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Environmental efficiency of investments in renewable energy: Comparative analysis at macroeconomic level

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ABSTRACT

This paper aims to bring into attention the concept of renewable energy investments' efficiency and to study one of the three concepts related to it, namely environmental efficiency of investments in renewable energy. The analysis is undertaken at macroeconomic level for several countries in Europe; some of them are member states of European Union and were observed over the period between 1990 and 2008. The method assumes the study of the econometric models based on Kaya identity, an equation widely used in studies regarding emissions, trends and future emissions scenarios. Working with time series and cross-sectional data, a panel data approach is needed. Indicators like energy intensity, CO_2 intensity and gross domestic product per capita and per unit of investment are used, as they establish a connection between effects and efforts (a prerequisite for studying the efficiency). A novelty of this research lies in the calculation of environmental efficiency index after an original method proposed by authors. The findings of this analysis reveal that there are both countries with high and low environmental efficiency of investments in renewable energy.

Contents

1. Introduction

The beginning of new millennium was marked by a series of developments that will surely be amplified in coming years. In the same time they will generate reactions triggered by the desire of permanently change in the human society lifestyle. In terms of more limited resources and of needs constantly multiplying and diversifying, the concept of efficiency has a permanently valability in actual economic and social life. Currently, any human activity (economic or social) is initiated considering the principles of efficiency and effectiveness. In a general sense, efficiency represents the interaction established between the volume and structure of undertaken efforts and the volume and structure of obtained results. Continuous improvement of individual living standards and the economic development of the community should be always based on a prior study of human activity's efficiency. Strongly connected with the study of economic efficiency, there is an another important concept, namely the investment's efficiency. The investments highly stimulate any development process and they are considered "as a material support for economic growth" [1].

As we stated before, the limited resources represent one of the main reasons for a moderate consumption; this moderation should keep the satisfying of individual necessities and should not affect the environment or the social well-being. As we considered in a previous work, energy consumption fits perfectly for discussing aspects like economic, social and environmental aspects of development. In the

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same time, we should not forget that energy field is the most debated issue in the last decades, due to the global context of sustainable development. Specialists are focused on renewable energies and on their promotion, considering the benefits they bring and the advantages they have against traditional energy. One of the many ways of convincing the humanity on the green energy's importance for our future, is to study the efficiency of investments allocated to this type of energy.

It is well known that the investments in renewable energy (RE) registered an increasing trend in the last decade all around the world [2]. Studying their efficiency provides insights for further developing of new investments. The topic of investments' efficiency is very complex, based on a large number of effects generated by those investments. As shown in a prior work [3], these effects generate three distinctive concepts:

- Economic efficiency of investments;
- Environmental (or ecological) efficiency of investments;
- Social efficiency of investments.

All three concepts will be treated in separate works. In the present paper, we will focus on studying the environmental efficiency of investments in renewable energy. The proposed investigation will be conducted at macroeconomic level (the society as a whole) using energy and economic indicators for several states from Europe, some of them part of European Union: CO_2 emissions from electricity and heat production, total (million metric tons); GDP per capita (constant 2000 dollars); electricity production (kWh); electricity production from renewable sources (kWh); gross inland consumption of energy (all products) (1000 tones oil equivalent). As far as we are concerned, there is no study at macroeconomic level for environmental efficiency of renewable energy investments. The method we are proposing is different from the classic (which asses the economic efficiency based on several specific indicators). Moreover, it follows an econometric approach, in order to build a linear regression model for revealing the efficiency of investments. Such an analysis reveals comparisons among countries and each country's position as against European Union's situation (here, European Union has 22 countries).

2. Literature review

Efficiency is a very complex topic. It should be analyzed from an economic and a social point of view, at macroeconomic and microeconomic level, static and dynamic, by branches of national economy, etc. An efficiency analysis provides guidance for projects in areas with priority for the national economy, projects that contribute to the achievement of sustainable development objectives [4]. The rapidly and unpredictable changes in the economic and social aspects of the economy (sometimes called new economy, digital economy, knowledge-based economy [5,6]), require complex approaches on investment decisions [7].

The environmental efficiency is a relatively new concept, born from the concerns about global warming, CO_2 emissions mitigation, resource recycling and other environmental factors [8–10]. Researches on environmental efficiency evaluation highlight the "urgent need" [11–14] for developing new methods and applications for efficiency assessment. Some use the Data Envelopment Analysis (DEA) method [15], others use estimation procedures of traditional distance functions that facilitate the deployment of environmental efficiency and productivity studies within a parametric stochastic context [16]. A methodological difficulty was afterwards associated to the first type of method [17]. The difficulty lies in unifying operational performance on desirable outputs with environmental performance on undesirable outputs. Therefore, economic and mathematical perspectives of environmental assessment were approached.

Another interesting perspective of assessing the environmental efficiency is the one of the Rodríguez Morilla et al. [18] who uses the Social Accounting Matrix and Environmental Accounts (SAMEA) for Spain, in order to determine the so-called multipliers for environmental efficiency evaluation.

The environmental efficiency is also found in the literature as ecological efficiency or eco-efficiency. In their research, Reith and Guidry [19] analyze the eco-efficiency in the agricultural sector; in the same area, Gómez-Limón et al. [20] study the eco-efficiency of the olive farms from Andalusia (in their study, they bring into light concepts like eco-efficiency management and eco-efficiency production). Michelsen et al. [21] present a methodology for understanding and measuring eco-efficiency in the furniture production, referring to extended supply chains. Li et al. [22] undertake an analysis at city level for determining the eco-efficiency of a residential development by proposing a new methodology with implications for policy-makers and decision-makers in the industry. In their work, Côté et al. [23] discuss different definitions for eco-efficiency, comparing several businesses and pointing out the driving forces of eco-efficiency. Fernández-Viñé et al. [24] perform their research in the small and medium sized enterprises from Venezuela in the context of eco-efficiency, revealing in the end differences among them. Taking into consideration the examples provided above, we appreciate that "environmental efficiency" is commonly used when conducting macroeconomic analysis; the "eco-efficiency" term is more used when conducting microeconomic analysis.

Moreover, the concept of ecological efficiency also seems to reflect facts happening at microeconomic level [25,26]. Slobodkin [27] appreciates that ecological efficiency represents "the fraction passed on to the next higher trophic level of energy consumed by a particular ecological unit – for example, a population or trophic level". He manages to measure this type of efficiency on a scale from 0 to 1, considering that "statements about ecological efficiency of entire communities are meaningless". There are also other authors who tried to evaluate the ecological efficiency, this time for a cogeneration system in a hospital [28]. Their findings revealed that the method can be applied to any sort of thermal system.

The environmental efficiency has been studied as a sole element of interest or in relation with other important aspects regarding efficiency. For instance, there are works which analyze the link between environmental and productive efficiency for EU members and states from US. The connection between the environmental efficiency and social well-being was transposed in a new indicator called Happy Planet Index (HPI) [29]. It establishes the environmental efficiency level that supports the well-being of people in a country. In addition to this, Knight and Rosa [30] constructed a measure for environmental efficiency of well-being (EWEB), using the ecological footprint per capita and average life satisfaction. Their findings reveal that countries widely vary in the efficiency and that the effect of economic development on EWEB is a negative one, as well as the one of income inequality; just the social capital has a positive impact on environmental efficiency.

Furthermore, the environmental efficiency was subject to studies all around the world; for instance, Zaim and Taskin [31] focused on OECD countries using non-parametric techniques. A year later, Zofío and Prieto [32] applied the Data Envelopment Analysis to calculate desirable output losses when specific environmental standards on undesirable production are set by the authorities. The same method is applied by Jaraitė and Di Maria [33] who measure environmental efficiency and productivity of the European Union's public power generation. Another scientific research is conducted for United States by Welch and