ISSN: 2757-6140
Bilim-Teknoloji-Yenilik Ekosistemi Dergisi
Journal of Science-Technology-Innovation Ecosystem
Cilt/Volume: 4, Sayı/No: 1 , Yıl/Year: 2023,

Modelling the Renewable Energy Utilization Rate of Türkiye Using Autoregressive Neural Networks

Türkiye'de Yenilenebilir Enerji Kullanımı Oranının Otoregresif Sinir Ağları Kullanılarak Modellenmesi

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Özet

Yenilenebilir enerji kullanımının çevre kirliliğini azaltma ve sürdürülebilirliği sağlama başta olmak üzere birçok faydası vardır. Bu noktadan hareketle bu çalışmada, Türkiye'de yenilenebilir enerji kullanım oranının modellemesi yapılmıştır. Dünya Bankası'nın veri tabanından alınan 1960-2015 aralığını kapsayan ve toplam elektrik üretimindeki hidroelektrik harici yenilenebilir enerji kaynağı kullanımı oranını ifade eden veriler kullanılmıştır. Öncelikle bu verilerin mevsimsellik bileşenleri ve doğrusal olmama davranışları Eviews yazılımı ortamındaki mevsimsel-trend ayrıştırması yöntemi ile elde edilmiş ve yorumlanmıştır. Daha sonra, yenilenebilir enerji kullanım oranını otoregresif bir şekilde modellemek üzere beş girişli ve bir çıkışlı olan, üç adet gizli katmanı bulunan bir yapay sinir ağı Python programlama dilinde SK-Learn kütüphanesinde bulunan sınıflar kullanılarak geliştirilmiştir. Geliştirilen otoregresif yapay sinir ağının kullanımı için yenilenebilir enerji kullanım oranı verisinden giriş verisini elde eden bir ayrıştırma fonksiyonu da yine Python ortamında yazılmıştır. Bir sonraki aşamada ise eldeki verilerin %70'i eğitim verisi olarak kullanılarak otoregresif yapay sinir ağı eğitime tabi tutulmuştur. Geri kalan %30'luk veri ise test verisi olarak kullanılmıştır. Gerçek yenilenebilir enerji kullanım oranı verisi ile geliştirilen otoregresif yapay sinir ağından elde edilen veriler aynı eksen takımı üzerinde çizdirilmiş ve model sonucunun gerçek verileri hassas bir şekilde temsil ettiği gözlemlenmiştir. Modele ilişkin performans parametreleri de bu hassasiyeti doğrulamaktadır.

Anahtar Kelimeler: Yenilenebilir enerji, otoregresif, yapay sinir ağları, modelleme, tahmin.

Jel Kodları: Q40, Q42, Q47.

Abstract

The use of renewable energy has many benefits, notably reducing environmental pollution and ensuring sustainability. In this study, the rate of renewable energy use in Turkey has been modelled. Data from the World bank database covering the period 1960-2015 and expressing the rate of use of renewable energy sources are employed. First of all, the seasonality components and nonlinearity behaviours of these data are obtained and interpreted. As the next step, an artificial neural network with five inputs and one output and three hidden layers is developed to autoregressively model the renewable energy usage rate. A parsing function that generates the lagged input data is also developed in Python environment for the usage of the autoregressive artificial neural network. In the next stage, the autoregressive artificial neural network is trained by using 70% of the available data as training data. The remaining 30% data is used as test data. The data obtained from the autoregressive artificial neural network developed and the real renewable energy usage rate data are plotted on the same axes and it is observed that the model result accurately represents the real data. The performance metrics of the model also confirm this accuracy.

Key Words: Renewable energy, autoregressive, artificial neural networks, modelling, estimation.

Jel Codes: Q40, Q42, Q47.

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1. INTRODUCTION

The renewable energy utilization rate is a critical factor in determining the success of global efforts to achieve a sustainable energy future. This metric indicates the proportion of energy consumption that comes from renewable sources such as solar, wind, hydro, biomass, and geothermal. According to the International Renewable Energy Agency (IRENA), the global renewable energy utilization rate stood at 26.2% in 2018, with hydropower being the primary contributor, followed by wind and solar energy. Nevertheless, there is still a long way to go in realizing a sustainable energy system.

The intermittent nature of renewable energy sources poses a significant challenge to achieving the renewable energy utilization rate. Solar and wind energy are reliant on weather conditions, resulting in their production varying significantly. Various approaches are being implemented to overcome this challenge, such as energy storage technologies, grid integration, and demand-side management. Energy storage technologies like batteries and pumped hydroelectric storage systems can store excess energy and discharge it when needed. Demand-side management involves shifting energy consumption to times when renewable sources are producing more power. Grid integration involves connecting various renewable energy sources and optimizing their use to ensure a stable and reliable supply of electricity. The high cost of renewable technologies is a significant challenge to the renewable energy utilization rate. Although renewable energy costs have been declining in recent years, they are still higher than those of fossil fuels in many regions of the world. This is particularly true for developing nations where access to financing is limited, and the cost of capital is high. To address this challenge, several initiatives have been launched, such as the Green Climate Fund, which finances renewable energy projects in developing countries.

Regulatory and policy barriers are also a significant obstacle to achieving the renewable energy utilization rate. Some countries have policies that favour fossil fuels over renewable energy, such as subsidies or tax breaks for oil and gas companies, creating an unfair competition environment for renewable energy technologies. To address this challenge, several countries have introduced policies that incentivize the adoption of renewable energy, such as feed-in tariffs, renewable portfolio standards, and carbon pricing. Public awareness and acceptance of renewable energy play a critical role in achieving the renewable energy utilization rate. Although significant progress has been made in recent years, many individuals still lack knowledge and understanding of renewable energy technologies. Educating the public about the advantages of renewable energy and addressing their concerns about the cost, reliability, and environmental impact of these technologies can increase public support and accelerate the transition to a sustainable energy future.

As the need for alternative energy sources continues to grow, renewable energy is becoming increasingly important in addressing both energy security and environmental concerns. Renewable energy sources, such as wind, solar, hydro, geothermal, and bioenergy, have been found to have lower environmental impacts than traditional energy sources, emitting fewer greenhouse gases and pollutants while using fewer resources. Among the renewable energy sources available, solar energy shows particularly great promise in reducing greenhouse gas emissions. Solar panels convert sunlight directly into electricity without producing harmful pollutants or greenhouse gases. Projections by the International Energy Agency indicate that solar energy could potentially provide up to a third of the world's electricity needs by 2050, offering the potential to mitigate climate change.

Wind energy is another renewable energy source with potential to significantly reduce environmental impacts. Wind turbines harness the power of wind to generate electricity, providing a clean and renewable energy source. However, there are some environmental impacts to consider, including noise pollution, bird and bat mortality, and visual impacts. Geothermal energy is another renewable energy source that can significantly reduce greenhouse gas emissions. Geothermal power plants use the Earth's heat to generate electricity, offering a clean and renewable resource. However, there are some environmental impacts to consider, such as subsidence, land use, and water use. Finally, bioenergy, which comes from organic matter such as plants and animal waste, is another renewable energy source. While bioenergy is considered carbon-neutral, its production can have environmental impacts, including changes in land use, soil degradation, and water use.

The necessity for alternative energy sources continues to grow, with renewable energy playing an increasingly important role in addressing energy security and environmental concerns. Renewable energy sources such as hydro, geothermal, wind, solar, and bioenergy have been found to have a significantly lower environmental impact than traditional energy sources. They emit fewer pollutants and greenhouse gases while also consuming fewer resources. Solar energy is considered one of the most promising renewable energy sources in reducing greenhouse gas emissions. Solar panels transform sunlight directly into electricity without producing harmful pollutants or greenhouse gases. According to the International Energy Agency, solar energy could potentially supply one-third of the world's electricity needs by 2050, making it a viable option in mitigating the effects of climate change.

Wind energy is another renewable energy source that has the potential to significantly reduce the environmental impact. Wind turbines use the power of wind to produce electricity, providing a clean and renewable source of energy. Nevertheless, several environmental factors such as noise pollution, bird and bat mortality, and visual impacts must be considered. Geothermal energy is another renewable energy source that can significantly reduce greenhouse gas emissions. Geothermal power plants use the Earth's heat to generate electricity, providing a clean and renewable energy source. Nonetheless, certain environmental considerations such as subsidence, land use, and water use must be considered. Bioenergy, which comes from organic matter like plant and animal waste, is another renewable energy source. While bioenergy is considered carbon-neutral, its production can have environmental impacts such as changes in land use, soil degradation, and water use.

In recent years, Turkey has become increasingly focused on the importance of renewable energy in reducing its dependence on fossil fuels and meeting its growing energy needs. The country is endowed with abundant natural resources that can be harnessed for renewable energy, including wind, solar, geothermal, and hydro power. The Turkish government has set targets to increase the share of renewable energy in the country's electricity generation mix, with an aim to achieve 38% by 2023 and 60% by 2040. Turkey's wind energy potential is one of the key sources of renewable energy in the country, with ample wind resources in coastal areas and mountainous regions. According to the Turkish Wind Energy Association, Turkey had an installed wind energy capacity of 9,300 MW in 2020 and aims to reach 16,000 MW by 2023.

Solar energy is also an important source of renewable energy in Turkey, with high solar radiation potential in the southeastern region. The government aims to install 10,000 MW of solar power by 2023, and as of 2020, Turkey's solar energy capacity was 6,200 MW, with an additional 10,000 MW under construction or in the planning stages. Turkey ranks third globally in geothermal power capacity, with significant potential to harness this renewable energy source. The country had an installed geothermal power capacity of 1,590 MW in 2020 and aims to reach 2,000 MW by 2023, with a further target of 4,000 MW by 2030.

Considering the importance of the subject, the renewable energy utilization rate in Türkiye is modelled in this work. The renewable energy rate of Türkiye is taken from the World bank database and then the seasonal-trend decomposition is performed in Eviews software followed by the inspection of the nonlinearity of the data. Then, an autoregressive neural network consisting of five inputs and one output is developed in Python programming language. The 70% of the available data is utilized as the training data whereas the remaining 30% is employed as the test data. The actual renewable energy utilization rate and the result of the developed model are plotted together indicating overlap in a wide range. The performance metrics of the developed model is also computed verifying the accuracy of the model.

2. LITERATURE REVIEW

There are large number of studies in the literature regarding the renewable energy production and consumption in Türkiye considering the importance of the subject. The renewable energy consumption is related to several macroeconomic parameters such as the economic growth. For example, the economic data of South Africa is investigated considering the renewable energy consumption, economic growth and capital formation and it is concluded that there is a bidirectional causality relationship between the renewable energy consumption and the economic growth using Granger causality test (Shakouri and Yazdi, 2017). In another work, the panel data analysis approach is utilized for the analysis of the relationship between the renewable energy consumption and the economic growth for the selected sixteen developed countries and it is observed that there exists a bidirectional causality relationship between the renewable energy consumption and the economic growth in the short term (Dogan et al., 2014). The economies of selected African countries are studied in another work where it is exposed that environmental sustainability has positive impacts on the economic growth (Dike, 2016). The impact of the utilization of the renewable energy consumption on the economic growth in Iran is studied for the 1981-2012 period employing the autoregressive distributed lag method and it is shown that the renewable energy consumption has little effects on the economic growth of Iran due to the focus on the usage of the fuel sources (Taghvae et al., 2017). In another study, the correlation of the renewable energy consumption and the economic growth of Türkiye is investigated for the 1990-2017 period and it is exposed that the renewable energy consumption positively affects the economic growth (Kilic and Acdoyuran, 2018). The economic data of 28 European Union countries is analysed for the 1990-2012 period and it is shown that the renewable energy consumption affects the economic growth positively in twelve of these countries (Simelyte and Dudzeviciute, 2017). Similarly, the economic data of the European Union countries are investigated in another work and it is observed that economic growth impacts the renewable energy consumption positively (Lee, 2019). The structural vector autoregressive method is utilized for the analysis of the economic data of Türkiye for the 1970-2014 period where it is shown that shocks of the renewable energy consumption decreases the per capita income (Cetin and Sezen, 2018). The economic data of the OECD countries are studied in another work for the 1996-2014 period and it is observed that the renewable energy consumption has positive impacts on the economic growth (Felix, 2020). Similarly, the

Vietnamese economy is investigated in another study where it is shown that the continuity of the renewable energy supply positively affects the economic growth (Tiep et al., 2020).

The generalized method of moments method is used to investigate the relationship between the renewable energy usage and the economic growth in selected developing countries and it is observed that the renewable energy consumption affects the economic growth in a positive way (Joseph and Charles, 2021). The economic data of eleven Eastern European countries are studied for the 1995-2015 period using the panel cointegration analysis and it is observed that there exists bidirectional causality relationship between the renewable energy consumption and the economic growth (Neagu et al., 2021). In another work, the relationship between the renewable energy consumption and the economic growth for Crotia in the 1996-2008 period employing the autoregressive distributed lag method and it is exposed that the renewable energy consumption has positive effects on the economic growth in the short and long terms (Pearson, 2021). A similar result was concluded for the Indian economy in the period of 1970-2018 employing the nonlinear autoregressive distributed lag model (Akadiri and Adebayo, 2021). The panel vector error correction model is employed for the analysis of the economic data of the South Asian Association for Regional Cooperation (SAARC) countries in the period of 1995-2018 and it is concluded that renewable energy consumption has positive effects on the economic growth (Yikun et al., 2021). The panel cointegration test is utilized for the analysis of the economies of India, Bangladesh and Pakistan for the 1971-2008 period and it is shown that there exists a unidirectional causality relationship from the energy consumption to the economic growth in the long term (Imran and Siddiqui, 2010). In another work, the real gross domestic product and the energy consumptions of G7 countries are investigated using panel cointegration and Granger causality tests and it is exposed that the 1% increase of the energy consumption increases the real gross domestic product by 0.12-0.39% (Narayan and Smyth, 2008). The economic data of Taiwan for the 1954-2003 period is studied utilizing the cointegration tests with structural breaks and it is shown that the energy consumption affects the gross domestic product in a positive way (Lee and Chang, 2005). The Turkish economy is analysed in another work using the cointegration tests for the 1970-2003 period and it is observed that there exists a bidirectional causality relationship between the energy consumption and the gross domestic product (Lise and van Monfort, 2007). Similarly, the economic data of Türkiye is studied employing the vector error correction model for the 1960-1995 period and it is observed that there is a unidirectional causality relationship from the energy consumption to the gross domestic product (Soytas et al., 2001).

The South African economy is investigated for the period of 1965-2006 period using the Granger causality test and it is shown that there is a unidirectional causality relationship from the energy consumption to the economic growth (Menyah and Wolde-Rufael, 2010). The vector autoregressive model and the Granger causality test are used for the analysis of the Turkish economy for the period of 1960-2010 and it is concluded that renewable energy consumption has positive effects on the economic growth (Buyukyilmaz and Mert, 2015). In another work, Toda-Yamamoto causality tests and the Bayer-Hanck cointegration analysis is used for the investigation of the relationships among the real gross domestic product, employment rate, renewable energy consumption and the gross fixed capital formation in Türkiye for the period of 1990-2017 where it is observed that the 1% increment of the renewable energy consumption leads to 0.19% increase in the economic growth (Findik, 2018). The economic data of the BRICS countries and Türkiye are analysed in another study for the period of 2000-2013 using panel cointegration and panel autoregressive distributed lag methods where it is exposed that there exists a positive causality relationship between the renewable energy consumption and the economic growth in long term (Ozsahin, 2016). In another work, the Johansen cointegration test and the vector autoregressive analysis are used on the economic data of Türkiye for the period of 1965-2017 where it is shown that there is a unidirectional causality relationship from the renewable energy consumption to the economic growth (Apaydin and Tasdogan, 2019). The US economy is investigated employing the Markov switching vector autoregressive model for the period of 1960-2015 and it is shown that there exists a bidirectional causality relationship between the energy consumption and the economic growth (Fallahi, 2011). The parameter sensitivity analysis is utilized to analyse the economic data of China for the period of 2006-2010 and it is observed that the increment of the renewable energy consumption leads to the increase in the employment rate (Cai et al., 2011). The economy of Pakistan is studied using the autoregressive distributed lag method for the period of 1972-2011 and it is exposed that the renewable energy consumption positively affects the economic growth (Shahbaz et al., 2015). In another study, the economic data of the US metropolitan areas is investigated using the regression method and it is shown that green energy policies have positive effects on the employment rate (Yi, 2013). Similarly, the economies of the OECD countries are studied for the period of 1997-2006 employing the panel threshold model and it is concluded that there is a correlation between the renewable energy consumption and the economic growth rate (Chang et al., 2009).

The economic data of the Middle East and North African (MENA) countries is analysed using panel vector autoregressive model for the period of 1988-2010 and it is shown that the increase of the renewable energy utilization rate leads to the increase in the economic growth rate (Akay et al., 2015). The short term and long-term causality relationships among several economic variables of the selected SAARC countries such as Bangladesh, India, Nepal, Pakistan and Sri Lanka are studied for the period of 1975-2010 using the Granger causality analysis and it is concluded that the renewable energy consumption leads to the increase in the gross domestic product (Zeb et al., 2014). Similarly, the economic data of selected developing countries are investigated in another study for the 1990-2013 period using the panel data analysis method and it is observed that the increase of the renewable energy consumption increases the economic growth (Yilmazer and Cinar, 2015). The impacts of the changes of the gross domestic products on the renewable energy consumptions of the G20 countries are studied for the 1992-2010 period and it is exposed that the 1% increase in the gross domestic product causes the 0.79% increase in the renewable energy consumption (Bakirtas and Cetin, 2015). The dynamical panel data analysis method is utilized to investigate the relationship between the renewable energy consumption and the per capita income of the first five countries employing the renewable energy where it is found out that the renewable energy consumption positively affects the per capita income (Acaravci and Erdogan, 2017). In another extensive work, the economic data of selected 80 countries are studied for the 1990-2013 period using Granger causality analysis and it is exposed that the renewable energy consumption decreases the unemployment rate (Apergis and Salim, 2015). The panel data analysis method is used to study the relationship between the renewable energy consumptions and the per capita income of the European Union countries for the period of 2006-2015 where it is concluded that the 1% increase of the renewable energy consumption leads to the 0.39% increase of the per capita income (Bayrac and Cildir, 2017). The Chinese economic data is studied for the period of 1978-2018 period using the ordinary least squares method and it is observed that there exists a unidirectional causality relationship from the renewable energy consumption to the economic growth (Fang, 2011). Similarly, the Portuguese economic data is studied for the 1970-2010 period using the generalized method of moments and the Granger causality analysis and it is exposed that there is a bidirectional causality relationship between the renewable energy consumption and the economic growth (Leitao, 2014). The structural variance analysis is utilized for the investigation of the Indian economy for the period of 1960-2009 in another study where it is concluded that the renewable energy consumption affects the gross domestic product in a positive way (Tiwari, 2011).

The panel estimation method with the ordinary least squares approximation is utilized to investigate the economic data of selected 38 countries in another work for the 1991-2012 period and it is shown that the renewable energy consumption positively affects the economic growth (Bhattacharya et al., 2016). The fully modified ordinary least squares and the dynamic ordinary least squares methods are utilized to investigate the economic data of 19 selected countries for the period of 1994-2003 and it is exposed that the increments in the per capita income increases the renewable energy consumption (Sadorsky, 2009). Similarly, the relationship between the renewable energy consumption and the economic growth of 42 selected developing countries are studied for the period of 1990-2012 using Canning and Pedroni causality tests and it is exposed that there exists a unidirectional causality relationship from the renewable energy consumption to the economic growth (Fotourehchi, 2017). In another work, the relationship between the renewable energy consumption and the economic growth of Türkiye for the period of 1990-2010 is studied employing the autoregressive distributed lag method and the Toda-Yamamoto causality test and it is argued that there exists a unidirectional causality relationship from the economic growth to the renewable energy consumption (Ocal and Aslan, 2013). The panel cointegration, error correction model and the Granger causality tests are utilized for the analysis of the economic data of OECD countries for the period of 1985-2005 and it is shown that there exists a bidirectional causality relationship between the renewable energy consumption and the economic growth (Apergis and Payne, 2010a). Similarly, the heterogenous panel cointegration test is applied on the economic data of 13 Eurasian countries for the period of 1992-2007 where it is concluded that there is a bidirectional causality relationship between the renewable energy consumption and the economic growth (Apergis and Payne, 2010b). The relationship between the renewable energy consumption and the economic growth of the selected 29 OECD countries are studied in the period of 1980-2011 utilizing the Granger causality tests and it is observed that there is a unidirectional causality relationship from the renewable energy consumption to the economic growth (Salim et al., 2014). In another study, the economic data of the selected 6 Central American countries are analysed for the period of 1980-2006 using the panel cointegration and error correction models and it is exposed that there exists a bidirectional causality relationship between the renewable energy consumption and the economic growth (Apergis and Payne, 2011). The relationships between the renewable energy consumption and the economic growth for five Mediterranean countries namely Türkiye, Italy, Greece, Spain and Portugal are analysed using the autoregressive distributed lag model for the 1965-2009 period and it is shown that there exists a bidirectional causality relationship between the renewable energy consumption and the economic growth (Fuinhas and Marques, 2012). In another extensive study, the economic data of 80 selected countries are investigated for the period of 1980-2007 using the panel causality tests and it is concluded that there exist bidirectional causality relationships between the renewable energy consumptions and the economic growths (Apergis and Payne, 2012).

The relationships between the renewable energy consumption and the economic growth rate for the G7 countries are analysed for the period of 1980-2009 using the Hatemi-j causality tests and it is shown that there exist bidirectional causality relationships between the renewable energy consumptions and the economic growths (Tugcu et al., 2012). The economic data of China is analysed for the 1977-2011 period using the Johansen cointegration and Granger causality test and it is concluded that there is a bidirectional causality relationship between the renewable energy consumption and the economic growth (Lin and Moubarak, 2014). Similarly, the structural vector autoregressive method is utilized for the analysis of the economies of four selected developed countries for the 1960-2004 period and it is exposed that there is a bidirectional causality relationship between the renewable energy consumption and the economic growth (Silva et al., 2012). The Brazilian economy is investigated for the 1980-2010 period using the error correction model and it is found out that there exists bidirectional causality relationship between the renewable energy consumption and the economic growth (Pao and Fu, 2013). The relationship between the renewable energy consumptions, CO2 emissions and the economic growths for the BRICS countries are studied using the autoregressive distributed lag model and the Granger causality tests and it is observed that there exist bidirectional causality relationships between the renewable energy consumptions and the economic growths (Sebri and Ben-Salha, 2014). The economic data of selected 69 countries are analysed for the period of 1980-2012 employing panel cointegration methods and it is concluded that there exist bidirectional causality relationships between the renewable energy consumptions and the economic growths (Jebli and Youssef, 2015). In another study, the economy of Germany is analysed using the vector error correction model and the Granger causality test for the 1971-2013 period and it is exposed that there is a bidirectional causality relationship between the renewable energy consumption and the economic growth (Rafindadi and Ozturk, 2017). The economic data of Türkiye is studied employing the Johansen cointegration and Granger causality test for the period of 1988-2012 where it is concluded that there is bidirectional causality relationship between the renewable energy consumption and the economic growth (Dogan, 2016). In another work, the economies of Türkiye, Mexico, Indonesia and Nigeria are studied for the 1993-2017 period utilizing the autoregressive distributed lag method and it is observed that there are bidirectional causality relationships between the renewable energy consumption and the economic growth in Türkiye and Mexico (Odugbesan and Rjoub, 2020). The economic data of Türkiye is studied for the 1980-2018 period using the Toda-Yamamoto causality test and it is concluded that the renewable energy consumption affects the economic growth in a positive way (Demirgil and Birol, 2020).

As it can be observed from the above literature survey, the renewable energy consumption affects several macroeconomic variables such as the economic growth, per capita income and the CO_2 emission. In this study, the renewable energy consumption rate of Türkiye is modelled employing a specially developed autoregressive neural network structure. The details of the utilized data and the developed autoregressive neural network model are explained in the next section.

3. MATERIAL AND METHODS

First of all, the electricity generation percentage from renewable sources excluding hydro, which is abbreviated as the renewable energy utilization rate, is gathered from the World bank database (World bank, 2023). The World bank data is a yearly data ranging from 1961 to 2015 as plotted in Figure 1.

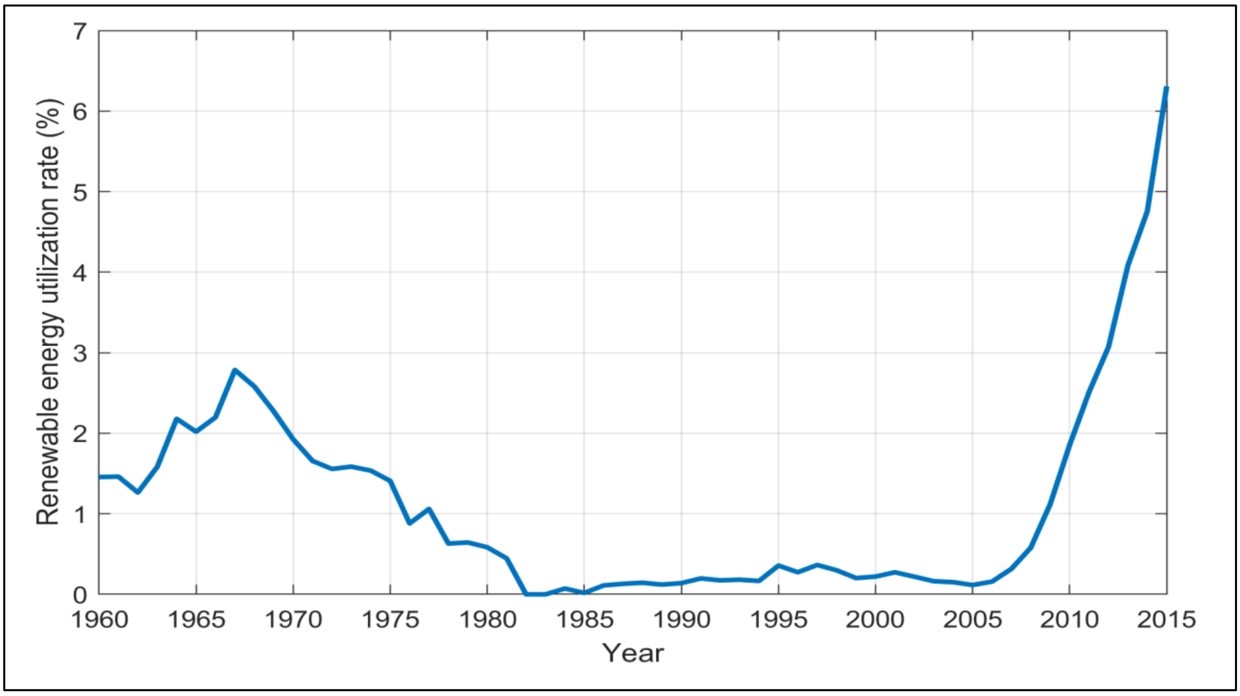

Figure 1. The variation of the renewable energy utilization rate of Türkiye in the period of 1960-2015

As the next step, the seasonal-trend decomposition employing loess (STL) is performed in Eviews environment on the renewable energy utilization rate for the investigation of the seasonality and the nonlinearity of the data. The seasonal, trend and seasonally adjusted components of the renewable energy utilization rate are obtained as in Figure 2.

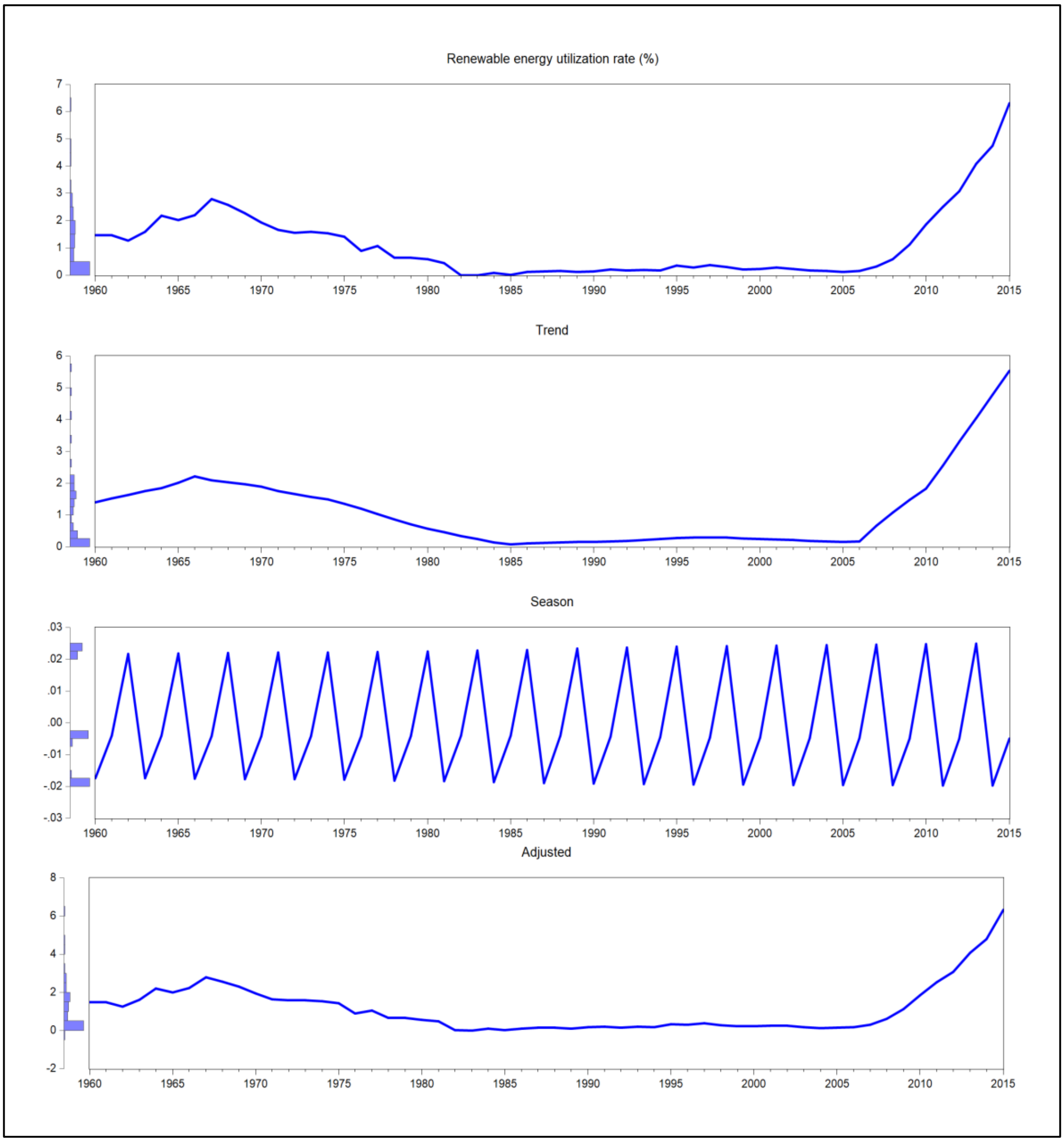

Figure 2. The renewable energy utilization rate data, its trend and seasonal components and the seasonally-adjusted renewable energy utilization rate data

As it can be observed from Figure 2, the renewable energy utilization rate data, its trend and seasonally-adjusted components have strong nonlinearity therefore nonlinear methods have to be utilized for the modelling of the renewable energy utilization rate for the accurate representation of the data. In order to fulfil this requirement, machine learning methods which provide the accuracy for the modelling of the nonlinear data can be used. Considering this, an autoregressive artificial neural network model is developed in this work for the accurate modelling of the renewable energy utilization rate. The developed artificial neural network has five inputs which are the previous values of the renewable energy utilization rate data therefore making the model an autoregressive artificial neural network. Furthermore, a parsing function is custom coded in Python programming language for the generation of the input vector which consists of the five lagged values of the output data. The structure of the developed autoregressive artificial neural network is shown in Figure 3. As it can be observed from Figure 3, the developed autoregressive artificial neural network structure consists of one input layer, three hidden layers and one output layer. The hidden layers employ ten neurons each and the number of the hidden layers and the number of neurons are optimized for the minimization of the modelling error.

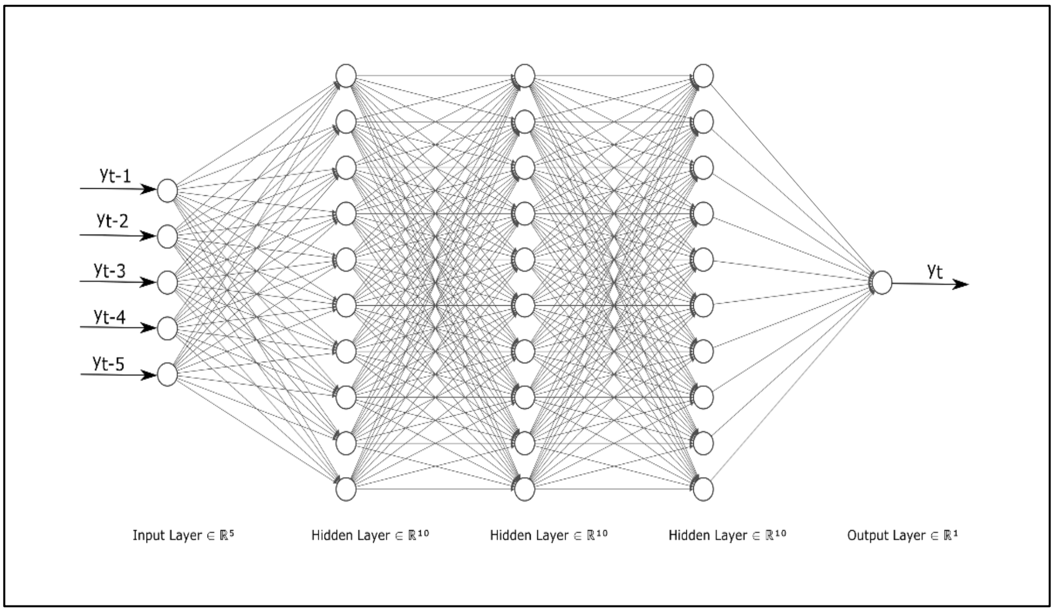

Figure 3. The developed autoregressive artificial neural network structure

The developed autoregressive neural network is trained by the 70% of the available data while the remaining 30% is used as the test data. The test_train_split method of Python programming language is utilized for the splitting of the training and the test data objectively. The results of the training phase and the assessment of the result of the developed model are presented in the next section.

4. RESULTS AND DISCUSSION

The developed autoregressive artificial neural network model is trained using the 70% of the available data. The loss curve regarding the training phase of the developed neural network is shown in Figure 4.

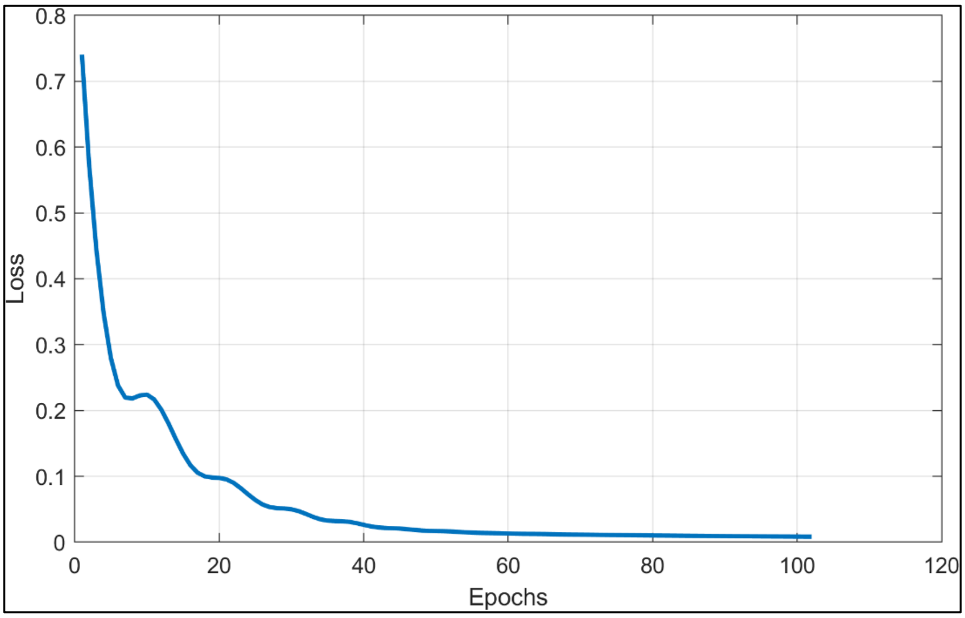

Figure 4. The loss curve of the training phase of the developed autoregressive neural network model

The Figure 4 shows that the training phase of the developed autoregressive artificial neural network model rapidly converges in 102 epochs. It is worth noting that the training convergence performance can be considered to be effective although the number of data samples is low. As the next step, the actual renewable energy utilization rate and the result of the developed autoregressive neural network model are plotted on the same axis pair as shown in Figure 5.

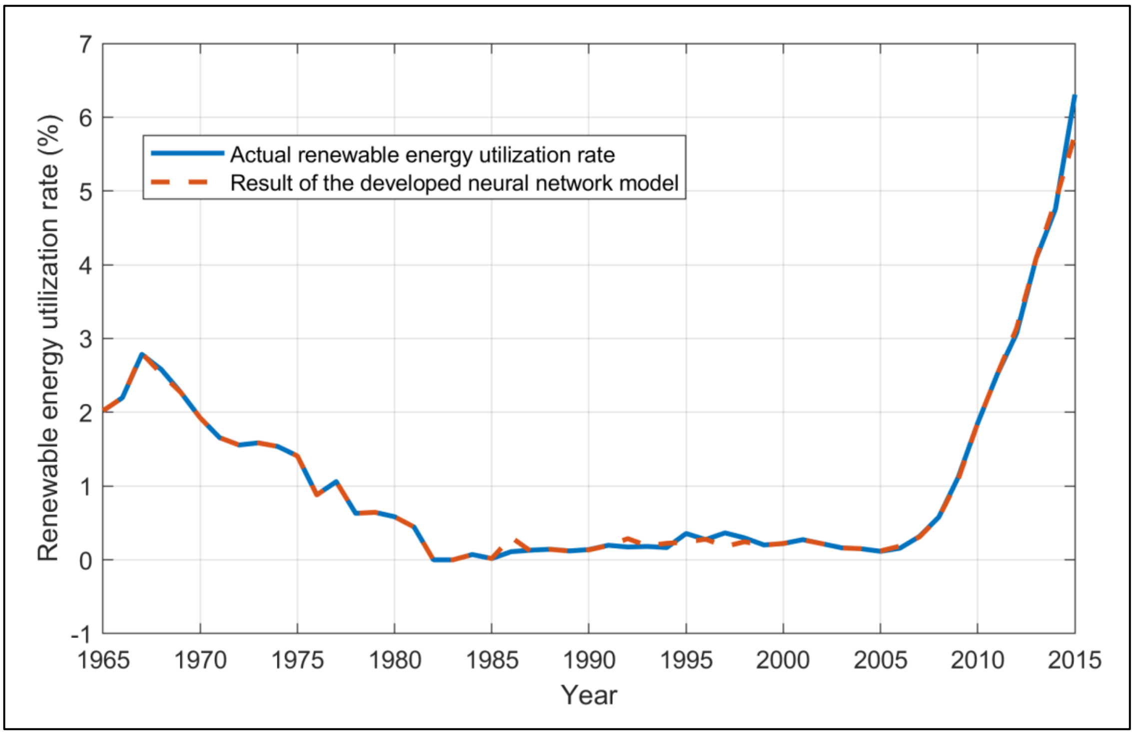

Figure 5. The actual renewable energy utilization rate and the result of the developed autoregressive artificial neural network model

As it can be observed from Figure 5, the developed autoregressive artificial neural network accurately models the renewable energy utilization rate of Türkiye. It is worth noting that the resulting data of the developed model starts from the year 1965 since the first five data are used as the input data as depicted in Figure 3. In order to assess the performance of the developed model, the coefficient of determination, mean absolute error, mean absolute percentage error and the root mean square error values regarding the developed model result are calculated according to Eqs. (1)-(4), respectively (Mombeini and Chamzini, 2015).

$$R^2 = \frac{\sum_1^d (O-avg(O))^2 - \sum_1^d (O-M)^2}{\sum_1^d (O-avg(O))^2} \quad (1)$$

$$MAE = \frac{\sum_1^d |O-M|}{d} \quad (2)$$

$$MAPE = \frac{100}{d} \sum_1^d \left|\frac{O-M}{M}\right| \quad (3)$$

$$RMSE = \sqrt{\frac{\sum_1^d (O-M)^2}{d}} \quad (4)$$

In Eqs. (1)-(4), O represents the original data, M is the model result and d is the number of samples. The obtained values of the coefficient of determination, mean absolute error, mean absolute percentage error and the root mean square error values are given in Table 1.

Table 1. The performance metrics of the developed autoregressive artificial neural network model

Performance metric	Coefficient of determination	Mean absolute error	Mean absolute percentage error	Root mean square error
Value	0.985	0.049	9.249%	0.160

The values shown in Table 1 indicates that the developed model accurately represents the actual renewable energy utilization rate data. It is worth noting that the coefficient of determination is found to be R^2=0.985 and the mean absolute percentage error is calculated as MAPE=9.249% further verifying the high accuracy of the developed model. The developed autoregressive model performs accurately even with low number of samples of the modelled data. Therefore, it can be argued that similar autoregressive artificial neural network architectures can be utilized for the modelling of other macroeconomic variables having low number of samples.

5. CONCLUSIONS

This study aims to model the rate of renewable energy use in Türkiye by employing data from the World bank database covering the period of 1960-2015. Firstly, the seasonality components and nonlinearity behaviour of the data are investigated using the seasonal-trend decomposition module of the Eviews software. Then, an artificial neural network with five input variables, three hidden layers and one output variable is developed to autoregressively model the renewable energy utilization rate. A parsing function is also developed in Python environment to generate the lagged input data for the autoregressive artificial neural network. In the next stage, the autoregressive artificial neural network is trained using the 70% of the available data as training data, while the remaining 30% of the data was used as test data. The available data is split as the training and the test data using the test_train_split method of the Python programming language to maintain objectivity. The loss curve regarding the training phase shows that the developed autoregressive neural network model rapidly converges in 102 epochs. After the training phase, the actual renewable energy utilization rate and the result of the developed autoregressive neural network are plotted on the same axis pair indicating an overlap in a wide range. Furthermore, the performance metrics of the developed model namely the coefficient of determination, mean absolute error, mean absolute percentage error and the root mean square error are computed for the objective assessment of the developed model. The coefficient of determination and the mean absolute percentage error regarding the developed model are obtained as R^2=0.985 and MAPE=9.249% indicating the high accuracy of the developed model. It s worth noting that high accuracy is achieved despite low number of data samples thanks to the optimization of the developed neural network. It can be argued that the developed autoregressive artificial neural network can be adapted for other modelling problems with low number of data samples.

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