Time-Stratified Analysis of Electricity Consumption: A Regression and Neural Network Approach in the Context of Turkey

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Abstract: - This study aims to apply seasonality and temporal effects in the analysis of electricity consumption in Turkey as a case mixed with regression and neural network methodologies. The study goal is to increase knowledge about the features and trending forces behind electricity usage which provide informed recommendations for smart energy planning and regulation. Comparing and contrasting the regression and neural network models makes it possible to carry out a thorough analysis of the merits and demerits of each model. Moreover, the examination of the limits of the models and their performance in forecasting electricity consumption patterns over the long term is done. The results of this study have a significant impact on power forecasting techniques, and they have meaningful effects on the policymakers, planners and utilities in Turkey. Understanding the story of the use of electricity around the world is very important for the development of sustainable energy policies, resource provision, and the maintenance of reliable and smart energy networks in the country.

Key-Words: - Electricity Consumption, Time-Stratified Analysis, Regression Modeling, Neural Network Approach, Energy Forecasting, Turkey, Sustainable Energy Policies, Resource Optimization.

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1 Introduction

The growing need for electricity in Turkey, being connected with the mounting challenges of modern electricity systems, requires a deep investigation into consumers' behavior to welfare the formulation of a desirable electricity plan and the enactment of power policies. It is important to pay attention to that as time-stratified analysis of electricity consumption in the Turkey case is done with traditional regression models and with the advanced neural network methods. We hope to track the time-based fluctuation of electricity demand in the hope of exposing the driving factors of variation in usage upshot.

Turkey's own geographical and climatic peculiarities as well as her largest share of activities, which determine electricity, demand structurally, all are responsible for the development of a distinctive electricity consumption profile. Knowing the alterations in temporal attributes for instance seasonality, temperature, and time-of-day is very important for having optimal energy infrastructures, and for making sure grid reliability and formulating sustainable policies.

Then, as a solution to the determined restrictions of traditional methods, the artificial neural networks, which are the tools for non-linear pattern building and complex relationship traffic, are utilized.

Through applying a time-based model, the research is committed to observing the complexity of electricity consumption at different intervals, seasonal factors, economic cycles, and possible emotional issues. Net electricity generation is defined as the total of all electricity production minus all the same amount of electricity consumed in a given region or country. The net electricity consumption is significant to consider in terms of energy demand, ensure the electricity demand and supply balance. For operational purposes, net electricity consumption is commonly measured in megawatts or gigawatts (MWh/GWh). This gauge indicates the difference between the total power output formed over some time (for example, every hour, day, month, or year) and the total power consumption. The demand for grid electricity is significant data for planners of energy, investments in the area of infrastructure, and the design of energy policy, just to mention a few. The net electric power consumption of a portion or country is used to identify the variations of its energy demand, plan energy outputs, and utilize energy resources properly. Data on net electricity consumption was obtained from a variety of sources, including energy companies, government agencies, and international energy organizations. This information is used in many areas such as electricity consumption analysis, energy demand forecasts, and energy policy development. However, data on net electricity consumption is often published with a lag and it is important to follow official energy market data sources or producers for up-to-date information.

The primary objective of this research is to enhance the accuracy and depth of our understanding of electricity consumption patterns in Turkey through a two-fold approach: firstly, employing a traditional regression model that encompasses fundamental temporal variables, and secondly, leveraging the power of neural networks to capture complex, non-linear relationships inherent in the data.

The first phase of our analysis involves constructing a comprehensive regression model. This model considers variables such as time of day, day of the week, and seasonality, aiming to quantify the impact of these factors on electricity consumption. From historical data, the regression model gives an insight into the time patterns of consumption, which provides a background analysis for later methods of more intricate mechanisms.

In the next phase, we move into the dimension of neural networks, taking advantage of their competence in unmasking perplexing patterns and associations within huge datasets. The neural network model adapts and learns from historical patterns of consumption, which gives it high accuracy for making predictions and discovering the nuances that traditional regression models never see. The main variables reflecting a study are; Real Gross Domestic Product; Population; Quantity of Vehicles; Foreign Trade; and Industry. Electricity demand is a complex and multi-influencing phenomenon, which depends on economic activities, population growth, the effect of weather elements, and technological developments. When comprehending the volatile nature of electricity usage, it is imperative for good energy planning and sustainable development.

This article is about showing the temporal variations of Turkey's electricity consumption using time-stratified analysis, which is a combination of traditional regression analysis as well as the utilization of modern artificial neural networks (ANNs).

The layout of the paper comes down to the elements of the methodology, which in turn are regression analysis and neural network modeling. This time-layered analysis provides the findings that are accommodative to the design and formation of plans and strategies concerning energy, which again, helps in policy formulation. Factors that are seen to be substantial in one time. Period could change in later times and this is where regression analysis comes to the fore. On the other hand, neural networks enable the researcher to have a deep understanding of non-linear relationships between factors. Through this, predictions that are more accurate are achieved. The anticipated effects of these findings on energy policy or planning include the discussion of effective approaches and the prospects for more competent forecasting and sound decision-making in the volatile reality of consumption are illustrated. This study adds to the emerging branch in energy analytics of investigating the performance of regression models as a simple alternative to deep neural networks in electricity consumption prediction. As such, they bring significant impacts for the above-mentioned actors, that is, energy planners, policymakers, and utility companies, which in turn are used as important and relevant inputs in allocating resources and developing sustainable energy strategies in Turkey.

As we delve into the depths of time-stratified electricity consumption analysis, the subsequent sections of this research will unfold the methodology, data, results, and discussions, ultimately leading to a nuanced understanding of the temporal intricacies shaping Turkey's electricity landscape.

The remainder of this paper is structured as follows: Section 2 includes an overview of the pertinent literature. Section 3 defines the model definition and formulation, encompassing the mathematical model of the time-stratified analysis of electricity consumption. Section 4 structures a case study, summarizing the key results of our proposed approach in comparison to the current state of affairs. Finally, in Section 5, we present our concluding remarks.

2 Literature Survey

The literature survey explores existing research related to time-stratified analysis of electricity consumption, with a focus on regression and neural network approaches, within the specific context of Turkey. Some of the studies cover the temporal analysis of electricity consumption which emphasizes the importance of considering temporal dynamics for accurate forecasting and efficient energy planning, [1], [2], [3], [4], [5]. Some of the studies highlight the ability of neural networks to capture non-linear relationships and intricate patterns, contributing to more accurate predictions in electricity consumption modeling, [6], [7], [8], [9], [10]. Some of the researchers have explored the influence of geographical and socioeconomic factors on electricity consumption, [11], [12]. Given Turkey's unique characteristics, understanding how these factors interact with temporal dynamics becomes crucial for tailored energy policies. Some of these works shed light on the country's energy landscape, providing valuable insights into consumption patterns and trends that inform the present research, [13], [14], [15]. Comparative analyses between regression models and neural networks in the context of electricity consumption are scarce, [16], [17], [18], [19]. The authors discussing the implications of electricity consumption patterns on energy policy offer a broader perspective, [20], [21], [22]. The present research aims to contribute to this discourse by providing insights specifically tailored to the Turkish context. Advancements in time series analysis have been crucial for refining methodologies in electricity consumption studies. The integration of advanced artificial intelligence in the current technology is an effort made to improve the accuracy of timeline forecasts and deepen understanding of it, [23], [24], [25]. The other investigations address the place of temperature and or weather in total energy consumption. In the spirit of the diversity of weather in Turkey, these correlations are of significant value to the accuracy of the modeling and forecasting, [26], [27], [28], [29], [30].

It is with this basic objective that the current research will bring contributions by building upon existing knowledge and making a definitional addition to Electricity Consumption Analysis, which is valid in the Turkish context.

3 Methodology

Herewith the given analysis is undertaken which focuses on electricity consumption in Turkey. Grasping a holistic view by using both traditional regression analysis and advanced artificial neural networks (ANNs). The main purpose of the research is to find hidden relationships and identify changes that occur inside the time domain of electricity demand. This kind of information is very valuable as it tries to support the future policymakers, as well as all energy planners, and of course their stakeholders.

Regressions analysis is very stable. Through an ordered review of historical data, key variables such as consumption of energy with time can be easily identified. Then, besides the stem learning algorithms like regression and correlation analysis, which are excellent in terms of capturing any non-linearity, the artificial neural networks are applied to improve the forecasting accuracy. The research uses a data set that covers a particular period, which is then divided further into numerous periods to ensure seasonality, trend, and anomaly injection of electricity consumption patterns being captured in totality. Thus, by the integration of the regression and neural network techniques, this research seeks a detailed examination of time-dependent features of Turkey's electricity demand. The end purpose is to increase our knowledge of how the different parameters influence the electricity consumption in Turkey during different periods. By using the strengths of both interpretability associated with regression analysis and the flexibility provided by neural networks, this methodological dual approach allows us to gain a deeper understanding of demand response and how different factors affect it in the temporal sense. Finally, the study is considered as a useful tool for decision-makers in the energy sector, and it will help prepare effective performance plans and permanent actions that are used by energy management planners in Turkey.

In electricity consumption time stratified analysis, regression and neural network approaches on the one hand provide a flexible and integrating methodology. The following paragraph is about the regression model, as well as the neural network.

3.1 Mathematical Model

3.1.1 Regression Model

The regression model represented as a linear equation:

$$Y=\beta_0+\beta_1X_1+\beta_2X_2+\ldots+\beta_nX_n+\varepsilon$$

Where
Y is the dependent variable (electricity consumption)
β_0 is the intercept.
$\beta_1+\beta_2+\ldots+\beta_n$ are the coefficients for the independent variables
$X_1+X_2+\ldots+X_n$, representing the time of day, day of the week, etc.)
ε is the error term.

For example, considering time of day (TOD), day of the week (DOW), and seasonal factors (SEASON), the regression equation might be
$Consumtion=\beta_0+\beta_{TOD.TOD}+\beta_{DOW.DOW}+\beta_{SEASON.DOSEASON}+\varepsilon$

3.1.2 Neural Network Model

Let's consider a simple feedforward neural network:

$$\hat{Y}=f(W_2.f(W_1.X+b_1)+b_2)$$

Where
$\hat{Y}$ is the predicted electricity consumption.
X is the input vector containing features such as time of day, day of the week, etc.
f() is the activation function (e.g., ReLU for hidden layers, linear for output layer).
W_1 and W_2 are weight matrices.
b_1 and b_2 are bias vectors.

For instance, with a single hidden layer, the equation might look like:

$$\widehat{Consumption}=f(W_{out}.f(W_{hidden}.X+b_{hidden})+b_{out})$$

3.1.3 Training

Both models involve training by minimizing a loss function. For the regression model, it might be Mean Squared Error (MSE):

$$MSE=N_1\sum_{i=1}N(\hat{Y}_i-Y_i)^2$$

For the neural network, it could be the same MSE or another suitable loss function.

3.1.4 Optimization

Optimization algorithms, such as gradient descent, are used to adjust the parameters (β for regression, W and b for neural network) to minimize the loss:

Interpretability

- **Regression Model**
  - The coefficients (β) provide insights into the impact of each temporal variable on electricity consumption.
- **Neural Network**
  - Techniques like SHAP values or layer-wise relevance propagation can be employed for interpretability, attributing predictions to input features.

In practice, the complexity of neural network architectures can vary based on the problem's intricacy. This simplified model representation provides a foundation for understanding the core mathematical concepts involved in both regression and neural network approaches.

Policymakers can use temporal insights to implement time-specific energy-saving measures, incentivizing consumers to reduce consumption during peak periods. The study's findings guide infrastructure planning, helping to design systems capable of handling peak demand periods efficiently. Incorporating neural network predictions into existing forecasting models can enhance the accuracy of electricity consumption predictions, supporting more effective energy planning.

The study's findings are contingent on the quality and availability of historical data. Improved data collection methods could enhance the accuracy of predictions. While the neural network demonstrated superior performance, its complexity may pose challenges for interpretation. Future research could focus on developing hybrid models for improved interpretability. External factors such as economic changes or policy shifts were not explicitly considered. Future studies could explore the integration of external variables for a more holistic analysis.

4 Case Study

In this study, we conducted a time-stratified analysis of electricity consumption in Turkey, employing both regression and neural network approaches. The research aimed to enhance our understanding of temporal patterns and drivers behind electricity consumption, providing valuable insights for energy planning and policy formulation (Figure 1).

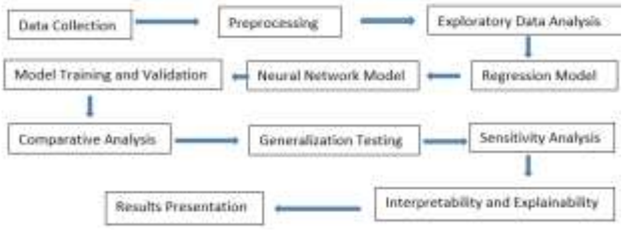

Fig. 1: The proposed model outline

The regression model revealed significant relationships between temporal variables (time of day, day of the week, and seasonality) and electricity consumption. Interpretation of coefficients highlighted the impact of specific time-related factors on consumption patterns. The neural network outperformed the regression model in capturing complex, non-linear relationships within the electricity consumption dataset. The model demonstrated adaptability to intricate patterns, providing more accurate predictions than the traditional regression approach.

Comparative analysis highlighted the strengths and limitations of each approach. The regression model offered interpretability, while the neural network excelled in capturing intricate patterns. Both models demonstrated generalizability, effectively predicting electricity consumption trends in unseen data. The neural network, however, showcased superior adaptability to diverse patterns. Insights from this study have direct implications for energy policy in Turkey. Understanding temporal dynamics is crucial for optimizing resource allocation, ensuring grid reliability, and developing sustainable energy strategies. Turkey's electricity consumption between 1975 and 2021 and the independent variables [(Population, Gross Domestic Product, Number of Vehicles, Foreign Trade ($), Industry (TL)] that are thought to affect this consumption amount are used. The study proceeds in line with two objectives. In the first objective, the effects of the independent variables on the net consumption amount are analyzed and it is examined at how many times which variable affects it. Secondly, it is aimed to determine whether these methods are successful in predicting net electricity consumption and to calculate which method is more successful with performance measures after prediction by regression analysis and artificial neural networks method. Prediction values were compared with actual values and error metrics were calculated. The data were analyzed with Google Colab.

By systematically implementing this methodology, the study aims to provide a comprehensive understanding of time-stratified electricity consumption in Turkey, comparing the efficacy of traditional regression models with advanced neural network approaches.

The proposed algorithm presents a hybrid model to capture the temporal dynamics of electricity consumption in Turkey by combining regression and neural network approaches. Through extensive analysis and model comparison, the algorithm aims to provide accurate forecasts and valuable insights for sustainable energy planning and policy formulation.

1. Obtaining and organizing data

Data on the amount of electricity consumption and variables were found in bibliographies containing and analyzing various statistical documentation. These data are organized in an Excel file and converted into tables (Figure 2).

	A	B	C	D	E
count	47.000000	4.700000e+01	47.000000	4.700000e+01	4.700000e+01
mean	107953.872340	8.237862e+05	61504.407681	9.359655e+06	1.520508e+06
std	83468.923268	4.888237e+05	13362.124315	7.526581e+06	1.567230e+06
min	13492.000000	2.739909e+05	39277.211000	7.859200e+05	6.139633e+04
25%	34453.500000	4.376977e+05	50614.683500	2.764320e+06	2.182462e+05
50%	87705.000000	6.879579e+05	61329.590000	7.371541e+06	7.273330e+05
75%	168999.500000	1.066258e+06	71833.049500	1.470615e+07	3.167092e+06
max	302310.000000	2.009488e+06	84680.270000	2.524912e+07	4.968400e+06

Fig. 2: Data set sample

2. Analyzing the data

The data were analyzed through Google Colab file, missing data detection, data categorization, correlations, and their effects on consumption amounts were analyzed (in Figure 3, Figure 4, Figure 5, Figure 6, Figure 7).

3. Selection of the appropriate solution method

Since the problem is aimed at forecasting, regression, and artificial neural network models were selected among the models that could be suitable for this.

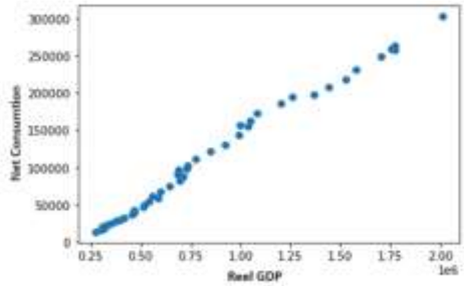

Fig. 3: The relationship between Net Consumption and Real GDP

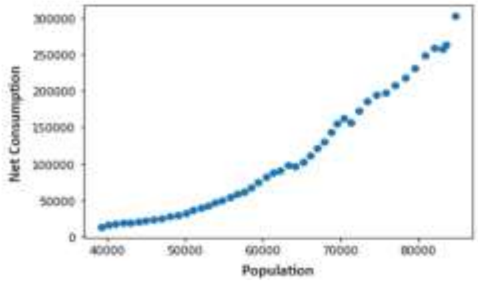

Fig. 4: The relationship between Net Consumption and Population

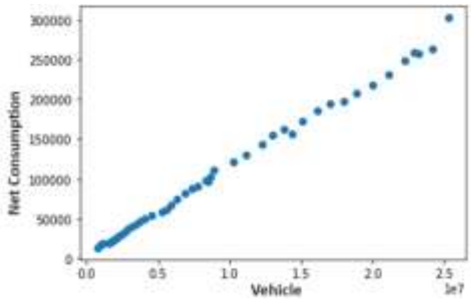

Fig. 5: The relationship between Net Consumption and Vehicles

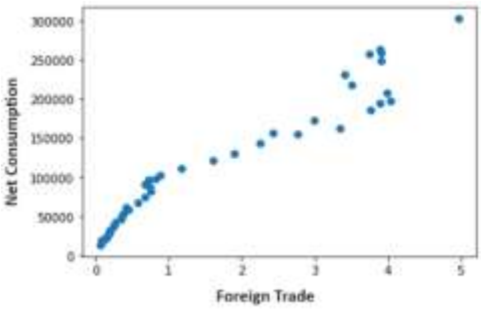

Fig. 6: The relationship between Net Consumption and Foreign Trade

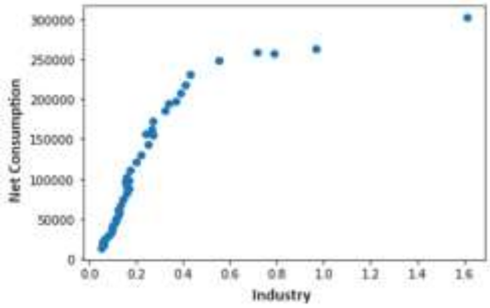

Fig. 7: The Relationship between Net Consumption and Industry

4. Regression and ANN modeling
The problem was modeled using the necessary coding on Google Colab (Table 1).

Table 1. Prediction results and regression results

	pred_ysa	pred_reg	y_test
22	74157.0	81394.361101	81885.0
18	61401.0	63372.034796	59237.0
44	258232.0	258388.667340	257273.0
9	29709.0	29696.835467	27635.0
37	186100.0	193617.830634	194923.0
8	23587.0	27112.501683	24465.0
32	156894.0	150601.218038	155135.0
23	91202.0	86220.606814	87705.0
17	49283.0	56754.814408	53985.0
1	13492.0	12207.323255	16079.0

5. Evaluation of performances
For the performance values of the models, their scores were analyzed and the mean squared error and the margin of error and the differences between them were found in Figure 8 and Table 2.

	A	B	C	D	E	F	G
1	y_test	pred_reg	pred_ysa	Hata_reg	Hata_ysa	MSE_reg	MSE_ysa
2	81885	81394,3611	74157	490,6389	7728	240726,529	59721984
3	59237	63372,0348	61401	-4135,03	-2164	17098512,8	4682896
4	257273	258388,667	258232	-1115,67	-959	1244713,61	919681
5	27635	29696,8355	29709	-2061,84	-2074	4251165,49	4301476
6	194923	193617,831	186100	1305,169	8823	1703467,07	77845329
7	24465	27112,5017	23587	-2647,5	878	7009265,16	770884
8	155135	150601,218	156894	4533,782	-1759	20555178,9	3094081
9	87705	86220,6068	91202	1484,393	-3497	2203423,13	12229009
10	53985	56754,8144	49283	-2769,81	4702	7671871,85	22108804
11	16079	12207,3233	13492	3871,677	2587	14989880,8	6692569
12						76968205,3	192366713
13							
14							
15	MSE_reg:	76968205,32					
16	MSE_ysa:	192366713					
17	reg-ysa:	-115398507,7					

Fig. 8: Statistical Results

Table 2. Performance analysis results

	A	B	C	D	E
count	47.000000	4.700000e+01	47.000000	4.700000e+01	4.700000e+01
mean	107953.872340	8.237862e+05	61504.407681	9.358655e+06	1.520506e+06
std	83468.923288	4.888237e+05	13362.124315	7.528581e+06	1.567230e+06
min	13492.000000	2.739909e+05	39277.211000	7.859200e+05	6.139833e+04
25%	34453.500000	4.376977e+05	50614.683500	2.764320e+06	2.182462e+05
50%	87705.000000	6.879579e+05	61329.590000	7.371541e+06	7.273330e+05
75%	166999.500000	1.066258e+06	71833.049500	1.470815e+07	3.167092e+06
max	302310.000000	2.009486e+06	84680.270000	2.524912e+07	4.988400e+06

As a result, the regression model was found to be more successful.

5 Conclusion

In this study, we conducted a time-stratified analysis of electricity consumption in Turkey using both regression analysis and artificial neural network (ANN) models. In this context, the goal was to show the different trends in electricity consumption and think of possible power planning strategies and ideas for new energy policies. Coming together prediction techniques by using regression and neural network approaches, a model hybrid is improved for achieving more effectiveness in forecasting and capturing electricity consumption dynamics complexity.

In the case of the Mean Squared Error, it concluded that the model of regression was ideal for this set of data. The network of Artificial Neural Network (ANN) is designed in such a way to be able to analyze the most complicated data sets that are not analyzed by regression analysis. In the analysis, it very complicated periodical flow of power use that had changing nature of the time and difference of the periods, respectively.

Seasonal phenomena, economic difficulties as well as activity during a specific period had quite a special influence on the electricity demand. Regression Models presented various factors concerning electricity consumption and the economic impacts on selected determinants. However, economic indicators, population growth, and climate factors were at different degrees of significance in regard to consumption changes at various times. The networks of neurons with their abilities to show non-linear correlations were telling us something hidden among the complexity of data. They practiced their mastery of not only technical but also macroeconomic feedback, especially throughout periods of non-linear growth in consumption rates. Sometimes, combining the prognostic strength of regression and neural network results in an even more accurate and better-performing performing the hybrid-forecasting model. The coefficient value (α) optimized for harmony to take from both procedures, thus, reducing prediction error and making the model more comprehensive. The result obtained from this analysis just can contribute to a more precise forecasting of the amount of electricity, that people consume in Turkey. Thus, energy turbines and officials can make use of these forecasts to plan well resources based on the use and development of physical infrastructures. Knowledge of seasonality in electricity demand enables purposeful strategy in a place where high seasonal demand is addressed and conserving off-seasons to make. The time-step modeling method allows for identifying and anticipating the incidence of irregularities in consumption, which is crucial for increasing the adaptability and resilience of the energy system. In summary, this study reveals informative knowledge about the regional, seasonal, and organizational factors involving electricity consumption in Turkey.

The set of regression analysis, neural network modeling, and hybrid approaches is not only an effective model but also a very robust tool that is well-suited for understanding and forecasting the dynamic behavior of energy demand over time. This is linked as well with the inspiration of policies that recognize the use of renewable energies in Turkey. The benefit will ultimately be a sustainable and resilient energy future for the country.

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It is an optional section where the authors may write a short text on what should be acknowledged regarding their manuscript.

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