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A Decision-Making Problem for Investment on Renewable Energy Sources in Turkey

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ABSTRACT: The priority of the countries is to achieve economic development and increase the wealth of their nations. In order to achieve this goal, countries need a crucial element which is energy. Most popular of these alternative energy sources are the renewable energy sources which are friendly to the environment and inexhaustible. Since there are several renewable energy sources, an important question arrived; "Which renewable energy source is better to invest?". In this study, in order to answer this question in the Turkish case, we checked the effects of each renewable energy sources to economic growth. With this result and the advantages and disadvantages of each renewable energy sources, we conduct a decision-making problem by using AHP (Analytical Hierarchy Process). In this way, we have created a hierarchical structure among the renewable energy sources in Turkey.

Keywords *– Renewable Energy, Cointegration Tests, AHP, Decision Making, Mathematical Modelling*

1. Introduction

As economies grow and become more complex, their energy needs have increased dramatically, and pre-developed energy methods become insufficient (Timmons et al., 2014:3). As the conventional energy sources (fossil fuels) are exhaustible and harmful to nature, the need for new energy sources has arisen. The most popular of these sources are renewable energy sources which are mostly harmless to the nature and considered inexhaustible since they are always renewed by the naturel process. These renewable energy sources are Hydraulic energy, Wind energy, Solar energy, Geothermal energy, Biomass energy, Marine energy, and Hydrogen energy.

Renewable energy sources can be restored after use in a short time by the natural process. As known, fossil fuel sources have been formed in billions of years, so it is impossible to return to their original state after use. This is the greatest advantage of renewable energy sources on fossil fuels. With this advantage, renewable energy sources are considered as a key solution to climate change and increased energy demand. Several economies are adjusting their policies to increase the use of renewable energies. However, the mechanism of how the renewable energy usage would improve the GDP is still unknown (Chien and Hu, 2008: 3046).

The biggest disadvantage of the renewable energy sources is the lack of continuity. For instance, energy cannot be generated from wind turbines when the wind is not blowing or from solar panel at night (or/and when the sun is not shining). In addition to this, because of the disadvantages such as high installing costs, underdeveloped technologies and too high storage costs, investments for renewable energies remained limited until 2000s. In last two decades, the investment costs of renewable energy sources have decreased by technological improvements and investments have become more attractive.

According to data from EUROSTAT, in 2015, Turkey's total energy consumption was 131 Thousand toe, and 115 Thousand toe of this consumption was obtained from fossil fuels. In other words, about 88% of the energy demand is met by fossil fuels. In addition, due to the lack of domestic fossil fuel reserves, Turkey meets the majority of the energy needs by import. According to the data taken from the TURKSTAT, total imports in the same year amounted about $207 billion, $37 billion of which was allocated for energy imports. These data demonstrate the potential contribution of investment in renewable energy sources to the Turkish economy.

In Turkey, which can be regarded as rich country in renewable energy sources, investments have remained low due to both political and economic reasons until the last decade. Economic potential of renewable energy sources in Turkey is calculated as 140 TWh/yr hydraulic, 120 TWh/yr wind, 305 TWh/yr solar, 6 TWh/yr geothermal and 17 mtoe/yr (246 TWh/yr) biomass (Demir and Emeksiz, 2016: 84; Benli, 2013: 41; Koçaslan, 2010: 58; Kapluhan, 2014: 114).

Although the renewable energy sources have the biggest advantage with being inexhaustible, they also have many disadvantages such as high initial investment cost, energy potential not the same everywhere, and storage problems. Therefore, when planning the investments, the advantages and disadvantages should be carefully determined, and care should be taken not to waste scarce resources. That is, it should be determined which renewable energy source is more advantageous for the country or region and which one should be given priority. At this point, a decision can be made with the help of mathematical modeling, using factors such as advantages and disadvantages of each resource, expert opinions, investment costs, etc. However, if the impact of each resource on the economy is not considered, a wrong decision is most likely to be made. For this reason, the contribution of each resource to the economy should be determined. Since econometric analysis can be used to estimate the actual values of these effects, we decided to conduct an econometric analysis and include the values in the mathematical model. So, we created a mathematical model using factors such as the potential of each of the renewable energy sources, investment cost, effects on economy and expert opinions. It was decided that using AHP (Analytical Hierarchy Process) in the model to create a hierarchical structure among renewable energy sources would help to make the most effective decision.

In the second section of the study, after giving information about each renewable energy sources, their advantages and disadvantages for Turkey were examined. The next section includes the information about the AHP model to be used in the analysis. In the fourth section of the study, the effects of each renewable energy sources to Turkish economy is determined by econometric analysis, and then using the data from the second part of the study and the econometric analysis results, mathematical model is formed. As a result of AHP model, hierarchical structure among the renewable energy sources in Turkey is created.

2. Renewable Energy Sources and Turkey

In this part of the study, we will explain the advantages and disadvantages of renewable energy sources in Turkey. Since no marine energy and hydrogen energy installed in Turkey, these two types of renewable energy have been ignored in our study.

2.1. Hydraulic Energy

Hydraulic energy is a kind of energy provided by converting the potential energy of the water into kinetic energy (TÜRÇEV, 2014: 13). The theoretical potential of hydroelectric in Turkey is about 433 TWh and economic potential of this is about 140 TWh. By the end of 2017, 27.27 GW of installed hydroelectric capacity approximately corresponds to 32% of Turkey's total installed power capacity. Hydroelectric production was calculated as 58.5 TWh in 2017. Which means 19.8% of Turkey's electricity production was obtained from hydroelectric[1].

According to the report prepared by the US Energy Information Administration (EIA) (2012), the installation cost of hydroelectric power plants is 2936 $/kW, the fixed cost is 14.13 $/kW and the variable cost is 0 $/kW. According to Lazard (2016), life span of a dam is 100-200 years.

Here are some advantages of hydroelectric energy (Adıyaman, 2012: 92-93):

- It has little effect on the environment.
- As well as it does not release greenhouse gas, it is an environment friendly energy that helps to prevent pollution in the atmosphere.
- Helps to meet the energy needs of rural areas with limited accessibility.
- A large part of the investment expenditures is made with domestic resources and there is very little foreign dependency.
- It has positive effects on development of agriculture, support of fisheries, etc. in the region where it is installed.

There are some disadvantages of hydroelectric energy (Adıyaman, 2012: 93; Ağaçbiçer, 2010: 55):

- It may cause ecological changes in the region since it causes changes in the river beds.
- It can cause the extinction of the living species (certain fish species, etc.).
- The efficiency of small hydroelectric power plants depends on the flow of water. Because of that, it is relatively lower.
- Since large dams store plenty of water, they may cause the deterioration of the microclimatic system in the region and the ecological balance.
- Trees and other natural environment in the areas where the power plants will be built might be destroyed.

2.2. Wind Energy

The air flow, which moves from the high-pressure region to the low-pressure region, is called the wind[2]. The kinetic energy of the wind is transformed into electrical energy by wind turbines. As we know the electrical energy is used almost every aspect of our daily lives. It powers almost everything that we use.

In Turkey, it is assumed that wind turbines with 5 MW capacity per kilometer square can be installed in the areas where the wind speed is 7.5 m/s 50 meters above ground. In the light of

[1] http://www.enerji.gov.tr/tr-TR/Sayfalar/Hidrolik date of access: 20.06.2018
[2] http://www.enerji.gov.tr/tr-TR/Sayfalar/Ruzgar date of access: 20.06.2018

these assumptions, the Wind Energy Potential Atlas (REPA), in which the wind resource information generated using the medium-scale digital weather forecast model and the micro-scale wind flow model, is prepared. According to REPA, the wind energy potential of Turkey is 48 GW. The sum of the corresponding potential area is equivalent to 1.30 % of Turkey's total surface[3]. In terms of wind energy potential, Turkey is way ahead compared with European countries with 120 TWh potential. Turkey is followed by the UK with 114 TWh potential. Despite having 24 TWh potential, Germany is making about one third (31%) of world wind energy production (Adıyaman, 2012: 55-56). This data shows Turkey's wind energy potential in the hand is very precious and the importance of the steps should be taken to use this potential.

By the end of 2017, 6.5 GW of installed wind energy capacity approximately corresponds to 7.6% of Turkey's total installed power capacity. Wind energy production was calculated as 17.9 TWh in 2017. Which means 6.06% of Turkey's electricity production was obtained from wind energy[4].

According to the report prepared by the US Energy Information Administration (EIA) (2012), the installation cost of wind power plants is 2213 $/kW, the fixed cost is 39.55 $/kW, and the variable cost is 0 $/kW.

The advantages of wind energy can be listed as follows (Özen et al., 2015: 88):

- In windy areas, the power plants do not need any raw materials, so using wind energy does not cause any fuel cost.
- Since it is a clean energy source, the damage to the surrounding area is negligible (the greenhouse gas emission is about 0.02-0.04-pound CO_2E / kWh[5]).
- Because the wind is constantly renewed by natural process, it will stay as an energy source till the end of the world.
- Installation time is very short compared to other power plants (12 months[6]).
- To eliminate the energy shortages, it is possible to replace the turbines that have reached the end of their useful life (20 years[7]) or have been damaged with new ones.
- The land where the power plants are installed can also be used for other purposes (agriculture, etc.).

Wind energy also has some disadvantages (Özen et al., 2015: 88; Adıyaman, 2012: 57):

- They are not consistent because the energy cannot be generated when the wind is not blowing. Less energy can be produced at the moment of demand or more energy can be generated when the demand is low.
- Since the wind fluctuates, the area to install the power plants must be well decided.
- Turbines cause birds to drift to death in blades.
- Turbines cause electromagnetic fields to interfere with the signals of surrounding radio and TV receivers. For this reason, they are prohibited from being installed near military territories.
- As aesthetically pleasing, they are installed in remote areas of life.

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[3] http://www.enerji.gov.tr/tr-TR/Sayfalar/Ruzgar date of access: 20.06.2018
[4] http://www.enerji.gov.tr/tr-TR/Sayfalar/Ruzgar date of access: 20.06.2018
[5] http://www.ucsusa.org/clean_energy/our-energy-choices/renewable-energy/public-benefits-of-renewable.html#.V58uUjWWFG0 date of access: 20.06.2018
[6] Lazard Ltd. Lazard's Levelized Cost of Energy Analysis – Version 10, https://www.lazard.com/media/438038/levelized-cost-of-energy-v100.pdf date of access: 20.06.2018
[7] Lazard Ltd. Lazard's Levelized Cost of Energy Analysis – Version 10, https://www.lazard.com/media/438038/levelized-cost-of-energy-v100.pdf date of access: 20.06.2018

2.3. Solar Energy

It is a renewable energy source with a constant solar intensity of 1370 W/m^2 in the space and of 0-1100 W/m^2 on the surface of the world. It can be used as a control in heating and cooling and electricity generation (TÜRÇEV, 2014: 15).

According to Solar Energy Potential Atlas of Turkey, which is prepared by the Turkish General Directorate of Renewable Energy, technical solar energy potential of Turkey is estimated to be 6105 TWh annually. 5% of this technical potential is available economically which means the economic solar energy potential of Turkey is 305 TWh annually (Benli, 2013: 41).

One of the reasons for solar power plants being uncommon in Turkey is that the solar energy systems are not fully developed. Installed solar power capacity of Turkey was 0 MW in 2013. At the end of 2017, total installed solar energy capacity of Turkey was 3.4 GW which approximately corresponds to 4% of total installed power capacity. Solar energy production was calculated as 2.68 TWh in 2017. Which means 0.91% of Turkey's electricity production was obtained from solar energy[8].

With the emergence of new technologies in solar energy systems, it is expected that the costs will decrease and therefore the usage of solar energy will increase. According to the report prepared by the US Energy Information Administration (EIA) (2012), the installation cost of solar power plants is 4183 $/kW, the fixed cost is 27.75 $/kW, and the variable cost is 0 $/kW. Solar energy systems have many advantages, some of which are (Adıyaman, 2012: 45-46; Ağaçbiçer, 2010: 62):

- Solar energy is abundant in many parts of the world.
- Since solar energy can be produced locally, using it reduces foreign dependency.
- It is a reliable system and requires virtually no maintenance.
- Solar energy will exist as long as the sun exists. It is therefore a source of energy that is never depleted.
- Since energy can be generated as long as the weather is clear, there is no need for raw materials.
- It is easily generated at the desired place therefore energy transfer is not an issue.
- Installation time of a plant is very short (3-9 months[9])
- It is possible to prevent the occurrence of energy shortages by replacing the damaged parts or by replacing the complete panels that have reached the end of their useful life (25-30 years[10]).
- Solar energy panels work silently so they do not cause noise pollution.

Disadvantages of solar energy (Adıyaman, 2012: 46-47):

- Installation costs of solar panels are very high.
- Since the energy generation depends on the weather conditions, it is not possible to generate energy continuously.
- Solar panels cover large areas since their efficiency is fairly low.
- In the absence of sunlight, special batteries are required for energy storage which increase the costs.

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[8] http://www.enerji.gov.tr/tr-TR/Sayfalar/Gunes date of access: 20.06.2018
[9] Lazard Ltd. Lazard's Levelized Cost of Energy Analysis – Version 10, https://www.lazard.com/media/438038/levelized-cost-of-energy-v100.pdf date of access: 22.08.2017
[10] Lazard Ltd. Lazard's Levelized Cost of Energy Analysis – Version 10, https://www.lazard.com/media/438038/levelized-cost-of-energy-v100.pdf date of access: 22.08.2017

- The solar energy potential is relatively low in northern countries where energy consumption is highest.

2.4. Geothermal Energy

Geothermal energy is basically the heat energy from the Earth[11]. Turkey, located on Alpine-Himalayan orogenic belt, is a country with relatively high geothermal potential. Turkey's theoretical geothermal potential is calculated as 31.5 GW. 78% of this potential is located western Anatolia region. Majority of Turkey's geothermal resources (90%) has low and medium temperature, which is suitable for direct applications such as heating, thermal tourism, etc. and the rest of the potential is suitable for indirect applications (electricity generation) [12].

At the end of 2017, total installed geothermal energy capacity of Turkey was 1.06 GW which approximately corresponds to 1.2% of total installed power capacity. Electricity production from geothermal energy was calculated as 5.9 TWh in 2017. Which means 2.02% of Turkey's total electricity production was from geothermal sources[13].
According to the report prepared by US Energy Information Administration (EIA) (2012), installation cost of geothermal power plants is 4362 $/kW, fixed cost is 100 $/kW and variable cost is 0 $/kW. According to Lazard (2016) report, the power plants have a life span of about 25 years.

Advantages of using geothermal energy (Karadaş, 2018: 158):

- Geothermal plants do not produce waste because they do not need fuel.
- The continuity problem found in other renewable energy sources is not an issue for geothermal energy.
- Geothermal power plants are the most stable of renewable energy types and can be started or stopped on demand.
- Geothermal energy systems have higher efficiency ratings than other renewable energy sources.
- The duration of use of geothermal energy systems is very high since they have a few moving parts.

Disadvantages of using geothermal energy (Adıyaman, 2012: 72; Ağaçbiçer, 2010: 73):

- It is necessary to use the generated energy in the region where the source is located.
- It firstly causes pollution of the water and later pollution of the soil by solving minerals in underground reservoirs.
- Various minerals (mercury, arsenic, lead, lithium, ammonia, etc.) that may be present in the geothermal fluid can cause serious environmental problems.
- It causes the release of carbon dioxide even it is too low compared to the fossil fuel power plants.

2.5. Bioenergy

Bioenergy refers to energy produced by using biomass. Biomass includes tree, animal and human organic wastes and agricultural products and their by-products and forest residues (TÜRÇEV, 2014: 16).

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[11] https://www.renewableenergyworld.com/geothermal-energy/tech.html date of access: 21.06.2018
[12] http://www.enerji.gov.tr/tr-TR/Sayfalar/Jeotermal date of access: 10.10.2017
[13] http://www.enerji.gov.tr/tr-TR/Sayfalar/Jeotermal date of access: 21.06.2018

Biofuels are different from other renewable energy sources because they are capable to replace currently dominant fossil fuels. In this respect, bioenergy is the most widely used renewable energy source in the world (Adıyaman, 2012: 80-81).

Turkey's biomass resources include agriculture, forestry, animal and organic municipal waste. The potential of biomass resources is estimated to be 8.6 mtoe biomass waste and 1.5 to 2 mtoe producible biogas[14]. Although the climate and growing conditions in Turkey are ideal for the cultivation of many trees used in energy forestry (eucalyptus, willow, poplar, pine, oak, ash, pine, acacia, etc.), only 15% of the ideal areas for energy forestry has been utilized (Adıyaman, 2012: 87).

As of the end of 2017, Turkey has 122 pieces Renewable Waste Energy Plant in operation with 634 MW of installed capacity which corresponds to approximately 0.7% of Turkey's total installed capacity. Electricity production from biomass was 2.8 TWh at the end of 2017 and 0.95% of Turkey's electricity production was derived from biomass sources[15].

According to the report prepared by the US Energy Information Administration (EIA) (2012), installation cost of geothermal power plants is 4114 $/kW, fixed cost is 105,63 $/kW, and variable cost is 5.26 $/kW. According to Lazard (2016) report, the power plants have a life span of about 25 years.

Advantages of using biofuels (Adıyaman, 2012: 84):

- Since biofuels are produced from materials that can cause environmental problems if not used, biofuel generation helps to avoid possible environmental problems.
- Significantly reduces greenhouse gas emissions when used in place of fossil fuels.
- Biofuels can be stored and used on demand like fossil fuels, so they do not have continuity problem.
- Wastes generated during production can be used as fertilizer.
- Energy forestry can help to prevent landslides, increase green areas and control forest fires.
- Biofuel production is simpler and more economical compared to other alternative fuels.

Disadvantages of using biofuels (Adıyaman, 2012: 84; Ağaçbiçer, 2010: 89):

- Burning garbage and wastes during the production may cause environmental problems.
- The increase in energy consumption leads to the use of basic nutrients (wheat, barley, corn, potatoes, sugar beet, etc.) of humans other than nutrition and to raise food prices.
- Energy forestry can cause destruction of forests since the system cannot renew itself in a short time.

3. Analytic Hierarchy Process

Decision-making is, as a word, the mental process that results in the selection of the appropriate option from the possible options of an idea or movement. People make a decision in every situation they encounter during the daily life. In some cases, this process is faster, and, in some cases, it is slower. But, sometimes, it is too hard to make a decision. The reason for this difficulty is the complexity and excess of the options (Atmaca and Karadaş, 2020:

[14] http://www.enerji.gov.tr/tr-TR/Sayfalar/Biyokutle date of access: 22.06.2018
[15] http://www.enerji.gov.tr/tr-TR/Sayfalar/Biyokutle date of access: 22.06.2018

13). For this reason, these difficulties are tried to be simplified by using various mathematical tools.

The AHP approach, which is widely used in multi-criteria decision-making methods, was developed by Thomas L. Saaty in 1977. Many researchers study on decision making and AHP such as Saaty (1990) and Yager (1977). AHP allows decision-makers to model complex decision problems in a hierarchical structure that shows the relationship between the main goal of the problem, the criteria, sub-criteria and alternatives. AHP is based on binary comparisons in a decision hierarchy process. By using a predetermined decision scale, it includes binary comparisons of both criteria and alternatives according to criteria. It is a method in which information, experience and individual's thoughts are logically combined. The method has a wide range of applications and is used effectively in many decision problems. The binary comparison scale used in AHP decision-making method is given in Table 1.

Table 1. Binary Comparison Scale

Value Definitions	**Importance values**
Both criteria have equal importance	1
The 1st criterion is moderately more important than the 2nd criterion	3
The 1st criterion is strongly more important than the 2nd criterion	5
The 1st criterion is very strong more important than the 2nd criterion	7
The 1st criterion is extremely more important than the 2nd criterion	9
Intermediate more important	2, 4, 6, 8

The method used to reach the decision with AHP is summarized as follows:

Step 1: Defining the Decision-Making Problem: For a decision-making problem, m decision points (alternatives) and n factors (criteria) affecting these decision points are determined and a hierarchical structure is formed.

Step 2: Determining the Binary Comparison Matrix: For a decision-making problem with n number of criteria, the nxn dimensional binary comparison matrix (A matrix) for the criteria is created.

$$A = \begin{bmatrix} a_{11} & a_{12} & \cdots & a_{1n} \\ a_{21} & a_{22} & \cdots & a_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ a_{n1} & a_{n2} & \cdots & a_{nn} \end{bmatrix} \tag{3.1}$$

By consulting with the experts, the importance levels of the criteria are compared according to each other and converted to numerical values according to the scale in Table 1. This matrix contains the values indicating how important the i^{th} row element is relative to the j^{th} column element. The following relationship exists between the elements of this matrix in which the diagonal elements are equal to 1.

$$a_{ij} = \frac{1}{a_{ji}} \tag{3.2}$$

Step 3: Determining the Normalized Binary Comparison Matrix: A normalized binary comparison matrix is generated by dividing each value in the binary comparison matrix by the total value of the column it belongs. So, the j^{th} column vector ($j = 1 \dots n$),

$$B_j = \begin{bmatrix} b_{1j} \\ b_{2j} \\ \vdots \\ b_{nj} \end{bmatrix} \quad (3.3)$$

is created by using the formula,

$$b_{ij} = \frac{a_{ij}}{\sum_{k=1}^{n} a_{kj}} \quad (3.4)$$

Then, by using *n* column vector, the normalized binary comparison matrix is formed as:

$$B = \begin{bmatrix} b_{11} & b_{12} & \cdots & b_{1n} \\ b_{21} & b_{22} & \cdots & b_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ b_{n1} & b_{n2} & \cdots & b_{nn} \end{bmatrix} \quad (3.5)$$

Step 4: Calculation of the Consistency Ratio for the Validity of Results: Consistency Ratio (*CR*) should be less than 0.1 in order for the paired comparisons to be consistent. It is possible to calculate the consistency ratio by the following method (Saaty, 1980):

$$CR = \frac{CI}{RI} \quad (3.6)$$

where, *CI* shows the consistency index and the RI random consistency index. The consistency index is calculated by the following formula:

$$CI = \frac{\lambda_{max} - n}{n - 1} \quad (3.7)$$

where, λ_{max} shows the largest Eigenvalue and *n* shows the column number of the binary comparison matrix. *RI*, random consistency index, can be calculated with the help of Table 2.

Table 2. Random Index Table

N	1	2	3	4	5	6	7	8	9	10
RI	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49

Source: (Saaty, 1980)

Step 5: Calculation of Relative Weights for Different Purposes: At each level of the decision hierarchy, the element with the highest score is more important. In order to choose among alternatives, the relative compound weight of each element at the last level should be calculated. The weight of each criterion is calculated by taking the arithmetic mean of the row elements of the normalized binary comparison matrix. So, by using the formula,

$$w_i = \frac{\sum_{k=1}^{n} b_{ik}}{n} \quad (3.8)$$

the weight of each criterion (w_i) is calculated and by using these values, the weight matrix (W) is obtained,

$$W = \begin{bmatrix} w_1 \\ w_2 \\ \vdots \\ w_n \end{bmatrix} \quad (3.9)$$

4. Data and Methodology

In this part of the study, first of all, the effects of each renewable energy source on the GDP will be examined with the help of econometrical analysis. Then, a mathematical model will be created with the obtained data and the advantages and disadvantages of renewable energy sources. A policy proposal will be made for the investment in renewable energy sources in Turkey.

4.1. Econometric Analysis

Panel data analysis is a method of estimating economic relations by using a dataset in which the behaviours of entities are observed across time. Therefore, the most important feature of this analysis is that it allows to create a data set with both time and cross-sectional dimension by combining time series and cross-sectional data. First, it should be noted that the increase in the number of observations leads to an increase in the degree of freedom on the one hand, and on the other hand, a decrease in the probability of a high linear relationship between the explanatory variables, depending on whether both the cross-sectional and the time series data are included in the panel data models (Karadaş and Koşaroğlu, 2015: 50).

Panel data analysis seems to have other advantages when compared to other regression models, time series and cross-sectional data. According to Baltagi, the results of the studies based on cross-sectional data only reveal the differences between the units, whereas the studies using panel data can show changes in both the units and the unit over time. Panel data analysis, on the other hand, allows to construct and test more complicated behavioural models than a single cross-sectional or time series data set. This advantage eliminates the variable problems that lead to significant deviations in estimation results in studies using only time series or horizontal section data. Thus, panel data analysis provides more precise, realistic, and comprehensive estimates for each outcome. In addition to all these advantages of this analysis, the significant and most important contribution is to measure the effects of unobserved factors which cannot be quantified (Karadaş and Koşaroğlu, 2015: 50).

In this section of the study, econometric analysis has been conducted between GDP and the renewable energy types used in Turkey (biomass, geothermal, hydraulic, solar and wind energy) in order to examine the effects of each renewable energy sources on economic growth. Since the data of renewable energy sources for Turkey is inadequate to make a healthy econometric analysis, the econometric analysis is performed using the panel data set of the countries with sufficient data (USA, Austria, Germany, China, Indonesia, Philippines, France, Guatemala, Italy, Japan, Kenya, Costa Rica, Mexico, Nicaragua, New Zealand and Turkey). The data of the installed capacity of the renewable energy sources of selected countries is derived from renewable energy electricity statistics of IRENA (International Renewable Energy Agency) and the data of GDP is derived from World Bank data base (World Development Indicators). The data are annual and belong to the period 2000-2016.

The basic model of the study is as follows:

$$LnGDP_{it} = \alpha_i + \beta_1 Lnbio_{it} + \beta_2 lngeo_{it} + \beta_3 Lnhydro_{it} + \beta_4 Lnsolar_{it} + \beta_5 Lnwind_{it} + \varepsilon_{it} \quad (4.1)$$

Where, LnGDP shows the natural logarithm of GDP, Lnbio, Lngeo, Lnhydro, Lnsolar[16], and Lnwind show the natural logarithms of installed power capacities of biomass energy, geothermal energy, hydroelectric energy, solar energy, and wind energy of selected countries, respectively.

4.1.1. Panel Unit Root Tests

In the econometric analyses, if the series are not stationary, spurious regression problems will occur which falsely imply the existence of a relationship. So, in this study we firstly examined the stability of the series with unit root tests. In the panel data models, Levin, Lin and Chu (2002), Im, Pesaran and Shin (2003), ADF Fisher Chi-square and PP Fisher Chi-Square tests are used for unit root examination (Yardımcıoğlu and Gülmez, 2013: 153). The unit root tests were applied by determining the appropriate lag length that resolves the auto correlation problem between the errors according to Akaike Info Criterion (AIC).

Table 3. Panel Unit Root Tests Results

	Levin, Lin and Chu t		**Im, Pesaran and Shin W-stat**		**ADF-Fisher Chi-square**		**PP - Fisher Chi-square**	
	Statistics	Prob.	Statistics	Prob.	Statistics	Prob.	Statistics	Prob.
GDP	4.41417	1.0000	6.65401	1.0000	9.57441	1.0000	13.1113	0.9998
D(GDP)	-7.37618*	0.0000	-5.44269*	0.0000	94.7816*	0.0000	109.476*	0.0000
BIO	4.00333	1.0000	7.27080	1.0000	16.9131	0.9972	9.90656	1.0000
D(BIO)	-4.45878*	0.0000	-2.43255*	0.0075	79.3486*	0.0000	87.0579*	0.0000
GEO	3.68024	0.9999	4.61953	1.0000	24.9080	0.8722	31.7642	0.5777
D(GEO)	-3.62593*	0.0001	-5.01640*	0.0000	96.5892*	0.0000	119.532*	0.0000
HYDRO	2.24868	0.9877	6.27392	1.0000	33.5170	0.5873	17.6563	0.9956
D(HYDRO)	-7.39267*	0.0000	-5.88275*	0.0000	111.507*	0.0000	126.100*	0.0000
SOLAR	0.83421	0.7979	5.39527	1.0000	11.2700	1.0000	9.29321	1.0000
D(SOLAR)	-2.57131*	0.0051	-0.11374	0.4547	53.6434**	0.0295	53.9030**	0.0279
WIND	8.61322	1.0000	11.0784	1.0000	9.85650	1.0000	30.4717	0.6413
D(WIND)	-3.32655*	0.0004	-2.79306*	0.0026	75.1467*	0.0000	63.4860*	0.0008

Note: **, * indicate significance at the level of 5% and 1%, respectively.

As seen in the Table 3, since we cannot reject the null hypothesis of unit root tests for each series, we determine that all the series are non-stationary at levels. So, we applied the unit root tests for first differences. We concluded that all series used in this study are integrated of order one -i.e. I(1).

4.1.2. Panel cointegration tests

Since all series in our model are integrated of order one, the long-term relationship between the series is investigated by using the Pedroni and Kao cointegration tests. Pedroni proposed seven test proposals that allowed heterogeneity in cointegration analyses in 1997, 1999, 2000 and 2004. These are panel v, panel rho, panel PP, panel ADF, group rho, group PP and group ADF tests. The null hypotheses of these tests are same, which is “There is no cointegration between the series”. The cointegration test presented by Kao in 1999 uses panel data analysis using DF and ADF tests. The null hypothesis of Kao cointegration test is also “there is no cointegration between the series” (Karadaş, 2018: 341).

[16] Since solar energy is a new developed technology, there is none installed solar power capacity in many countries during the used period. So, in order to get natural logarithm, +1 is added to all solar power installed capacities.

Table 4. Panel Cointegration Tests Results

Pedroni Residual Cointegration Test		
Variables: LNGDP LNBIO LNJEO LNHIDRO LNGUN LNRUZ		
Null hypothesis: No Cointegration		
	Statistic	**Prob.**
Panel v-Statistic	1.286710***	0.0991
Panel rho-Statistic	4.383876	1.0000
Panel PP-Statistic	-1.514596***	0.0649
Panel ADF-Statistic	-0.601876	0.2736
Alternative hypothesis: individual AR coefficients (between-dimension)		
	Statistic	**Prob.**
Group rho-Statistic	6.306289	1.0000
Group PP-Statistic	-15.31904*	0.0000
Group ADF-Statistic	-2.661486*	0.0039
Kao Cointegration Test		
Null hypothesis: No Cointegration		
	t- Statistic	**Prob.**
ADF	-2.363967*	0.0090
Residual variance	0.000928	
HAC variance	0.001257	

Note: ***, * indicate significance at the level of 10% and 1%, respectively.

According to the results of the Pedroni cointegration test we applied, the null hypotheses were rejected in four of the seven tests constituting the panel and group statistics, and Panel PP, Panel v, Group PP and Group ADF statistics were significant at the 1% significance level. Also, Kao cointegration test result shows that the null hypothesis was rejected at the 1% significance level. That is, the alternative hypotheses "the existence of cointegration between the series" has been accepted.

After determining the existence of the long-run relationship between the series as a result of cointegration tests, the long-run coefficients of the series are estimated by the FMOLS (Fully Modified Ordinary Least Square) method developed by Pedroni. The FMOLS method corrects deviations arising from problems such as endogeneity and serial correlation that may occur in the system (Karadaş and Koşaroğlu, 2015: 53).

Table 5. Panel FMOLS Results

Dependent Variable: LNGDP				
Method: Panel Fully Modified Least Squares (FMOLS)				
Variable	**Coefficient**	**Std. Error**	**t-Statistic**	**Prob.**
LNBIO	-0.445499*	0.042988	-10.36335	0.0000
LNGEO	0.153639*	0.035127	4.373784	0.0000
LNHYDRO	0.769271*	0.020646	37.25929	0.0000
LNSOLAR	0.405764*	0.018331	22.13499	0.0000
LNWIND	-0.040998*	0.007882	-5.201389	0.0000

Note: * indicates significance at the level of 1%.

According to the panel FMOLS test results, coefficients of each series cannot be rejected at the 1% significance level. In other words, changes in the installed capacity of renewable energy sources will affect long-term economic growth.

Our model with the coefficients obtained from FMOLS method is as follows:

$$LnGDP_{it} = \alpha_i - (0.4454)Lnbio_{it} + (0.1536)lngeo_{it} + (0.7692)Lnhydro_{it} + (0.4057)Lnsolar_{it} - (0.0409)Lnwind_{it} + \varepsilon_{it} \quad (4.2)$$

Now that we have found the effects of renewable energy installed power capacities on economic growth, we can move on to mathematical modelling.

4.2. Mathematical Modelling

As stated before, in this study, it was aimed to decide which of the renewable energy sources should be invested or given priority in Turkey. AHP approach was used to make a decision to determine the most appropriate energy source. The criteria in this process are determined with the help of literature review and expert opinions. We obtained the data in Table 6 from the values of the criteria in the second section of the study and the results of the econometric analysis, and we used expert opinions for the criteria without value.

Table 6. Quantitative Data for Criteria to be Used in AHP Approach

	Impact on GDP	**Fixed Cost ($/Kw)**	**Variable Cost ($/Kw)**	**Lifetime (Years)**	**Installation Cost**	**Potential (%)**	**Construction Time**	**Impact on Environment**	**Continuity**	**Technological Innovation Potential**
	K1	K2	K3	K4	K5	K6	K7	K8*	K9*	K10**
Hydraulic	0.769	14.13	0	200	2936	41	36	1	1	1
Solar	0.406	27.75	0	30	4183	0.008	3	0	0	9
Geothermal	0.154	100	0	25	4362	0.03	36	1	1	3
Wind	-0.041	39.55	0	20	2213	10	12	0	0	8
Biomass	-0.445	105.63	5.26	25	4114	16.8	36	1	1	4

Note: * 0: not exist, 1: exists. ** Rated 1 to 10 (1-least developed, 9 most likely to develop).

The factors in the columns of Table 6 will be used as the decision-making criteria. The binary comparison matrix for the criteria was formed by taking the common opinions of the experts and the evaluation of the alternatives according to the criteria was formed by using the data and information of the previous years. The binary comparison matrix and normalized paired comparison matrices for these criteria are given in Table 7 and Table 8, respectively.

Table 7. Binary Comparison Matrix Between Criteria

	K1	**K2**	**K3**	**K4**	**K5**	**K6**	**K7**	**K8**	**K9**	**K10**
K1	1.000	7.000	3.000	4.000	4.000	5.000	9.000	8.000	5.000	6.000
K2	0.142	1.000	0.142	0.166	0.166	0.200	5.000	3.000	0.200	0.250
K3	0.333	7.000	1.000	3.000	3.000	4.000	8.000	7.000	4.000	5.000
K4	0.250	6.000	0.333	1.000	1.000	2.000	7.000	5.000	2.000	3.000
K5	0.250	6.000	0.333	1.000	1.000	2.000	7.000	5.000	2.000	3.000
K6	0.200	5.000	0.250	0.500	0.500	1.000	6.000	4.000	1.000	2.000
K7	0.111	0.200	0.125	0.142	0.142	0.166	1.000	0.333	0.166	0.200
K8	0.125	0.333	0.142	0.200	0.200	0.250	3.000	1.000	0.200	0.333
K9	0.200	5.000	0.250	0.500	0.500	1.000	6.000	5.000	1.000	2.000
K10	0.166	4.000	0.200	0.333	0.333	0.500	5.000	3.000	0.500	1.000

Table 8. Normalized Binary Comparison Matrix Between Criteria and Weight Matrix

	K1	K2	K3	K4	K5	K6	K7	K8	K9	K10	W
K1	0.360	0.169	0.519	0.369	0.369	0.310	0.158	0.194	0.311	0.263	0.302
K2	0.051	0.024	0.025	0.015	0.015	0.012	0.088	0.073	0.012	0.011	0.033
K3	0.120	0.169	0.173	0.277	0.277	0.248	0.140	0.169	0.249	0.219	0.204
K4	0.090	0.144	0.058	0.092	0.092	0.124	0.123	0.121	0.124	0.132	0.110
K5	0.090	0.144	0.058	0.092	0.092	0.124	0.123	0.121	0.124	0.132	0.110
K6	0.072	0.120	0.043	0.046	0.046	0.062	0.105	0.097	0.062	0.088	0.074
K7	0.040	0.005	0.022	0.013	0.013	0.010	0.018	0.008	0.010	0.009	0.015
K8	0.045	0.008	0.025	0.018	0.018	0.016	0.053	0.024	0.012	0.015	0.023
K9	0.072	0.120	0.043	0.046	0.046	0.062	0.105	0.121	0.062	0.088	0.077
K10	0.060	0.096	0.035	0.031	0.031	0.031	0.088	0.073	0.031	0.044	0.052

Let us calculate the consistency ratio for the validity of the results:

$$\lambda_{max} = 10.905 \text{ and } n = 10 \quad (4.3)$$

$$CI = \frac{\lambda_{max} - 10}{10 - 1} = 0.1 \quad (4.4)$$

$$CR = \frac{CI}{RI} = \frac{0.1}{1.49} = 0.0674 \quad (4.5)$$

Since $CR = 0.0674 < 0.1$, the comparisons are quite consistent. Now, the binary comparison matrices of alternative energy sources can be acquired for each criterion. Table 9 shows the binary comparison matrix and weights of the energy sources according to GDP.

Table 9. Binary comparison matrix and weight according to GDP criterion

	Hydraulic	Solar	Geothermal	Wind	Biomass	W
Hydraulic	1	3	6	8	9	0.513
Solar	0.333	1	3	5	7	0.245
Geothermal	0.167	0.333	1	4	6	0.141
Wind	0.125	0.200	0.250	1	4	0.068
Biomass	0.111	0.143	0.167	0.250	1	0.032

The weights of the alternatives for other criteria were calculated in the same way and given in Table 10.

Table 10. Weights Table for Energy Resources

	Criteria	Impact on GDP	Fixed Cost	Variable Cost	Lifetime	Installation Cost	Potential	Construction Time	Impact on The Environment	Continuity	Technological Innovation Potential		
Alternatives	**Weights**	0.302	0.033	0.204	0.110	0.110	0.074	0.015	0.023	0.077	0.052	Weights	Rank
	Hydraulic	0.513	0.536	0.243	0.648	0.321	0.029	0.056	0.090	0.382	0.032	0.365	1
	Solar	0.245	0.243	0.243	0.138	0.063	0.499	0.587	0.507	0.048	0.473	0.240	2
	Geothermal	0.141	0.051	0.243	0.081	0.041	0.255	0.056	0.101	0.382	0.088	0.163	4
	Wind	0.068	0.136	0.243	0.072	0.512	0.132	0.244	0.214	0.048	0.145	0.169	3
	Biomass	0.032	0.035	0.027	0.061	0.063	0.085	0.056	0.088	0.141	0.262	0.064	5

According to these results, if the government allocates 36.5% of the investment budget to hydroelectric power plants, 24% to solar power plants, 16.9% to wind power plants, 6.4% to bioelectric power plants and 16.3% to geothermal power plants when deciding to invest in renewable energy resources, it will utilize renewable energy resources in the most efficient way and maximize the contribution of renewable energy resources to the country's economy.

5. Conclusion

Turkey is regarded as a rich country in terms of renewable energy sources. Even though it is a rich country, the renewable energy investments have not been enough. In this study, we tried to find the answer the question “Which renewable energy source is better to invest for Turkey?”. According to the results of our decision-making model, Turkey should invest 36.5% of its investment budget to hydroelectric power plants, 24% to solar power plants, 16.9% to wind power plants, 16.3% to geothermal power plants and 6.4% to bioelectric power plants. The reasons why hydro energy has the highest share are the high level of impact on GDP due to low investment costs due to long years of use of technology, the life of the power plant is very high compared to other renewable energy sources and it is a continuous energy source unless it is drought. Solar energy is in second place due to the fact that they are in a very good condition compared to other sources in terms of technological development potential and addition to this it has high effect on GDP. Bioenergy has the lowest share since it has more impact on the environment than other renewable energy sources due to their similar structure and production technique to the fossil fuels and also its negative impact on GDP.

Based on the advantages and disadvantages in terms of impact on GDP, fixed cost, variable cost, lifetime, installation cost, potential, construction time, impact on the environment, continuity and technological innovation potential, investment in hydroelectric power plants has been found to be most advantageous. In this context, it is known that the advantages of other renewable energy sources will increase in the near future as a result of the elimination of disadvantages due to the development of technologies. Since the technological developments in, especially, wind and solar energy increase rapidly, it is expected that the efficiency of these two renewable energy sources will increase significantly. The fact that very little part of the potential of these two energy sources in Turkey has been used shows that the advantages of them will increase even more. Therefore, while investments in energy are carried out in parallel with the results obtained in this study, it is necessary to follow the technological developments and select the most beneficial for the country's economy and ecology.

In addition, if sufficient data are available, the model we have created in this study can be useful for similar decision-making for other countries or the world and other decision-making problems in different areas.

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