World Economics & Finance Bulletin (WEFB)
Available Online at: https://www.scholarexpress.net
Vol. 54, January, 2026
ISSN: 2749-3628,

FORECASTING IRAQ'S CONSUMPTION OF ELECTRICITY USING TEN POLYNOMIALS

Dr. Mona Mohamed Ghareeb
Lecturer of Economics, College of Administrative and Financial Sciences, Imam Jaafar Al-Sadiq University, Baghdad, Iraq. Email : mona_ghareeb@hotmail.com

Article history:
Received: 24th October 2025
Accepted: 20th November 2025

Abstract:
The problem of this paper is to Forecasting electricity consumption in Iraq using ten Polynomials to the year 2030. The reason for this is that forecasting electricity consumption in Iraq is relatively rare and only exists at the level of specific regions or governorates, not at the national level. If it exists, it is for past years, and it is also just suggestions or for a specific year from those concerned and commenting on it only. This is in addition to the use of limits up to the third degree only in previous studies in general. To solve this problem, ten polynomial models are built with degrees from first to tenth. Computing the model's parameters is based on the actual consumption in the period from 1993 to 2022 and applying the method of least-squares with the aid of Excel and php software. A comparison between the ten models is performed based on two measures; the root mean Square Residuals (RMSE), the complement of coefficient of determination ($1-R^2$) .The best model is the second-degree polynomial. This model is tested for sensitivity and significance and it passes the tests. The model is used for forecasting the consumptions for the period from 2023 to 2030. The forecasted consumption is 205.74 TWh in the year 2030.

Keywords: forecasted, electricity consumption, Polynomials.

1- INTRODUCTION

Iraq faces significant challenges in providing electricity, especially with the increasing demand during the summer months. Studying and forecasting electricity consumption is crucial for its management and distribution, as it is used intensively in both businesses and homes. In other words, electricity is the lifeblood of citizens and their standard of living, and economic development in general. This necessitates forecasting its quantities for comprehensive national economic planning. Forecasting electricity consumption is the process of predicting the amount of electricity required at a specific time and how this demand will affect the electricity grid. This is used to ensure sufficient power availability to meet consumption needs, while avoiding waste and inefficiencies.

2- RESEARCH PROBLEM:

Predicting Iraq's electricity consumption for the period from 2023 to 2030 AD, based on a sample size of 30 observations representing Iraq's actual electricity consumption from 1993 to 2022 AD. The reason for this is that forecasting electricity consumption in Iraq is relatively rare and only exists at the level of specific regions or governorates, not at the national level. If it exists, it is for past years, and it is also just suggestions or for a specific year from those concerned and commenting on it only. This is in addition to the use of limits up to the third degree only in previous studies in general.

3- THE IMPORTANCE OF RESEARCH:

The importance of this study lies in the fact that the process of forecasting consumption is extremely important for future planning in any economy in general and the energy economy in particular. This study will also allow us to shed light on polynomial forecasting models and show how to ensure the stability and degree of confidence in the outputs of these models using appropriate scientific methods.

4- RESEARCH OBJECTIVES

1. Identifying forecasting models based on first-order to tenth-order parametric equations.
2. Using models to forecast past consumption to determine the degree of convergence with actual consumption from 1993 to 2022 AD.
3. Evaluating the reliability of model outputs using sensitivity analysis.
4. Assessing the degree of confidence in the model outputs using statistical tests.

5. Forecasting electricity consumption values using the best models for the period from 2023 to the end of 2030.

5- STUDY METHODOLOGY:

The descriptive-analytical approach was used, describing Iraq's electricity consumption from 1993 to 2022, then analyzing this data and creating polynomials mathematical models to forecast consumption. The different models were evaluated and the best one was chosen. The selected models were chosen to ensure their reliability and the significance of their results. Ultimately, the best models were used to forecast consumption for the period from 2023 to 2030.

6- Temporal and spatial boundaries:

Timeframe: The research includes archival data on electricity consumption for the period (1993-2022) and then a consumption forecast for the period (2023-2030).
Geographical boundaries: Republic of Iraq.

7- RESEARCH SAMPLE:

The study sample consists of 30 observations of actual consumption for the years (1993-2022).

8- SEARCH TOOLS :

The following software programs were used in the sample study: Excel and PHP.

9- RESEARCH HYPOTHESES :

- The accuracy of forecast using specific models is high, and their results are highly reliable.
- Forecasting accuracy using specific models is low, and the degree of confidence in their results is low.

10- STUDY ITEMS :

The following items in this study will be as follows:
Item 11: Previous studies, Item 12: General overview of the models to be applied, Item 13: Calculating model parameters, Item 15: Comparing models, Item 16: Identifying the best model, Item 17: Sensitivity testing of the best model, Item 18: Significance testing of the best model, Item 19: Using the best model to predict consumption, Item 20: Conclusion, and finally, references.

11- PREVIOUS STUDIES:

The first study: A research paper presented by Farhad Ali Ahmed and Munim Aziz Mohammed in March 2024, entitled " Forecasting Electricity Consumption Using Spectral Analysis in Sulaymaniyah Governorate." The researchers used hourly data within the time range of July to September 2022, and proposed a new model consisting of a sinusoidal explanatory variable and a non-linear quadratic variable.
In this model, the most important periodic syntheses present in the time series under study were identified through the use of the cycle diagram and the Fourier expansion method, which is capable of identifying hidden cycles in the data.
Subsequently, each of these periodic components was added to the model based on the principle of capture. The proposed composite model includes a quadratic element and two harmonic components with periods of 24 and 12 hours.
The researchers concluded that this model demonstrates efficiency and accuracy because it outperforms the classical autoregressive moving average (ARMA) model, based on MSE=0.0009 and MAE=23.819 when compared.[1]

The second study: A research paper forecast by Zahra Hussein Zein Al-Thalabi and Kholoud Moussa Omran in 2015 entitled "Identifying the best model for forecasting electricity consumption in the southern region". This research aimed to compare some forecasting methods in analyzing time series data on electricity consumption in the southern region, such as the Box-Jenkins method and the artificial neural network method. The researchers concluded that neural network models are more accurate than traditional models in long-term predictions; they are more efficient and accurate than other traditional models in dealing with non-linear time series data.**[2]**

The third study: A research proposal submitted by Duaa Rahim Abdul Hussein and Hiba Ali Kadhim in 2017, under the supervision of Ahmed Naeem, entitled " Forecasting the cash received for electricity consumption in Al-Diwaniyah Governorate through comparison between time series and regression analysis".
The study sought to compare some of the forecasting methods in time series analysis of cash collected in Al-Diwaniyah Governorate. The research concluded that the Box-Jenkins (0,1,4) ARIMA model is suitable because it has the lowest mean sum of squared errors, and all the model parameters are significant according to the t-test. This model is suitable

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Available Online at: https://www.scholarexpress.net
Vol. 54, January, 2026
ISSN: 2749-3628,

for forecasting cash collected for electricity consumption in Al-Diwaniyah. It was recommended that the results of this study and the formula adopted by the relevant authorities be used to adopt the appropriate scientific method for forecast. **[3]**

The fourth study: A research paper presented by Husam Ibrahim Khashman and others entitled "Future Electricity Needs in Duhok Governorate - Kurdistan Region of Iraq until 2030". The research aimed to determine Duhok Governorate's electricity needs until the year (2030) by using statistical methods, and to determine the electricity needs of the administrative units in Duhok Governorate until the year (2030). The systematic presentation relied on statistical analysis and the research included three main axes. The first required studying the general development of electricity consumption in Duhok Governorate, sectorally and geographically, according to administrative units. The second focused on forecasting future electricity consumption needs for different consumer sectors in Duhok Governorate up to the year (2030). The third topic discussed forecasting future electricity consumption needs spatially by administrative unit up to the year 2030. At the end of the research, the results were presented, indicating a significant disparity in electricity consumption across different sectors in Duhok Governorate. It also showed substantial differences in both supply and consumption levels between the spatial units within the study area, reflecting administrative importance, population density, and economic activity. **[4]**

12- GENERAL OVERVIEW OF THE MODELS USED:

The general overview of these models is **[5]**

$$y = a_0 + a_1x + a_2x^2 + \cdots + a_nx^n$$

Where **y** is the dependent variable and represents the value Consumption of electricity (unit is terawatt-hour), **t** is the independent variable and represents time (unit is year), $a_0 + a_1x + a_2x^2$are the model parameters, and n is the degree of the boundary, which will be from 1 to 10.

13- CALCULATING MODEL PARAMETERS:

The following actual consumption data **[6]** will be used to calculate the model parameters by applying the least squares method and using Excel and PHP **[7].**

Table (1): Time series of consumption (research sample)

Consumption TWh	Period x	Year	Consumption TWh	Period x	Year
35.3	16	2008	27.1	1	1993
41.3	17	2009	26.7	2	1994
41.7	18	2010	26.5	3	1995
42.2	19	2011	26.0	4	1996
47.8	20	2012	26.7	5	1997
62.1	21	2013	26.7	6	1998
71.2	22	2014	24.7	7	1999
75.3	23	2015	27.2	8	2000
86.3	24	2016	31.7	9	2001
93.6	25	2017	35.4	10	2002
100.2	26	2018	26.6	11	2003
106.0	27	2019	30.7	12	2004
105.5	28	2020	28.3	13	2005
110.8	29	2021	30.6	14	2006
117.2	30	2022	32.3	15	2007

Data source: Reference [6]. Table prepared by the researcher.

The results were as follows, where $\hat{y}$ is the forecasting consumption:

First-degree boundary model:

$\hat{y}$ = 2.2526436781609194 + 3.2174638487208007x

Second-degree boundary model:

$\hat{y}$ = 33.384581280788176 - 2.6197744517718102x + 0.18829800969331004x^2

Third-degree boundary model:

$\hat{y}$ = 32.87276774311257 - 2.4365059312246x + 0.1737578523729803x^2 + 0.00031269155527590835x^3

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Available Online at: https://www.scholarexpress.net
Vol. 54, January, 2026
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Fourth-degree boundary model:
$\hat{y}$ = 17.955029963650656 + 5.956383528031491x - 0.9985928997846855x^2 + 0.05848123236200129x^3 - 0.000938202271076215$8x^4$

Fifth-degree boundary model:
$\hat{y}$ = 29.05207073386384 - 2.7772159947081794x + 0.8465868405833155x^2 - 0.0961760764000262x^3 + 0.004625153730033335x^4 - 0.0000717852387239942x^5

Sixth degree boundary model:
$\hat{y}$ = 36.35441556145003 - 10.216398433702576x + 3.016713822699178x^2 -0.3640344804199411x^3 + 0.020504513562077505x^4 - 0.0005192328384535407x^5 + 0.0000048112645132209$3x^6$

Seventh-degree boundary model:
$\hat{y}$ = 23.150473686233607 + 6.261549839217837x - 3.2185949232002553x^2 + 0.681184496583162x^3 - 0.06911219801482263x^4 + 0.003574528237424166x^5 - 0.0000899441035632086$9x^6$ + 8.7332136475972e-7x^7

Eighth-degree boundary model:
$\hat{y}$ = 28.052569715139004 - 0.9349033536090362x + 0.15449403017877186x^2 - 0.04559126671829243x^3 + 0.01442814226100336$1x^4$ - 0.0018744954370793641x^5 + 0.0001121403571328415$9x^6$ - 0.0000030942217213794$7x^7$ + 3.19963152108e-8x^8

The ninth-degree boundary model:
$\hat{y}$ = 20.64361961872339 + 11.476978466325221x - 6.7990406617156625x^2 + 1.803375767162671x^3 - 0.2563310307085433x^4 + 0.021569240147722796x^5 - 0.001117522764554406x^6 + 0.0000352488722134468$6x^7$ - 6.2146642529197e-7x^8 + 4.68432072045e-9x^9

Tenth-degree boundary model:
$\hat{y}$ = 17.787424716027072 + 16.81282531759816x - 10.272214009779054x^2 + 2.9075336843957x^3 - 0.45474565072594386x^4 + 0.04329316630084107$5x^5$ - 0.0026184979733762303x^6 + 0.0001009563945669024x^7 - 0.0000023878428171999$5x^8$ + 3.127522433529e-8x^9 - 1.7155421687e-10x^{10}

14- COMPARISON BETWEEN MODELS:
The ten models will be compared based on the following two criteria:
First: Root Mean Square Error (RMSE)
It is calculated using the formula **[8]**

$$\mathbf{RMSE} = \sqrt{\frac{1}{X}\sum_{x=1}^{X}(y_x - \hat{y}_x)^2}$$

Where y_x is the actual consumption, $\hat{y}_x$ is the estimated consumption, and **X** is the sample size. The lower the value of this criterion, the better the model.

Table (2): Comparison between models based on root mean square error (RMSE)

10	9	8	7	6	5	4	3	2	1	**borderline degree**
2.188	2.190	2.221	2.249	2.611	2.796	3.452	4.958	4.960	13.538	**RMSE**

Source: Researcher

From Table (2), we can see that the tenth-degree boundary is the best.

Second: The complement of the coefficient of determination (1-R^2)
The coefficient of determination is the square of the correlation coefficient between the actual consumption series and the estimated consumption series. It is calculated using the equation **[9]**:

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Available Online at: https://www.scholarexpress.net
Vol. 54, January, 2026
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$$\mathbf{R^2} = \left(\frac{\sum_{x=1}^{X} (y_x - \bar{y}_x)(\hat{y}_x - \bar{\hat{y}}_x)}{\sqrt{\sum_{x=1}^{X} (y_x - \bar{y}_x)^2} \sqrt{\sum_{x=1}^{X} (\hat{y}_x - \bar{\hat{y}}_x)^2}} \right)^2$$

Where y_x is the actual consumption, $\hat{y}_x$ is the estimated consumption, X is the sample size, $\bar{y}_x$ is the average of the actual consumption values, and $\bar{\hat{y}}_x$ is the average of the estimated consumption values. The closer this criterion value is to one, the better the model.To standardize the nature of the criteria so that models with small values are preferred, the criterion $1 - R^2$ will be used, such that the closer its value is to zero, the better the model.

Table (3): The relationship between the degree of borderline and the complement of the coefficient of determination 1-R^2

10	9	8	7	6	5	4	3	2	1	**borderline degree**
0.005	0.005	0.005	0.005	0.007	0.008	0.012	0.026	0.026	0.191	**1-R^2**

Source: Researcher

From Table (3), we find that polynomials of degree seven through ten are equally preferred.

15- Identifying the best model:
The result of the first criterion, **RMSE**: The tenth-degree borderline is the best.
The result of the second criterion **1-R^2** : Polynomials of degree seven through ten are equally preferred.
To determine the best model, the standard values for each of the above criteria will be calculated so that they can be plotted together on a single graph, and then the point or area of common advantage will be identified, thus determining the best model. The standard values **z** of **x** are calculated using the relation **[9]:**

$$z = \frac{x - \bar{x}}{s}$$

Where $\bar{x}$ is the average value of **x**, and **s** is its standard deviation.

Table (6): Standard values for comparison criteria between models

1-R^2	RMSE	borderline degree
2.816	2.705	**1**
-0.052	0.242	**2**
-0.052	0.242	**3**
-0.296	-0.191	**4**
-0.365	-0.379	**5**
-0.382	-0.432	**6**
-0.417	-0.536	**7**
-0.417	-0.544	**8**
-0.417	-0.553	**9**
-0.417	-0.554	**10**

Source: Researcher

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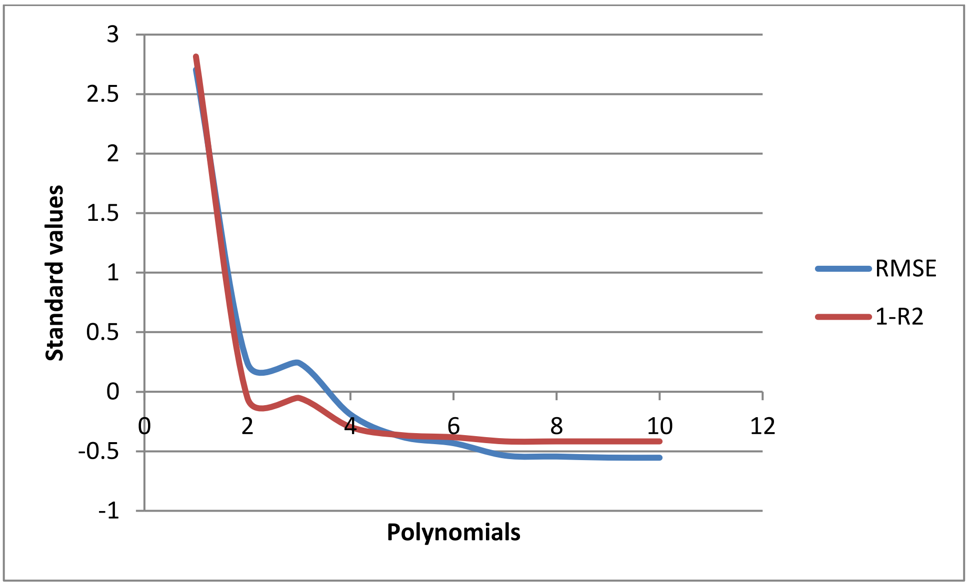

Figure (1): Identifying the point of convergence of the comparison criteria between the models.
Source: Researcher

We can see from Figure (1) that there are two main points of convergence for the comparison criteria: The first point is near the second-degree boundary, and the second point is near the fifth-degree boundary, Since the fewer the model parameters, the simpler and better the model, a second-degree polynomial is the optimal polynomial, and These are the data that will be used for future forecasting if they pass the sensitivity and moral testing.

16- Sensitivity analysis test for the second-order boundary model :

Sensitivity analysis **[10]** is the study of how changes in a model's inputs effect its outputs. The inputs to the model are the values of the independent variables, and the outputs to the model are the values of the dependent variables. The concept of sensitivity analysis is synonymous with the concept of model stability. If a limited change in input leads to a limited change in output, the model is stable, and If a limited change in input leads to an unlimited change in output, then the model is hypersensitive, (unstable) . Limited in value means that it does not reach infinity.
Unlimited value, meaning it reaches infinity. If the model is stable (not overly sensitive) it is suitable for use in the forecasting process. polynomial is generally stable. For example, a limited change of 0.1 was made in the independent variable, and the largest value of change in the dependent variable was 0.8697, meaning it is limited, and therefore the model is stable and suitable for forecasting .

Table (7): Calculating the change $\Delta\hat{y}$ in the dependent variable $\hat{y}$ as a result of the change Δx = 0.1 in the independent variable x

x	$\hat{y}$	**Δx**	**x+Δx**	$+\Delta\hat{y}\hat{y}$	$\Delta\hat{y}$
1	30.9531	0.1	1.1	30.73067	-0.22243
2	28.8982	0.1	2.1	28.7134	-0.1848
3	27.2199	0.1	3.1	27.0728	-0.1471
4	25.9183	0.1	4.1	25.8088	-0.1095
5	24.9932	0.1	5.1	24.9214	-0.0718
6	24.4447	0.1	6.1	24.4105	-0.0342
7	24.2728	0.1	7.1	24.2763	0.0035
8	24.4775	0.1	8.1	24.5186	0.0411
9	25.0588	0.1	9.1	25.1376	0.0788
10	26.0166	0.1	10.1	26.1331	0.1165
11	27.3511	0.1	11.1	27.5053	0.1542
12	29.0622	0.1	12.1	29.2540	0.1918
13	31.1499	0.1	13.1	31.3794	0.2295

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Available Online at: https://www.scholarexpress.net
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14	33.6141	0.1	14.1	33.8813	0.2672
15	36.4550	0.1	15.1	36.7598	0.3048
16	39.6725	0.1	16.1	40.0149	0.3424
17	43.2665	0.1	17.1	43.6467	0.3802
18	47.2372	0.1	18.1	47.6550	0.4178
19	51.5844	0.1	19.1	52.0399	0.4555
20	56.3083	0.1	20.1	56.8014	0.4931
21	61.4087	0.1	21.1	61.9395	0.5308
22	66.8858	0.1	22.1	67.4542	0.5684
23	72.7394	0.1	23.1	73.3455	0.6061
24	78.9696	0.1	24.1	79.6134	0.6438
25	85.5765	0.1	25.1	86.2579	0.6814
26	92.5599	0.1	26.1	93.2790	0.7191
27	99.9199	0.1	27.1	100.6766	0.7567
28	107.6565	0.1	28.1	108.4509	0.7944
29	115.7697	0.1	29.1	116.6018	0.8321
30	124.2596	0.1	30.1	125.1293	0.8697

Source: Researcher

17 - Significance test of a second-order boundary model :

In this section, we will perform the F-test **[11]** to determine the significance of the chosen model.
The general image of the model is :

$$y_x = a + b\,x + c\,x^2$$

The test aims to determine whether there is a relationship between the dependent variable $\mathbf{y_x}$ and a subset of variables **x** ، $\mathbf{x^2}$..

The hypotheses are the null hypothesis $\mathbf{H_0}$ and the alternative hypothesis $\mathbf{H_1}$, and they are as follows:

$$\mathbf{H_0 : a = b = \dots = f = 0}$$

$$\mathbf{H_1 : \text{at least one of } a, \dots, f \neq 0}$$

Rejecting the null hypothesis $\mathbf{H_0}$ means that at least one of the variables **x** and $\mathbf{x^2}$ ontributes significantly to the model.
The testing procedures include analysis of variance (mean sum of squared errors) by dividing the total sum of squared errors (SST) into two parts.
The first part is the sum of the squared errors resulting from the model regression process (SSF), and the second part is the sum of the squared errors resulting from the residuals (SSR).

That is :

SST = SSF + SSR

Whereas

$$SSF = \sum_{i=1}^{n} (\hat{y}_i - \bar{\hat{y}})^2 = 28026.28251$$

$$SSR = \sum_{i=1}^{n} (y_i - \hat{y}_i)^2 = 94.26237$$

The statistical significance of the model test is...

$$F_0 = \frac{SSF/k}{SSR/(n-p)}$$

k : is the number of independent variables in the model (equal to 2 in the case under study).
n : is the number of Sightings (equal to 30 in the case under study).
p : is the number of parameters in the model (equal to 3 in the case under study).

In the case under studyis :

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ISSN: 2749-3628,

$$F_0 = \frac{28026.28251/2}{94.26237/(30-3)} = 4013.848$$

Comparing the value of F_0 with the value of

$$F_{\alpha,k,n-p}$$

Taken from the probability distribution table **F** with a significance level of **α=0.05**, degrees of freedom for the numerator **k=2**, and degrees of freedom for the denominator **n-p=27**, that is,

$$F_{0.05,2,27} = 3.354$$

In comparison, we find that

$$F_0 > F_{0.05,2,27}$$

Therefore, we reject the null hypothesis H_0 with 95% confidence and accept the alternative hypothesis H_1. This means there is a significant relationship between the dependent variable and a subset of the independent variables, and therefore we accept the model.
In addition to the previous test, we can also use the coefficient of determination **(R^2),** which measures how well the model fits the data of the sample under study.
The coefficient of determination was previously calculated and its value was 0.974. It is known that the value of the coefficient of determination lies between zero and one, and the closer the value is to one, the better the model fits the sample data.
From this, we can conclude that the chosen model fits the data perfectly.
From the above, we conclude that the model as a whole is significant with a 95% confidence level and fits the data very well. Therefore, the model can be relied upon for prediction.

18-Using a second-order boundary model in predicting consumption

Table (8) and Figure (2) illustrate the quantity of consumption forecast using the second-order boundary.

Table (8): forecasting consumption at the second-order threshold for the period 2023-2030

year	$\hat{y}_x$ $\hat{y}_x$ forecasting consumption	year	$\hat{y}_x$ forecasting consumption
2023	133.13	2027	172.36
2024	142.37	2028	183.11
2025	151.99	2029	194.23
2026	161.98	2030	205.74

Source: Researcher

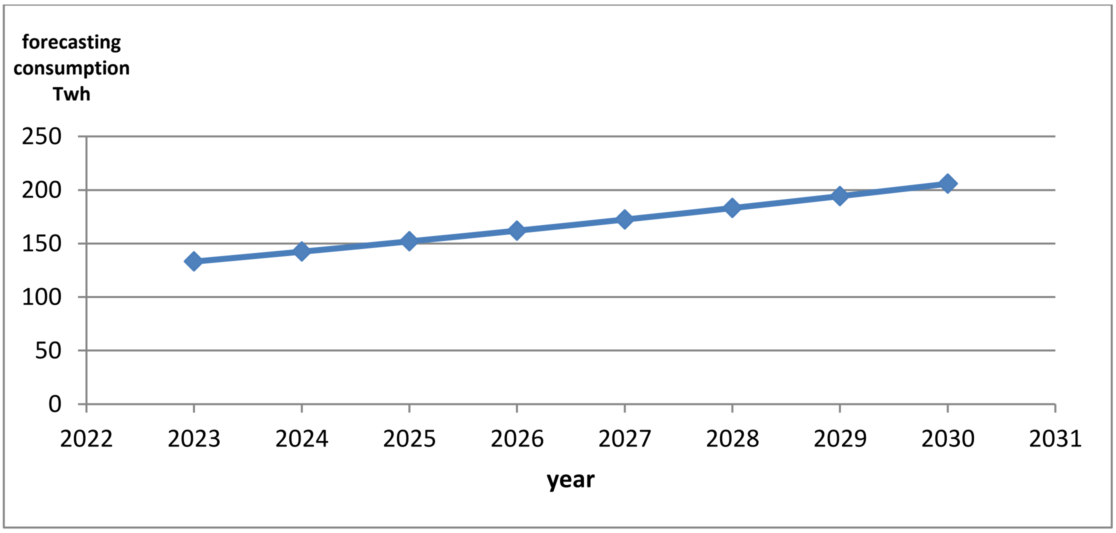

Figure (2): forecasting consumption at the second-order frontier for the period 2023-2030.
Source: Researcher

19- CONCLUSION :

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The research problem is to forecast Iraq's electricity consumption up to the year 2030. The motivation for this research is that forecasting electricity consumption in Iraq is relatively limited and only exists at the level of specific regions or governorates, not at the national level, and if it does exist, it is for years past. It also includes suggestions or feedback for a specific year from interested parties, and comments on them only, this is in addition to the fact that previous studies generally only used limits up to the third degree. To solve this problem, ten mathematical models were constructed, representing polynomials of degree one through degree ten. The parameters of these models were calculated based on actual consumption data from 1993 to 2022. By applying the least squares method with the help of Excel and PHP software, the sum of the squared deviations between actual and estimated consumption during the sample period was reduced.
The ten models were compared based on two criteria:
The first criterion is the root mean square error (RMSE) it is the root mean square of the differences between actual and estimated consumption, and the lower this value, the better the model.
The second criterion is the complement of the coefficient of determination ($1 - R^2$).
The coefficient of determination is the square of the correlation coefficient between actual and forecasting consumption. The value of the complement of the coefficient of determination lies between zero and one, and the lower its value, the better the model. It was chosen instead of the coefficient of determination to conform to the first criterion, which states that the optimal value is closest to zero.
Given the variability in the performance of the boundary markers according to each criterion, standard values for the results were calculated and graphically represented together, and then the optimal graphical model was determined**.** The comparison process resulted in the selection of the second-order boundary model. The selected model was subjected to sensitivity analysis to ensure its stability. The sensitivity analysis test is based on the principle that if a limited change in the independent variable leads to a limited change in the dependent variable, then the model is stable, this model passed the test successfully. The chosen model was also subjected to statistical testing to ensure that it was meaningful. The F-test was applied at a significance level of $\alpha=0.05$ to compare the variance of two sets of model-related errors, this model also passed this test successfully. Finally, the chosen model was used to forecast consumption for the period from 2023 to 2030.
The projected consumption value is 205.74 Twh in 2030.

Recommendations:

Forecasting accuracy using these specific models is high, and their results are 95% reliable. Researchers should be encouraged to use them more frequently for forecast in other research topics due to their ease of application and accuracy.

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