An Evaluation of Renewable Energy Indicators within the Sustainability Framework

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The North American Conference on Sustainability, Energy & the Environment 2014
Official Conference Proceedings

Abstract
Environmental concerns such as security of available resources, global warming, greenhouse effect, Carbon and Nitrogen emissions force governments to take preventive actions and make restrictive regulations. One way to provide a clean environment for the future generations is to promote the usage of renewable energy sources and development of renewable energy technologies. In this perspective the researchers used different methods and indicators to evaluate governments and their policies on renewable energy.

In this study, a two-phased taxonomy framework is designed to evaluate renewable energy. The framework has two dimensions; these are general and sustainability dimensions, respectively. For the general dimension three properties are defined, which are global, economic and usage. Sustainability dimension has its own well-known aspects which are environmental, economical and social ones. Each indicator provided from the literature is classified by two properties from each dimension, providing six indicator types. The literature is surveyed with this point of view and a two-phased framework for the indicators that are used evaluate renewable energy is proposed. It is seen that some of these indicators can be easily reached from organizations (OECD, IEA, World Bank, etc.) statistical data, where as some are computed by using these data.

This framework and indicators hereby are presented to provide a basis for researchers who aim to evaluate renewable energy usage. The proposed framework constitutes initial step of an ongoing research project to classify the world countries in the context of renewable energy approach by using data mining techniques.

Keywords: Renewable Energy, Sustainability, Energy Taxonomy, Literature Survey

Introduction

Environmental concerns such as security of available resources, global warming, greenhouse effects, Carbon and Nitrogen emissions force governments to take preventive actions and make restrictive regulations. One way to provide a clean environment for the future generations is to promote the usage of renewable energy sources and development of renewable energy technologies. Long-term initiatives are also a source of motivation for governments to use renewable energy. Energy and oil price volatility makes it difficult to make investment decisions for them. Because energy is a fundamental economic input – for transportation, agriculture, industry and other sectors, low energy prices decrease production costs. Countries are also being exposed to economic and political changes outside the country borders (price hikes, supply shortages) because of dependency on foreign energy sources and security of energy supply.

Sustainability is defined as meeting the needs of the present without compromising the ability of future generations to meet their own needs (Our Common Future, 1987). One interpretation of that definition, in the context of electricity, is to transition away from fossil fuels entirely – due to their carbon emissions and their finite supply (Komor & Bazilian, 2005). Kyoto carbon targets are important in for governments and they intend to reduce their carbon emissions. It is known that over one-third of the greenhouse gas reduction opportunities are identified in the electricity production sector (IEA, 2003). Fossil fuel burning emits various compounds such as SO_x and NO_x that contribute to local and regional air quality problems (Komor & Bazilian, 2005).

In this perspective the researchers used different methods and indicators to evaluate governments and their policies on renewable energy. Some methods used in evaluation of renewable energy are:

- DEA (Chien & Hu, 2007, Wang et al., 2012),
- Granger causality tests (Jinke et al., 2008; Apergis & Payne, 2010; Nazlioglu et al., 2011),
- Emprical studies, interviews (Hirschl, 2009; Martins & Pereira, 2011; Nagy & Körmendi, 2012),
- General evaluations (Valentine, 2011; Baris & Kucukali, 2012),
- Other (Liddle, 2012; Reuter et al, 2012), etc.

Renewable Energy and Sustainability

The definition below is given for Renewable Energy and Sources by The Renewable Energy Working Party of the International Energy Agency (OECD/IEA, 2012).

"***Renewable Energy*** *is derived from natural processes that are replenished constantly. In its various forms, it derives directly or indirectly from the sun, or from heat generated deep within the earth. Included in the definition is energy generated from solar, wind, biofuels, geothermal, hydropower and ocean resources, and biofuels and hydrogen derived from renewable resources.*"

The renewable energy sources are classified by OECD with the given definitions:

"**Hydroelectricity:** Hydroelectricity refers to potential and kinetic energy of water converted into electricity in hydroelectric plants.
Geothermal: Energy available as heat emitted from within the earth's crust, usually in the form of hot water or steam. It is used for electricity generation, heat production for sale to third parties or directly as heat in its primary form.
Solar energy: Solar radiation exploited for electricity generation and hot water production. Passive solar energy for direct heating, cooling or lighting of dwellings or other buildings is not included.
Tide / wave / ocean: Mechanical energy derived from tidal movement, wave motion or ocean current and exploited for electricity generation.
Wind: Kinetic energy of wind exploited for electricity generation by wind turbines.
Biofuels and Renewable Waste: Includes solid biofuels, biogases, liquid biofuels, and the renewable portion of municipal waste."

Energy sector was one of the first in using the term ''sustainable development'' in order to turn the related economic activity into green energy (Sheinbaum-Pardo, 2012). According to "Annual Energy Outlook 2012 with Projections to 2035" which is published by U.S. Energy Information Administration Office, (2012) renewable energy is the fastest growing source of marketed energy. While the fossil fuels share in electricity production is increased between 3% and 4%, the renewable energy share is increased from 10% to 15% in 2010 (Annual Energy Outlook, 2012).

In order to maintain economic growth and provide economic opportunity to citizens which are a vital role of governments, economic sectors such as energy have a significant public sector presence (Komor & Bazilian, 2005). Apart from the recent escalation in energy prices, the dependency on foreign energy sources for petroleum, global climate change, and carbon emissions, government policies (such as renewable energy production tax credits, rebates for the installation of renewable energy systems, renewable energy portfolio standards, and the establishment of markets for renewable energy certificates by various states) has also critical effects on the increasing growth of renewable energy (Bowden & Payne, 2010).

There are a vast range of potential renewable energy programs, ranging from low-cost, low-intervention education programs; to regulatory-based and high intervention forced investments, and many ways to classify renewable energy programs, including demand versus supply, regulatory versus incentive-based, by degree of market intervention, etc (Komor & Bazilian, 2005). In Figure 1 Renewable Energy Goals, Programs, and Technologies for Ireland can be found. There is various programs to promote the usage and development of renewable energy. Strategic Assessment Framework for the Implementation of Rational Energy (SAFIRE) computer model devised by Energy for Sustainable Development Ltd (ESD, UK) was one of them which elaborates development scenarios for renewable energy calculate their financial, environmental and social implications (Oniszk-Popawska et al, 2003).

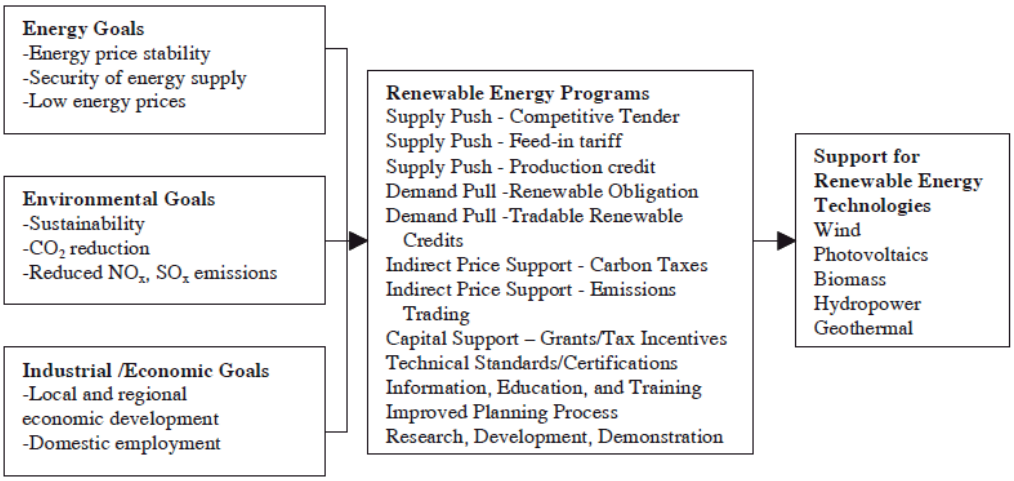

Figure 1. Ireland Renewable Energy Goals, Programs, and Technologies (Komor & Bazilian, 2005)

Owing to the significance of renewable energy around the world, International Energy Agency and OECD, measures the usage of energy and share of renewables annually (Selam et al., 2014). In Figure 2 renewable energy shares for Africa, Asia, China, Latin America, Middle East, OECD countries, Turkey and the World is given for years between 2006 and 2010.

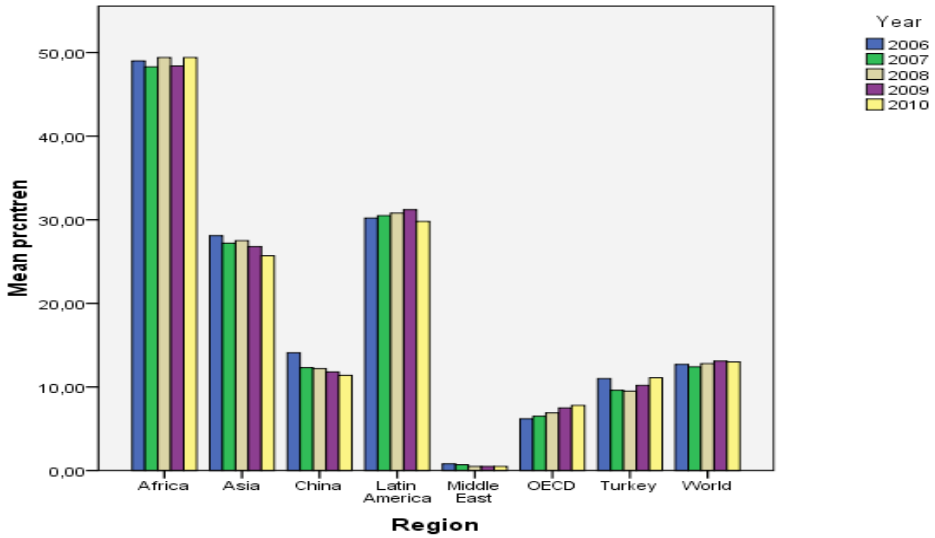

Figure 2. Renewable Energy Share for the World and some important regions (%) (Selam et al., 2014)

Besides, renewable energy is measured with three main categories which are hydro; geothermal, solar, wind, ocean, and tide; biofuels, and renewable waste, respectively. In Table 1 renewable energy usage percentages can be found according to average share of main categories between years 2006 and 2010.

Table 1. Average Renewable Energy Usage for the World and some important regions (%) (Selam et al, 2014)

Region	% Renewable	% Hydro Share	% Geothermal, Solar, Wind Tide & Ocean Share	% Biofuels and Renewable Waste Share
Africa	48,9	1,3	0,2	47,4
Latin America	30,5	10,3	0,5	19,7
Asia	27,1	1,5	1,6	24,0
China	12,4	2,3	0,4	9,7
Middle East	0,6	0,2	0,2	0,2
OECD	7,0	2,1	1,0	3,9
World	12,8	2,3	0,7	9,8
Turkey	10,3	3,5	1,9	4,9

Indicator Taxonomy and Selection

In this study, a two-phased taxonomy framework is designed to evaluate renewable energy. The framework has two dimensions; these are general and sustainability dimensions, respectively. For the general dimension three properties are defined, which are global, economic and usage. Sustainability dimension has its own well-known aspects which are environmental, economical and social ones (Sheinbaum-Pardo et al., 2012).

The indicators hereby have been selected from a variety of articles about renewable energy evaluation. The most frequent and accessible indicators are selected among each group. For the second selection process brainstorming activities and debates have been held among the researchers. The list is eliminated and 14 final indicators have been determined.

Each indicator provided from the literature is classified by two properties from each dimension, providing six indicator types. The literature is surveyed with this point of view and a two-phased framework for the indicators that are used evaluate renewable energy is proposed. The indicator taxonomy under this framework is given in Table 2.

It is seen that some of these indicators can be easily reached from organizations (OECD, IEA, World Bank, Eurostat, World Energy Council etc.) statistical data, where as some are computed by using these data. Data is collected and published yearly for world countries under certain classifications by such organizations.

Table 2. Indicator Taxonomy

General Dimension	**Sustainability Dimension**
Global	Environmental
Economic	Economic
Usage	Social

Energy Indicators

The general information, unit and definition about the selected indicators are referred from the World Bank, World Development Indicators (2014). Apart from that information, literature is surveyed with the aim of analyzing how the selected indicators are used for energy and sustainability evaluation.

The Total Primary Energy Supply (TPES) is the most frequent and basic indicator used to evaluate energy among researchers. This value is calculated by TPES = Indigenous production + imports - exports - international marine bunkers - international aviation bunkers +/- stock changes (World Bank, 2014). In other words, this value provides a country's energy usage. Geller et al., (2006), used TPES in the form of "TPES/GDP" to evaluate OECD energy intensity trends. Similarly, Liddle (2012) used TPES in the same form for the econometrics of endogenous structural breaks to examine changes in energy intensity trends in OECD countries over 1960-2009.

The next two indicators, "of which renewables" and "share of renewables in TPES" are related. The former is the Mtoe value of primary energy supply which is obtained by renewable energy, and the latter is the percentage of it in TPES. Renewable energy is used as a variable to estimate the Technical Efficiency Score of OECD and non-OECD countries in regression analysis (Chien & Hu, 2007). In a study to examine the relationship between renewable energy consumption and economic growth, Apergis and Payne (2010) used Granger Causality Tests for growth for a panel of twenty OECD countries over the period 1985-2005. They also conducted the same test for 6 Central American countries over 1980-2006.

In more detailed researches share of main fuel categories in total renewables are investigated. These categories are hydro; geothermal, solar, wind, tide; biofuels and renewable waste as a percentage of renewable energy. In a prior study the importance of renewable energy is mentioned for the entry of Poland to European Union (Wohlgemutha & Wojtkowska-Lodej, 2003).

Share of hydro fuel in renewable energy and share of geothermal, solar, tide and wind (GSTW) fuel in renewable energy are two other variables in Chien and Hu's (2007) article where Technical Efficiency Score is estimated. Renewable energy sources are used to analyze the Mexican energy policy with the methodological framework for sustainable energy development (Sheinbaum-Pardo et al., 2012). This methoodology is proposed by the Economic Commission for Latin America and the Caribbean and takes renewable energy sources as a general sustainability indicator for the energy sector (Sheinbaum-Pardo et al., 2012).

The two other vital energy sources are natural gas and nuclear energy. Both of the indicators are given in the form of % in TPES. In 2010, world Total Primary Energy Supply (TPES) was 12 782 Mtoe, of which 13,0%, or 1 657 Mtoe, was produced from renewable energy sources (Renewables, 2012). The shares of other energy sources were as follows: 32,2% oil, 27,3% coal, 21,6% natural gas and 5,6% nuclear energy (Renewables, 2012). In this context, natural gas is being used more than renewable energy and nuclear is nearly used as half percent of renewable energy.

Two important indicators in energy evaluation are electricity production; total and from renewable resources. The most commercial type of electricity production mostly relies on rotating turbines attached to electrical generators. It is a continuous process of generating electric power from various renewable and nonrenewable energy sources. Nonrenewable energy sources include coal, oil, gas, nuclear power which raise environmental concerns. On the other hand, hydropower, geothermal, solar, wind, tide, biomass and biofuels are considered as clean, sustainable and renewable energy sources. Wohlgemutha & Wojtkowska-Lodej (2003) studied on electricity industry restructuring approaches employed in the European Union and Poland with a focus on the promotion of the use of renewable-energy sources for electricity generation. In another study, Baris and Kucukali (2012) examined the availability and potential of renewable energy sources in Turkey and assessed government policies, financial and environmental aspects utilizing electricity production and renewable energy sources as significant parameters.

PPP, GDP is gross domestic product converted to international dollars using purchasing power parity rates (World Bank, 2014). In the study of Chien and Hu (2007), GDP is used as an output variable of DEA where they aimed to analyze the effects of renewable energy on the technical efficiency of 45 economies. Apergis and Payne (2011) also used GDP while conducting Granger Casuality Tests to analyse the relationship between renewable energy consumption and economic growth for OECD countries over the period 1985-2005.

Population is one of the development indicators among the world. Instead of separately, population can be used calculate ratios with some other indicators. Labor force participation rate is the proportion of the population ages of 15 and older which is economically active: all people who supply labor for the production of goods and services during a specified period (World Bank, 2014). Capital and labor force are used as the control variables for the panel of fourteen OECD countries during the period 1980-2007 in the empirical model to determine the direction causality between nuclear energy consumption and economic growth in OECD countries (Nazlioglu et al., 2011). Apergis and Payne (2011) have also used labor force in their article when conducting Granger Causality Tests. Labor force has also been a variable to estimate Technical Efficiency Scores in Chien and Hu's (2007) research.

Most of the literature on renewable energy includes carbon dioxide emissions (CO_2). World Bank (2014) defines CO_2 emissions as follows: "Carbon dioxide emissions are those stemming from the burning of fossil fuels and the manufacture of cement. They include carbon dioxide produced during consumption of solid, liquid, and gas fuels and gas flaring." In this study CO_2 emissions are taken as kg per 2011 PPP $ of GDP.

One of the principal environmental goals of Ireland is to reduce carbon emissions and other atmospheric pollutants such as NO_x and SO_x and encourage "emission free" renewable energy generation (Komor & Bazilian, 2005). Especially, electricity production sector focus on CO_2 emissions to mitigate climate change (Komor & Bazilian, 2005). According to Jinke et al. (2008) the world energy economy is carbon based and CO_2 emission is obviously linked to economic growth. Also Jinke et al. (2008) suggest the major OECD or non-OECD countries (especially China, India and South Africa) to make efforts to reduce their CO_2 emissions resulted from coal consumption. Hirschl (2009) analyze renewable energy policy at the international

level and provide content analyses of numerous official documents and information obtained through interviews with different experts. Some notes from the article are as follows: i) As CO_2-based projects, renewable energy projects yield lower reduction quantities than the industrial projects aiming other greenhouse gases with much higher CO_2 equivalents. ii) Although in theory, the increase in CO_2 prices can provide a boon to investors in renewable energy, experiences in the emissions trading market show that the stability of the price developments has not been sufficient for satisfactory investment security and investment incentive (Hirschl, 2009).

Energy consumption in transport is represented by the consumptions of petrol and diesel oil. In our study, fuel prices and road sector energy consumption are also taken into account. The fuel prices are represented as the pump price for gasoline (US$ per liter) and pump price for diesel fuel (US$ per liter) (World Bank, 2014). World Bank calculates these pump prices by taking the pump prices of the most widely sold grades of gasoline and diesel fuel and converting them from local currency to U.S. dollars. Road energy consumption is used as a % of total energy consumption. World Bank definition of road sector energy consumption is as follows: "the total energy used in the road sector including petroleum products, natural gas, electricity, and combustible renewable and waste". According to Strategic Assessment Framework for the Implementation of Rational Energy (SAFIRE) computer model, database of the model include fuel sector data containing fuel prices and each fuel's share in the individual sectors (Oniszk-Poplawska et al., 2003). As well as road energy consumption, fuel prices play a vital on the energy sector. Especially depletion of fossil fuels have important effect on fuel prices which lead the sector to the biofuels.

Conclusion

Each indicator provided from the literature is classified by two properties from each dimension, providing six indicator types. The literature is surveyed with this point of view and a two-phased framework for the indicators that are used evaluate renewable energy is proposed. This framework and indicators hereby are presented to provide a basis for researchers who aim to evaluate renewable energy usage.

Finally, the 14 selected indicators can be classified as energy-based indicators (TPES, of which renewables, share of renewables, share of main fuel categories, share of natural gas, share of nuclear energy, electricity production, road energy consumption), economy-based indicators (GDP, population, labor force participation rate, pump prices for gasoline and diesel fuels) and environment-based indicator (CO_2 emissions). The increasing usage of energy-based indicators leads researcher to the assessment of renewable energy around the world. Economy-based indicators are also widely used to evaluate countries. Reduction of CO_2 emissions is emphasized in most of the studies in the literature as an objective for using renewable energy.

The proposed framework constitutes the initial step of an ongoing research project to classify the world countries in the context of renewable energy approaches by using data mining techniques. In Table 3 selected indicators can be found with their dimensions assigned hereby and a detailed description from the World Bank is provided.

Table 3. Selected Indicators

Indicator Name	Indicator Unit	General Dimension	Sustainability Dimension	Definition
TPES	Mtoe	Usage	Economic	Consists of: Indigenous production + imports - exports - international marine bunkers - international aviation bunkers +/- stock changes
Of which renewables	Mtoe	Usage	Environmental	Primary energy supply from renewables
Share of renewables in TPES	% in TPES	Usage	Environmental	Percentage of renewable energy in TPES
Share of main fuel categories in total renewables	% in renewables	Usage	Environmental	a- Hydro b- Geothermal, solar, wind, tide c- Biofuels and renewable waste
Share of natural gas	% in TPES	Usage	Environmental	Primary energy supply from natural gas
Share of nuclear energy	% in TPES	Usage	Environmental	Primary energy supply from nuclear energy
Electricity production	kWh	Usage	Economic	Electricity production is measured at the terminals of all alternator sets in a station.
Electricity production from renewable sources	kWh	Usage	Environmental	Electricity production from renewable sources includes hydropower, geothermal, solar, tides, wind, biomass, and biofuels.
GDP, PPP	constant 2011 international $	Economic	Economic	PPP GDP is gross domestic product converted to international dollars using purchasing power parity rates.
Population	Midyear estimates	Global	Social	Total population is based on the de facto definition of population, which counts all residents regardless of legal status or citizenship.
Labor force participation rate, total	% of total population ages 15+	Global	Social	Labor force participation rate is the proportion of the population ages 15 and older that is economically active.
CO_2 emissions	kg per 2011 PPP $ of GDP	Global	Environmental	CO_2 emissions are those stemming from the burning of fossil fuels and the manufacture of cement.
Road sector energy consumption	% of total energy consumption	Usage	Environmental	Road sector energy consumption is the total energy used in the road sector including petroleum products, natural gas, electricity, and combustible renewable and waste.
Pump price for gasoline & diesel fuel	US$ per liter	Economic	Environmental	Fuel prices refer to the pump prices of the most widely sold grade of gasoline & diesel fuel.

Acknowledgments

This research was supported by Marmara University, Scientific Research Fund (BAPKO), Istanbul, Turkey. Project No. FEN-A-100713-0330.

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