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Forecasting the natural gas demand of Türkiye: A deep learning approach

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Abstract

Natural gas is an important input for the production of electricity and other forms of energy. The aim of this study is to investigate the relationship between the natural gas consumption, population and the gross domestic product of Türkiye. For this purpose, deep learning methods are utilized for the modelling of the natural gas consumption for the data covering the period of 1982-2021. First of all, the data required for the modelling are taken from the official sources and then the Granger causality relationship among these variables are studied together with the seasonal and trend decomposition. After assessing the nature of the data that contain high seasonality and nonlinearity, a deep learning network is developed in Python programming language. It is visually demonstrated that the developed deep learning model can be successfully used to describe and forecast the natural gas consumption dependent on the population and the gross domestic product. The performance of the developed deep learning model is also verified using the performance metrics such as the coefficient of determination and the mean absolute percentage error. The developed model is shown to be useful for energy planners and for economists dealing with the energy pricing.

Keywords: Natural gas consumption; Population; Gross domestic product; Deep learning; Machine learning

1. Introduction

Industrialization, urbanization, economic growth and the increment of the population causes an inescapable increase in energy demand. Energy is one of the most common inputs of the industrial sector therefore the economic growth expectations also constitute a driving force for the energy demand. On the other hand, the number of studies regarding the energy supply and demand in the economics literature has increased in 1970s due to the estimates of the reducement of the energy supplies caused from the environmental problems. In this context, various solutions to energy supply problems such as the reducement of the fossil energy usage, transformation of the majority of sources to renewable resources and the development of energy reducing systems in the industry and electricity generation sectors. In addition, the concerns regarding the future include the maintaining of the economic growth as well as the protection of the environment. Therefore, the relationships among the energy demand, population and the domestic income constitute an active and important research field.

Fossil fuels still constitute the great portion of the energy supplies and obviously there exists a need for the development of the efficiency and continuity of renewable energy sources. Hence, the fossil fuels such as petroleum, coal and the natural gas are still an important input for both household and the industrial energy demands. Among the fossil fuels, natural gas is an outstanding resource type thanks to its lower carbon emission figures compared to other fossil fuel alternatives. The importance of choosing the natural gas has increased especially after the Kyoto Protocol and the Paris Agreement. The governments strive to decrease their carbon emissions under given figures which also mandate the use of natural gas over the other fossil fuels. Apart from the carbon emission advantage, utilization of the natural gas has other advantages such that the construction duration and the cost of electricity power plants employing natural gas are

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lower than those using other fossil fuel types. Moreover, the natural gas can be stored easily which is also an advantage for both distribution companies and the small and middle sized business which need stored energy sources.

The natural gas supply, storage and distribution systems have also become crucial concepts from the geopolitical point of view. Therefore, the accurate modelling and forecasting the natural gas supply and demand is a significant problem for almost all countries. The estimation errors regarding the natural gas supply and demand also has great amount of importance because these errors contribute to the price imbalances and market price fluctuations. On the other hand, Türkiye is a rapidly developing country which maintains an economic growth rate above the World and European average. Moreover, Türkiye is considered to be a country whose population is dominantly young people. Therefore, the economic growth rate is a crucial factor for the wealth of the Turkish people and a positive economic growth is required. Considering that the natural gas is an important input of the industrial sector of Türkiye, accurate modelling of the natural gas demand is obviously a vital economic concept. The agreements regarding to the natural gas trade are made in advance therefore, the accurate modelling and forecasting the natural gas consumption also carries importance regarding the price levels.

In this work, the relationships among the natural gas consumption, population and the gross domestic product of Türkiye for the period of 1982-2021 are investigated. First of all, the seasonal decomposition of the gathered natural gas consumption, population and the gross domestic product data are performed followed by the Granger causality analysis. Then, the natural gas demand is modelled dependent on the population and the gross domestic product according to the Granger causality results. A deep learning network is developed in Python programming language for the modelling of the natural gas demand. The performance of the deep learning model is firstly analyzed visually by plotting the actual natural gas consumption data and the developed deep learning model results on the same axis pair. And then, 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 calculated which verify the accuracy of the developed deep learning model. Finally, it is argued that the natural gas consumptions of different countries and regions can also be modelled using a similar deep learning approach.

2. Literature Analysis

There are several types of studies regarding the modelling and forecasting of the natural gas demand. For example Lim and Yoo studied the relationship between the economic growth and the natural gas consumption of South Korea for the 1991-2008 period using Granger causality test and the Johansen-Juselius cointegration test and they have concluded that there exists a bidirectional causality relationship between the economic growth and the natural gas consumption [1]. In another work, the natural gas consumption of G-7 countries are investigated for the 1970-2008 period employing Granger causality test with the bootstrap correction and it is found out that there is bidirectional causality between the natural gas consumption and the economic growth for the U.S., France and Germany while there is a unidirectional causality from the natural gas consumption to the economic growth for Italy and there is a unidirectional causality from the economic growth to the natural gas consumption for the U.K. and finally there is no causality relationship between the natural gas consumption and the economic growth for Canada and Japan [2]. Similarly, the relationship between the natural gas consumption and the economic growth for the BRICS-T countries are studied for the period of 1980-2011 utilizing the autoregressive distributed lag (ARDL) cointegration test and the Granger causality test and it is concluded that there is a bidirectional causality relationship between the natural gas consumption and the economic growth for Brazil, Russia and Türkiye while there exists no causality relationship between the natural gas consumption and the economic growth for India, South Africa and China [3]. In another work, the relationship between the natural gas demand and the economic growth for Pakistan for the period of 1972-2010 is investigated using ARDL and Johansen cointegration tests and it is shown that there is a unidirectional relationship from the natural gas demand to the economic growth [4]. Toda-Yamamoto and nonlinear Granger causality tests were utilized in another study for analyzing the relationship of the natural gas demand and the economic growth for Poland for the period of 2001-2009 where it is concluded that there exist a unidirectional causality relationship from the economic growth to the natural gas demand in the long-run [5]. In another work, the relationship between the natural gas consumption and the economic growth for Türkiye in the 1995-2012 period is investigated employing the ARDL and Granger causality tests and it is shown that there is a bidirectional causality relationship between the natural gas consumption and the economic growth [6]. ARDL, Bayer-Hanck cointegration test and the Granger causality test are utilized for the analysis of the natural gas consumption and the economic growth of Malaysia for the 1971-2012 period and it is concluded that there is a bidirectional causality relationship between the natural gas consumption and the economic growth [7]. In another study, the economies of the Gulf Arabian States are analyzed for the 1980-2012 period using the Pedroni panel cointegration test and the Granger panel causality test where it is concluded that there are bidirectional causality relationships between the natural gas consumptions and the economic growths [8]. The British and European economies are investigated in another work for the 1997-2011 period utilizing panel causality test and it is shown that there exists a unidirectional relationship from the economic growth to the natural gas consumption while there is no causality relationship for other countries [9]. In contrary, the economies of 26 EU countries for the period of 1997-2011 are studied using Pedroni cointegration test and panel causality test and it is concluded that there exist a unidirectional causality relationship from the natural gas demand to the economic growth for all of these 26 EU countries [10].

The ten countries with the most natural gas consumption are studied in another work for the period of 1994-2015 using the Pedroni cointegration test, Kao cointegration test and the Granger causality test and it is shown that there are bidirectional relationships between the natural gas consumption and the economic growth for Thailand, there is a unidirectional causality relationship from the economic growth to the natural gas consumption for Britain and Germany and there exist no causality relationship between the natural gas consumption and the economic growth for India, Canada, Russia, Mexico, China, Japan and the United States [11]. The panel Granger causality tests are performed for the OPEC countries for the 1980-2012 period and it is demonstrated that there exist a unidirectional causality relationship from the natural gas consumption to the economic growth for Nigeria, Saudi Arabia, Iraq, Kuwait and Libya, there are unidirectional causality relationships from the economic growth to the natural gas consumption for Iran, United Arab Emirates and Algeria [12]. In another study, the economies of the selected 12 EU countries are investigated for the 1991-2016 period where it is observed that there exist unidirectional causality relationship from the natural gas demand to the economic growth for Austria, Switzerland and Bulgaria while for the U.K and Italy there is a unidirectional causality relationship from the economic growth to the natural gas consumption [13]. In another work, the Northeastern Asian countries are studied for the 1991-2015 period utilizing the panel causality test, Pedroni cointegration test and the Kao cointegration test and it is concluded that there exists no causality relationship between the natural gas consumption and the economic growth for Japan and South Korea and there is a unidirectional causality relationship from the natural gas consumption to the economic growth for China [14]. The economic data of Malaysia is studied for the 1980-2014 period using ARDL cointegration test and the Granger causality test where it is observed that there is a unidirectional causality relationship from the natural gas consumption to the economic growth [15]. Similarly, the economy of Indonesia is investigated in another work using the ARDL cointegration test for the 1980-2017 period where it is concluded that there exist a bidirectional causality relationship between the natural gas consumption and the economic growth [16]. The Gregory-Hansen cointegration analysis is utilized in another study for the analysis of the economic data of Pakistan for the period of 1965-2019 where it is shown that there is a bidirectional causality relationship between the natural gas consumption and the economic growth [17]. Similarly, the Chinese economic data for the period of 1989-2020 is investigated in another work employing wavelet coherence method and it is concluded that there is a bidirectional causality relationship between the natural gas consumption and the economic growth [18]. In another study, the Nigerian economy is analyzed for the period of 1981-2009 utilizing ARDL cointegration test where it is observed that there exists a unidirectional causality relationship from the natural gas demand to the economic growth [19]. In another work, the panel cointegration test is employed for the investigation of the economic data of Mexico, Indonesia, South Korea, Turkey and Australia where it is shown that there is bidirectional causality between the natural gas consumption and the economic growth [20].

The economic data of Taiwan for the 1954-1997 period is examined using the Granger causality analysis in another work and it is shown that there is a unidirectional causality relationship from the natural gas consumption to the real GDP [21]. Similarly, the economic data of the U.K. is studied utilizing Granger causality in another work where it is exposed that there exists a unidirectional causality relationship from the gross national product (GNP) to the natural gas demand [22]. In another study, the economies of Australia and New Zealand are investigated for the period of 1960-1999 using ARDL, Toda-Yamomoto causality tests and the Johansen maximum likelihood method where it is exposed that there exists no causality relationship between the GDP and the natural gas consumption [23]. The economic data of Pakistan is studied for the period of 1955-1996 using the Granger causality analysis and it is shown that there exists no causality relationship between the GDP and the natural gas consumption [24]. In another study, the economic data of the U.S. is investigated for the period of 2001-2005 utilizing the generalized forecast error variance decomposition method and it is concluded that there is a unidirectional causality relationship from the natural gas consumption to the GDP [25]. The economic data of Taiwan for the period of 1954-2003 is investigated using the Johansen maximum likelihood method and the weak externality test where it is shown that there is a unidirectional causality relationship from the natural gas consumption to the GDP [26]. The vector error correction model is utilized in another work for the Taiwanese economy for the 1982-2006 period where it is concluded that there exists a bidirectional causality relationship between the natural gas consumption and the GDP [27]. In another work, the economic data of Iran is investigated for the period of 1967-2003 using Johansen maximum likelihood method and the vector error correction model where it is exposed that there is a unidirectional causality relationship from the natural has consumption to the GDP [28]. The Toda-Yamamoto test is utilized for the analysis of the economic data of Bangladesh, Pakistan, India, Nepal and Sri-Lanka for the period of 1971-2003 in another study and it is shown that for Bangladesh there is a unidirectional causality relationship from the GDP to the natural gas consumption and no causality relationship has been detected for the other countries [29]. In another work, the ARDL and the vector error correction model are employed for the analysis of the U.S. economy for the 2001-2005 period where it is concluded that there exists a unidirectional causality relationship from the GDP to the natural gas consumption [30].

The economic data of Nigeria is studied in another work using the vector error correction model for the period of 1980-2006 and it is shown that there is a unidirectional causality relationship from the GDP to the natural gas consumption [31]. Similarly, the economy of Iran is investigated for the period of 1973-2003 employing ARDL and the vector error correction model where it is concluded that there is a unidirectional causality relationship from the GDP to the natural gas consumption [32]. In an extensive study, the economic data of selected 67 countries are studied for the period of 1992-2005 using Pedroni causality test and the Granger causality test where it is concluded that there exists bidirectional causality relationship between the natural gas consumption and the GDP [33]. In another work, the Nigerian economy is investigated for the 1970-2005 period employing the Johansen maximum likelihood method and the vector error correction method where it is exposed that there is a unidirectional causality relationship from the natural gas consumption to the GDP [34]. The economic data of the OECD countries are studied for the 1991-2003 period utilizing the fully modified ordinary least squares method, the dynamic ordinary least squares method, the vector error correction model and the Granger causality test where it is shown that there exists a bidirectional causality relationship between the natural gas consumption and the GDP in the long-run [35]. The Turkish economy is investigated in the period of 1977-2008 using the ARDL model and it is concluded that there exists a bidirectional causality relationship between the natural gas consumption and the GDP [36]. In another work, the economic data of Middle Eastern countries are investigated for the 1980-2014 period using the panel data analysis where it is shown that there is a bidirectional causality relationship between the natural gas consumption and the GDP [37]. The relationship between the natural gas consumption and the economic growth is studied for APEC countries in the period of 1990-2015 using panel data analysis approach and it is concluded that the natural gas consumption impacts the economic growth [38]. The Cobb-Douglas production function and the panel ordinary least squares methods are utilized for the investigation of the relationship between the natural gas consumption and the economic growth for the period of 2000-2014 in another work and it is exposed that the natural gas consumption has significant effect on the economic growth [39]. In another study, the time-varying causality test approach was utilized to investigate the relationship between the natural gas consumption and the economic growth for Türkiye in the period of 1983-2017 and they have exposed that there exists a unidirectional causality relationship from the natural gas consumption to the economic growth for the 1997-2011 period [40].

The economic data of Pakistan for the period of 1972-2011 is investigated in another work where ARDL, Johansen cointegration test and the Granger causality test are utilized for the determination of the relationship of the natural gas consumption and the economic growth and it is shown that there is a bidirectional causality relationship between the natural gas consumption and the economic growth [41]. The ARDL cointegration and the Granger causality test were used also in another study in which the economic data of India and China are examined for the period of 1965-2016 and it is found out that in the short run, there exists no causality relationship between the natural gas consumption and the economic growth for India however there is a unidirectional causality relationship from the natural gas consumption to the economic growth for China and for the long run there is a bidirectional causality relationship between the natural gas consumption and the economic growth [42]. In another study, the natural gas consumption and the economic growth of ten highest CO_2 emitting countries for the period of 1990-2014 are investigated using the panel cointegration test and it is concluded that there is a unidirectional causality relationship from the natural gas consumption to the economic growth [43].

There are various studies regarding the relationship of the natural gas consumption and the GDP or economic growth as it can be seen from the above literature analysis. It is because the supply and demand modelling and forecasting the natural gas consumption is of high importance due to the reasons explained in the Introduction section such as the balanced formation of the market price of the natural gas. Considering this importance, the relationship among the natural gas consumption, GDP and the population of Türkiye for the period of 1982-2021 is investigated. The Granger causality among these variables are analyzed after the seasonal decomposition. Then, the natural gas demand of Türkiye is modelled dependent on the GDP and population utilizing a new deep learning model which is developed in Python programming language. The study is completed by the assessment of the of the developed model using the performance merits.

3. Material and methods

The natural gas demand data of Türkiye is taken from the official Energy Market Regulatory Authority (EPDK) in the range of 1982-2021 [44]. The population data is gathered from the Turkish Statistical Institute (Turkstat) [45]. On the other hand, the gross domestic product data is taken from the Electronic Data Distribution System of the Central Bank of Türkiye [46]. First of all, these data are imported into the Eviews software for the seasonal-trend decomposition process [47]. The seasonal-trend decomposition using Loess method is utilized for this aim [48]. The original data, seasonal components and the seasonally adjusted results for the natural gas consumption, population and the GDP are given in Figure 1, Figure 2 and Figure 3, respectively.

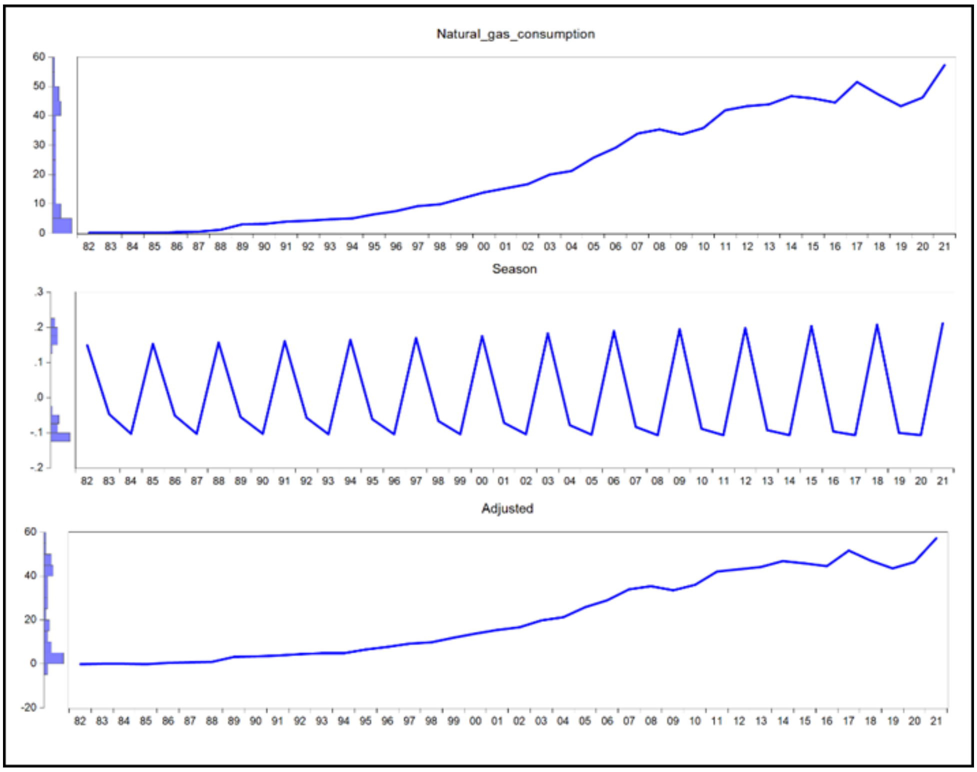

Figure 1 Seasonal-trend decomposition of the natural gas data

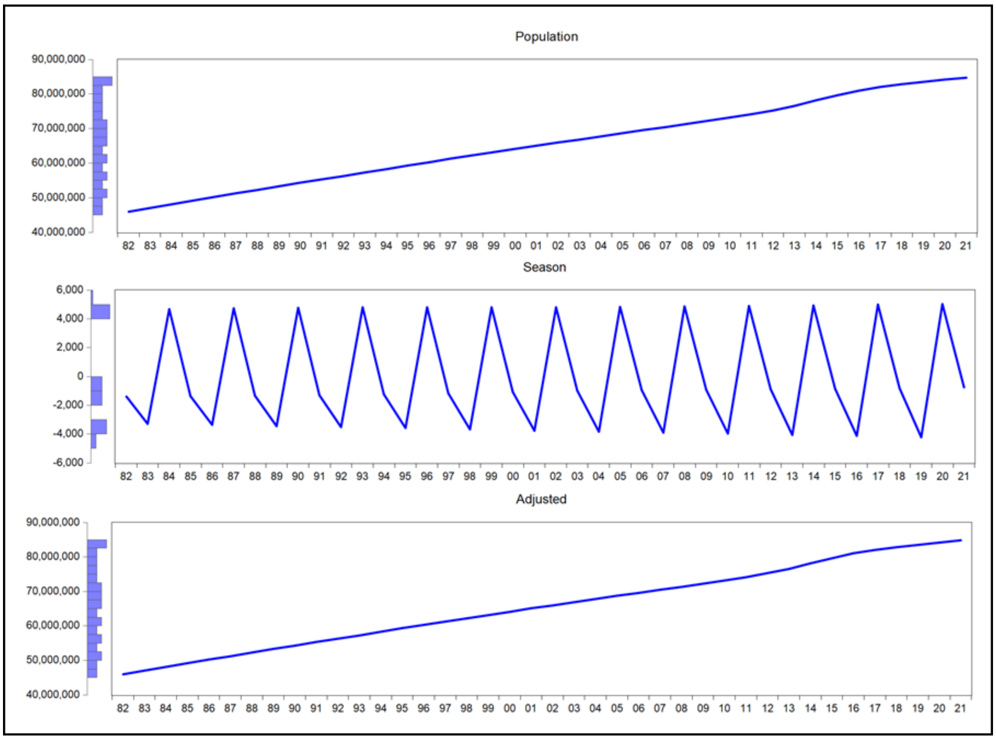

Figure 2 Seasonal-trend decomposition of the population data

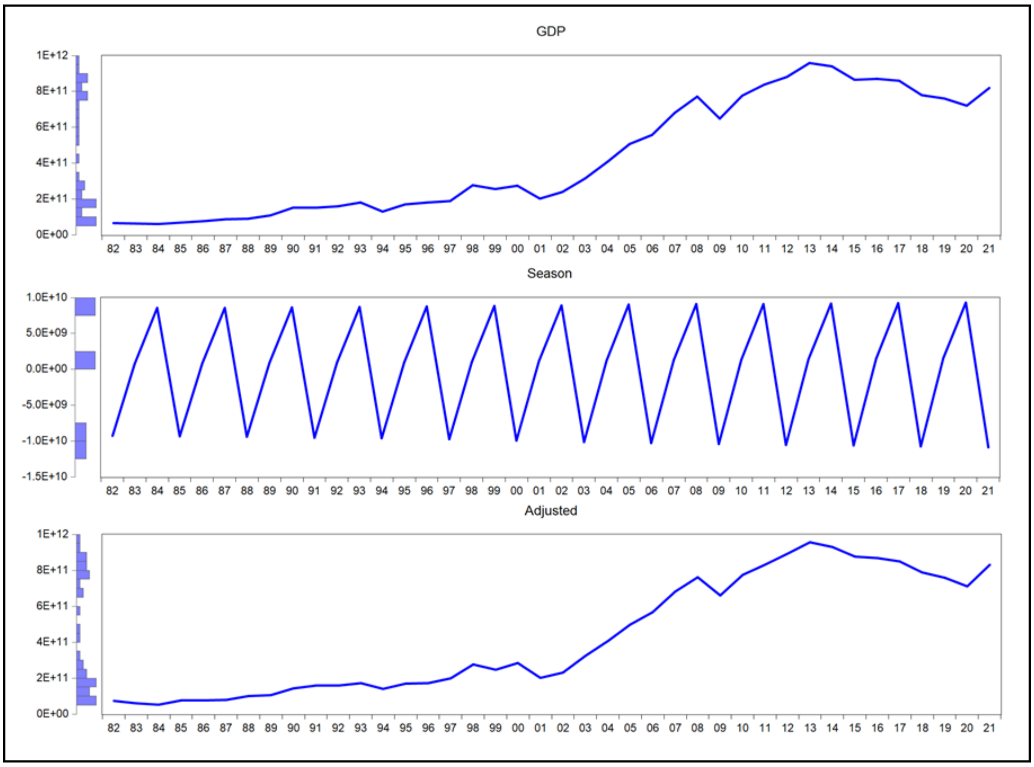

Figure 3 Seasonal-trend decomposition of the GDP data

As it can be observed from Figure 1, Figure 2 and Figure 3, the natural gas demand, population and the GDP data have strong seasonal components implying to utilize the seasonally adjusted data for the analysis and modelling phases. As the next step, the Granger causality analysis is performed in Eviews software [49]. The results of the pairwise Granger causality tests is given in Table 1.

Table 1 Pairwise Granger causality test results

Pairwise Granger Causality Tests			
Date: 04/01/23 Time: 20:57			
Sample: 1982 2021			
Lags: 4			
Null Hypothesis:	Obs	F-Statistic	Prob.
NATURAL_GAS_CONSUMPTION_SA does not Granger Cause GDP_SA	36	2.06147	0.1139
GDP_SA does not Granger Cause NATURAL_GAS_CONSUMPTION_SA		2.92136	0.0396
POPULATION_SA does not Granger Cause GDP_SA	36	3.25983	0.0264
GDP_SA does not Granger Cause POPULATION_SA		2.26745	0.0881
POPULATION_SA does not Granger Cause NATURAL_GAS_CONSUMPTION_SA	36	5.82066	0.0016
NATURAL_GAS_CONSUMPTION_SA does not Granger Cause POPULATION_SA		4.95471	0.0040

The Granger causality test results indicate that there is a unidirectional causality relationship from the GDP to the natural gas consumption. Additionally, there is also a unidirectional causality from the population to the GDP. And finally, there exist a bidirectional causality relationship between the population and the natural gas demand. These causality relations are summarized in Figure 4.

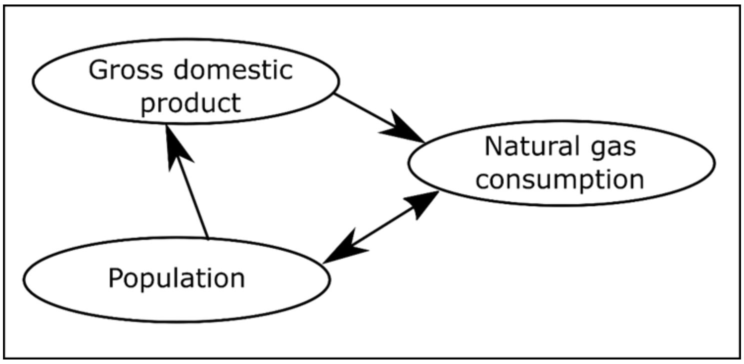

Figure 4 The Granger causality relationships between the considered variables

The causality relationships between the variables shown in Figure 4 imply that the natural gas demand can be modelled dependent on the gross domestic product and the population. Furthermore, this modelling has to be performed using nonlinear tools since the seasonal-trend decompositions of the considered data are highly seasonal and nonlinear as it can be observed from Figures 1, 2 and 3. Therefore, in this study deep learning networks, which is a subset of the nonlinear machine learning concept, is utilized for the development of the forecasting model of the natural gas demand dependent on the gross domestic product and the population data [50-53]. The deep learning network is developed in Python programming language employing the SciKit library and the MLPRegressor class [54-58]. The structure of the developed deep learning network is shown in Figure 5.

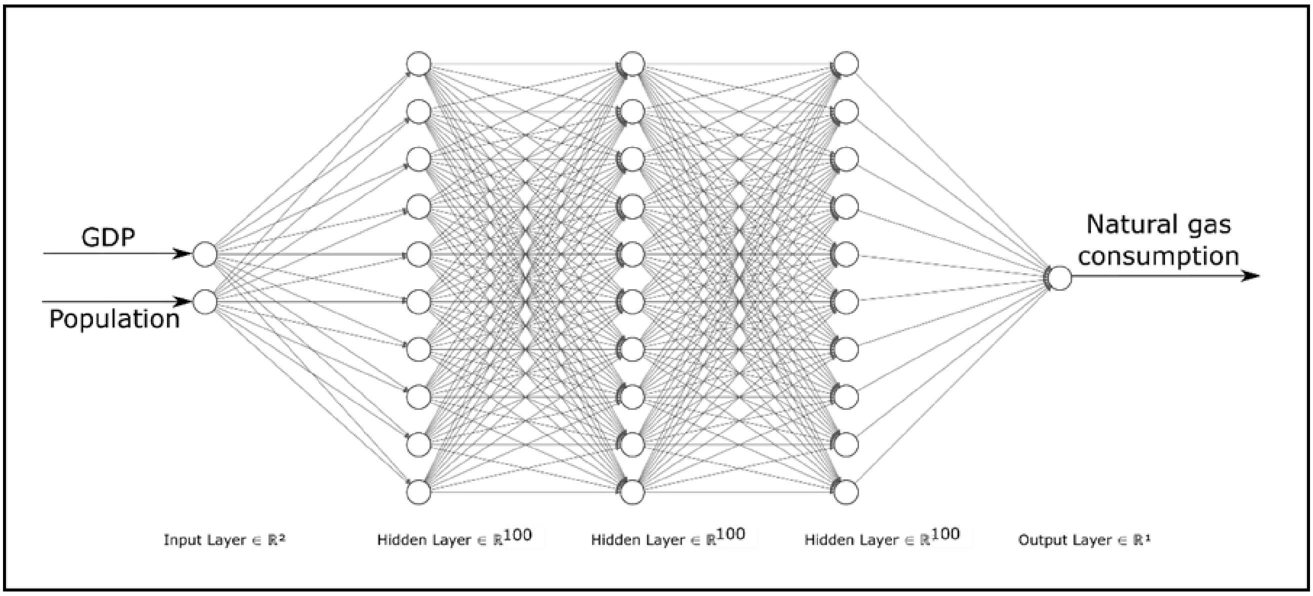

Figure 5 The structure of the developed deep learning network

The structure of the developed deep learning network is as follows: there are two input data namely the GDP and the population and there exist three hidden layers. Each hidden layer has 100 neurons and the nonlinear activation function of the neurons are the tangent sigmoid function [59-61]. The 70% of the available data is used as the training data while the 30% of the data is the test data. The separation of the train and test data are automatically performed using the test_train_split class of the SciKit Learn library [62, 63]. The results of the modelling and forecasting the natural gas demand using the developed deep learning network is presented in the next section.

4. Results and discussion

The developed deep learning network is trained using the 70% of the available data and then the forecasting result of the natural gas demand is obtained from the deep learning model. The actual natural gas demand and the results of the developed forecasting model are plotted on the same axis pair in Figure 6.

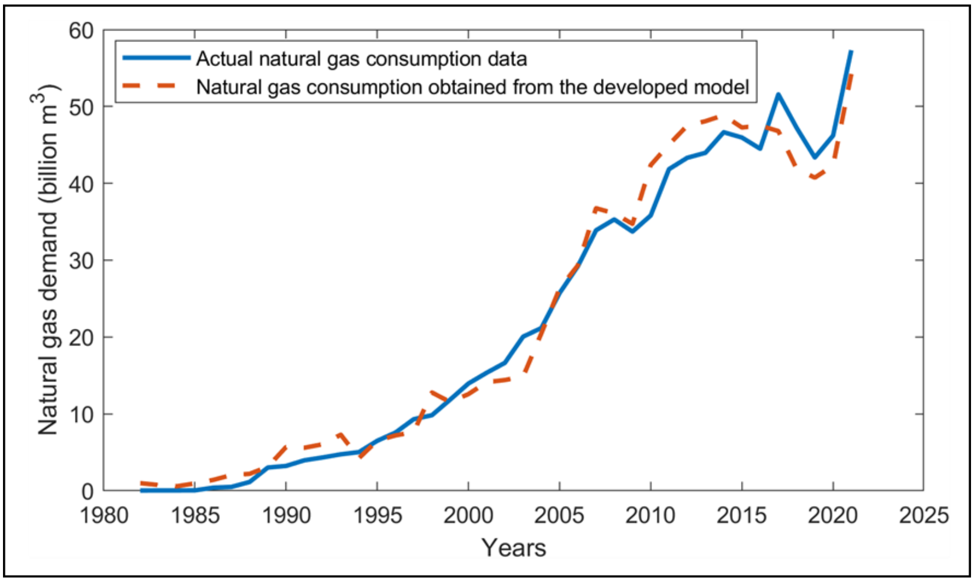

Figure 6 The actual natural gas demand and the natural gas demand obtained from the deep learning model

As it can be observed from Figure 6, the developed deep learning model accurately models the natural gas demand dependent on the gross domestic product and the population data. It is worth noting that the developed deep learning network has 100 neurons in each of the three hidden layers such that this complex network can be used to model the natural gas demand with relatively low number of samples.

As the next step, the results of the developed deep learning network is assessed using quantitative performance metrics namely the coefficient of determination (R^2), mean absolute error (MAE), mean absolute percentage error (MAPE) and the root mean square error (RMSE). These figure of merits are defined as in Equations (1), (2), (3), and (4), respectively [64].

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

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

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

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

In these equations, d is the length of the time series, O is the original data and M is the data obtained from the developed deep learning model. These figure of merits are calculated using the classes existing in the sklearn.metrics library [65] of the Python programming language as given in Table 2.

Table 2 Performance metrics of the developed deep learning model

Coefficient of determination (R^2)	**Mean absolute error (MAE) – billion m^3**	**Mean absolute percentage error (MAPE)**	**Root mean square error (RMSE) – billion m^3**
0.948	3.035	2.315%	4.218

The performance metrics of the developed deep learning model shown in Table 2 indicate that the developed model accurately represents the actual natural gas demand. The models having MAPE values less than 10% are considered as highly accurate [66-70] therefore the developed deep learning model can be considered to be highly accurate since it has the MAPE value of 2.315%. Other performance metrics given in Table 2 also verify the high accuracy of the developed deep learning model. Therefore, it can be stated that the natural gas demand can be accurately modelled dependent on the gross domestic product and the population employing deep learning networks.

5. Conclusion

In this work, the relationship among the natural gas consumption, population and the gross domestic product of Türkiye for the period of 1982-2021 is studied. A subset of machine learning called deep learning methods are employed for the modelling of the natural gas consumption. Firstly, the natural gas consumption, population and the gross domestic product data are gathered from the official resources. Then, the seasonal-trend decomposition is applied and it is observed that the considered data has high linearity and seasonality. After this analysis, the pairwise Granger causality relationship between these variables are performed. The Granger causality results indicate that the natural gas demand can be modelled dependent on the gross domestic product and the population. As the next step, a deep learning network is developed in Python programming language for the modelling of the natural gas consumption dependent on the gross domestic product and the population. The plots of the actual natural gas demand and the developed deep learning model results show an accurate overlapping. Then, the accuracy of the developed model is also quantitatively assessed using the performance metrics namely the coefficient of determination, mean absolute error, mean absolute percentage error and the root mean square error. These performance metrics also verify the high accuracy of the developed model for the estimation of the natural gas demand. It can be argued that the developed deep learning model can be used by the energy planners and the economists dealing with the energy market.

Compliance with ethical standards

Acknowledgments

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Disclosure of conflict of interest

The authors declare no conflict of interest.

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