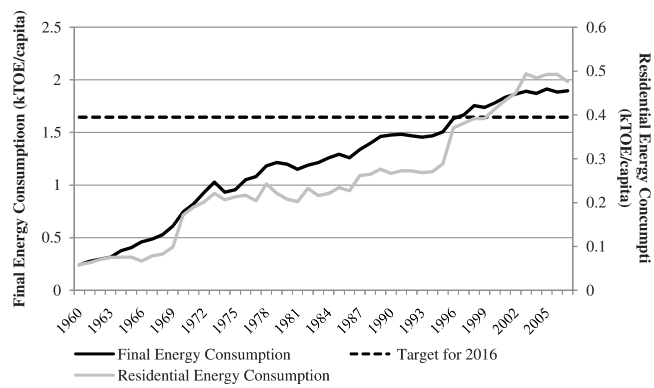

Fig. 2. Final and residential energy consumption, in million tons of oil equivalent per capita (ECO1).

the country's industrialization, which was almost complete at that time, while for the residential energy consumption, the increase is due to the rapid urbanization that was observed as a result of the political circumstances. In the two years following the restoration of democracy, a short decline is noted due to the social and political instability.

Over the next two decades (1976–1995) residential energy consumption continues to increase at a steady rate proportional to that of the population growth whereas the final energy consumption increases at a higher rate. A few abnormalities can be observed in the curve (stabilization or even decline) in years following general elections (1981, 1985 and 1989). Particularly in the last case the consumption remained stable for almost 5 years as a result of the political instability. Both curves reach their peak during the period that followed the assignment of the Olympic Games, an event that led to considerable infrastructure improvement in the country. During the last years of the period under study, consumption appears to stabilize, most probably due to energy saving measures that were implemented within the framework of the European policy. This trend is expected to remain the same over the following years or even decline because of the recent economic crisis.

Primary energy intensity (ECO2), defined as the ratio of the total primary energy supply per unit of gross domestic product, reflects the general relationship between energy use and economic development (Streimikiene et al., 2007). It is a good marker of the overall productivity of the energy system. Fig. 3 presents the evolution over time of the primary energy intensity as well as its decomposition, thus clarifying the main factors affecting it. The decomposition analysis is based on a Divisia Index approach as presented by Ang (2004).

This analysis reveals that the changes in energy intensity are mainly influenced by the overall growth of the economy (activity impact) rather than by changes in the structure of the economy or the contributions of each sector (structural impact). Moreover, the activity and structural effects showed positive values throughout the period and were increasing until 1990, reflecting the industrialization of the country. The decline observed in the last decade results from the shift of the economy towards less energy intensive sectors such as services and tourism.

Another way of monitoring the productivity of the system is by comparing the GDP per capita with its efficiency, defined as the inverse ratio of its energy intensity. Fig. 4 presents the evolution of these two values by dividing the period under study into three distinct phases. The first phase, lasting from 1960 until the first oil crisis, is characterized by quite high efficiency but low GDP per capita. In the second phase, from 1973 until 2001, the Greek energy system shows increasing GDP but decreasing efficiency. This was triggered by the policies aiming to introduce indigenous energy sources in order to minimize the dependence of the system on oil imports and the

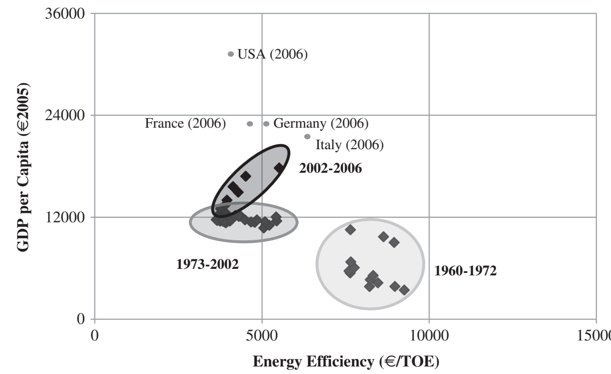

Fig. 4. GDP per capita vs. energy efficiency of the energy system (euros per ton of oil equivalent).

situation remained the same during the following 30 years. The share of lignite in electricity generation increased drastically (from 30% in 1973 to 70% in 2000) but this had a negative impact to the efficiency of the energy system. The sudden change observed in the last few years is due mainly to the preparations for the Olympic Games, which have led to the improvement of both the efficiency and the per capita GDP, and secondly to the implementation of energy saving measures. Efficiency was further improved by introducing more efficient electricity generation technologies (natural gas turbines, wind turbines). This trend, however, is expected to be completely reversed in the near future as the current GDP rate of change is zero or even negative because of the economic crisis.

Energy dependency (ECO3) is also a big issue for the Greek energy system, which was highly dependent on imported fossil fuels during the first years of the period under study (~80% in 1968). The energy policies focusing on the exploitation of domestic sources were successful and the ratio of the energy imports per total amount of primary energy supply was reduced to 50% in just 7 years (Fig. 5). It remained steady for the following 20 years but presented a slight increase as a result of the substitution of indigenous lignite with imported natural gas.

In conclusion, with respect to the economic dimension of the system the continuous increase of energy consumption has been reduced, possibly due to energy saving measures. On the other hand, energy intensity and, to a lesser degree, energy security are declining, due both to the GDP growth, rather than energy efficiency improvements, and to the increase of natural gas share against indigenous lignite.

Environmental dimension

Fig. 6 displays the total annual greenhouse gas emissions per capita and the emissions intensity, defined as the ratio of the greenhouse gas

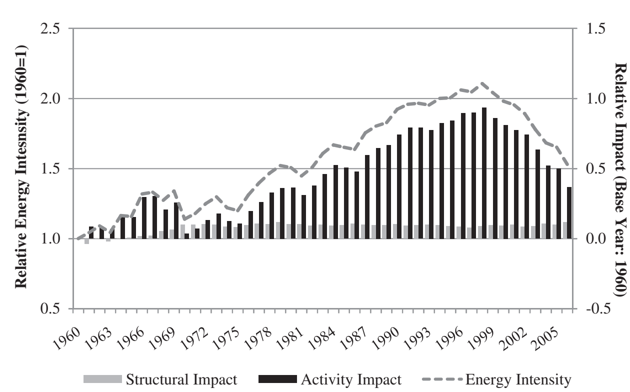

Fig. 3. Total primary energy supply per unit of GDP in relative values (ECO2).

Fig. 5. Energy imports per total amount of primary energy supply (ECO3).

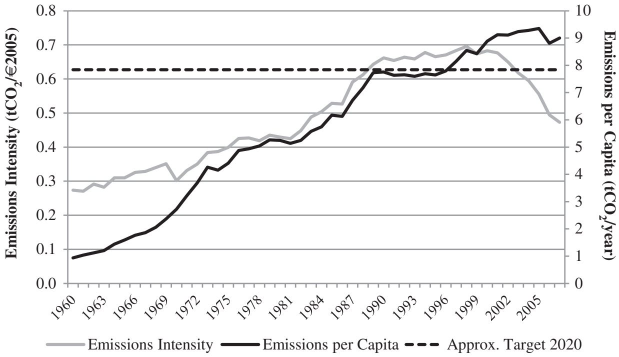

Fig. 6. GHG emissions per capita and per unit of GDP (ENV1).

emissions per unit of GDP (ENV1). It is obvious that the evolution of the Greek energy system and of the country in general in the last 50 years has completely ignored its environmental dimension. The same four-period pattern can be used for further analysis, similar to energy consumption.

However, in this case the stabilization of the emissions during the first half of the 1990s is more obvious. This is due to increased environmental awareness, which was significant during that period but improved drastically due to the Kyoto Meeting in 1997. The sudden decrease in emissions intensity during the last decade is caused by the increase of GDP rather than actual emissions reduction.

The shares of RES in final energy consumption (ENV2) and in electricity generation (ENV3) are displayed in Fig. 7. They both remain steady for the last 25 years, at around 4% and 18% respectively, and it becomes obvious that further efforts are needed in order to reach the targets set for 2020. Furthermore, the following observations concerning the evaluation of these two indicators should be noted:

- Fluctuations in electricity generation are due to the varying ratios of the available hydroelectric capacity used for this purpose.
- The peak of 1969 is not "real" and is caused by the lack of data for biomass consumption in the previous years.

It is pointless to include in the environmental indicators the penetration of RES in the transport sector, because its share has been insignificant throughout the whole period. However, in a study of the future evolution of the system, it should be taken into account because it reflects the corresponding EU Directive.

In conclusion, concerning the environmental dimension of the system, positive trends are observed in all indices. However, there is still a lot to be done in order to achieve the objectives set by the European Union.

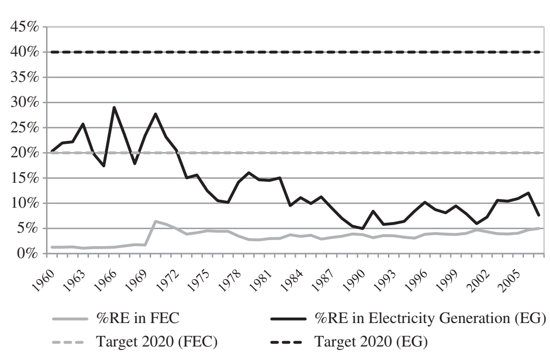

Fig. 7. Share of renewable energy sources in final energy consumption (ENV2) and in electricity generation (ENV3).

Overall sustainability assessment of the energy system

For monitoring the overall progress of the energy system towards sustainable development, the energy indicators are aggregated into three overall indices. The procedure of creating these consists of the following steps:

a. Scaling of the indicators' values to a 0–1 interval, where 0 corresponds to the worst and 1 to the best value of the period examined. The following equation is used:

$$SI'_x = RelMax-(RelMax-RelMin)*(\max \mathrm{SI}-SI_x)/(\max SI-\min SI) \quad (1)$$

where SI_x is the selected indicator for the year x, SI'_x is the respective normalized indicator, $\max SI, \min SI$ are the maximum and minimum values of the indicator for the period under study ($1, 2, \ldots, n$ *years*) and *RelMax*, *RelMin* are two 0–1 values indicating whether the optimal value of the indicator is the lowest or the highest possible. $RelMax = 1$ and $RelMin = 0$ when the indicator has a positive influence, i.e. higher values are better, whereas $RelMax = 0$ and $RelMin = 1$ when the indicator has a negative influence.

b. Assessment of the weights (W_x) for each individual indicator. In the present analysis, all indicators are considered to have equal weights.

c. Calculation of the three overall indices using the following equations

$$OSI_x = \sum W_x SI'_x / \sum W_x \quad (2)$$

where OSI_x is the overall sustainability index for the year x.

The evolution of all three overall indices in absolute values is displayed in Fig. 8. It reveals that the social viability index has been continuously increasing and is currently at a higher level compared to the economic and environmental indices. At the same time the similarities in the evolution of the economic and environmental indices during the period under study should be underlined. They have remained stable until 1972 and then followed a continuously decreasing trend until 1990. A differentiation is observed only during the last decade, when the environmental dimension improves, mainly because of the public awareness associated with the Kyoto protocol, whereas the economic index remains stable. This last observation is worrying in combination with the current economic situation of the country and indicative of the efforts that should be made for its development.

In addition, a ternary diagram is used in order to further illustrate the relative changes in the evolution of the three indices and to identify how balanced the development of the country's energy system has been. According to Xu et al. (2006) the use of such a diagram seems to hold promise as an analytical management tool, given its simplicity, ease of use and flexibility.

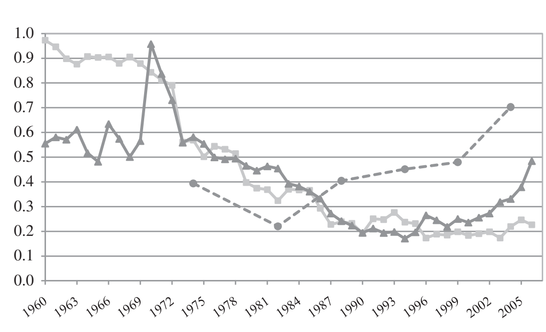

Fig. 8. Evolution of sustainability indices (in absolute values).

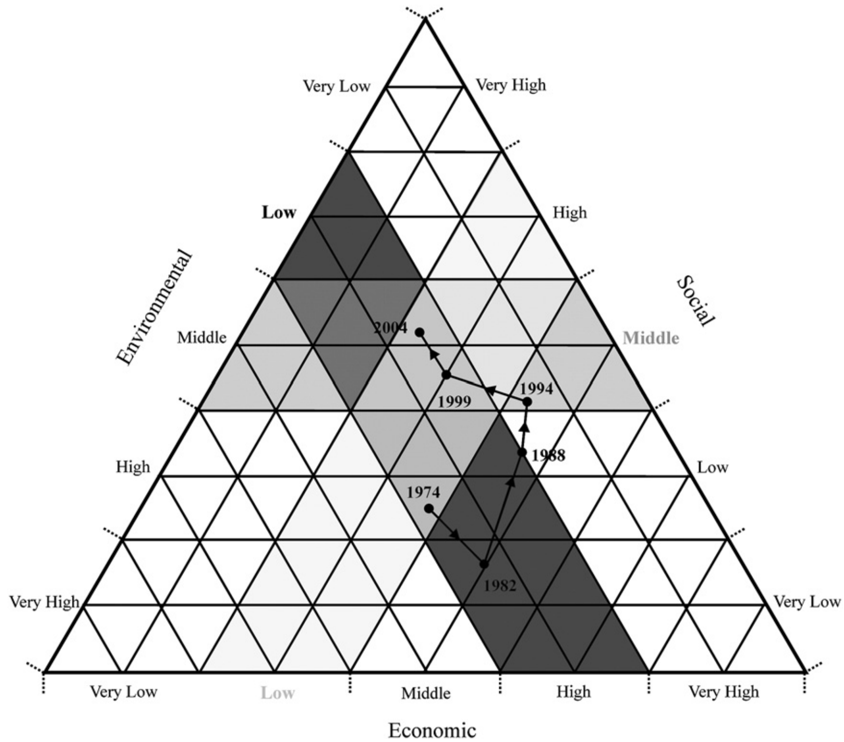

Fig. 9. Evolution of sustainability indices (in relative values).

Fig. 9 reveals an increase of the social sustainability index from a low to high relative value over the last years. This confirms the emphasis given to the improvement of the social dimension of development as compared to the other two, initially the environmental and later the economic dimensions. Unfortunately, due to lack of data for the calculation of social indicators, the diagram displays results for six years only.

Discussion — further research

The preceding analysis shows an unbalanced development of the Greek energy system. During the last 47 years, emphasis has been given on the social dimension, improving the accessibility to modern and commercial types of energy, and not so much on economic viability. The environmental dimension of the problem, which has been given particular attention in recent years due to international agreements and obligations, shows signs of improvement. However, more drastic measures are required in this direction.

It should be underlined that the proposed subset of indices is representative, reflecting the events and developments of the period under study. Hence, it may be used as a tool for the evaluation of future energy strategies. Results obtained through this work could be complemented through further research on alternative indicator weights, focusing on the objectives set and energy policy axes, and on the development of an overall composite index, integrating different sustainability indicators. Finally, alternative actions and strategies could be defined and assessed towards the development of a future long term energy plan for Greece.

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