Forecasting sector-wise electricity consumption for India using various regression models

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Electricity is an important and one of the most dominant energy sources used in the world. It governs a major share in the Indian as well as world economy. Thus, forecasting its consumption can be useful in better planning of its future production and supply. In the present study, electricity consumption in seven different sectors, namely industry, domestic, agriculture, commercial, traction and railways, others along with total electricity consumed is forecasted using regression analysis. The study uses four regression modelling approaches to forecast electricity consumption by sectors in India. These are linear, logarithmic, power and exponential regression models. The accuracy of the models is tested using R^2 (coefficient of determination) and MAPE (mean absolute percentage error) values. The model having the highest R^2 and lowest MAPE value is selected for better accuracy results. The result/forecast is then compared with the available data published by the Central Electricity Authority, Government of India.

Keywords: Electricity consumption, energy policy, forecasting, regression analysis.

ELECTRICITY is one of the most important energy sources in India. It can be used for many applications and in different sectors such as industry, agriculture, domestic, commercial, traction and railways and others. Among these, the industrial sector is found to dominate the consumption of electricity.

Literature review

Electricity forecasting has been done employing various methods to predict electricity price and/or demand forecasting. Some of them are regression models, time-series models, artificial neural networks (ANNs), genetic programming, ARIMA models, etc.

Morales and Acevedo[1] forecasted future electrical energy demand in Mexico for the next 40 years. The study first defined and then took into account three variables, viz. population growth rate, gross domestic product (GDP) per capita and energy intensity for prediction. The forecast was based on a simple model on the future evolution of variables for different scenarios. The researchers[1] had also recommended some suggestions to electrical energy planners and policy makers based on their results obtained.

Bianco *et al.*[2] forecasted electricity consumption in Italy using multiple and single regression models. The models were developed using historical electricity consumption data[2], GDP per capita and population. The developed forecast was then compared with the available national forecast.

Çunkas and Taskiran[3] used genetic programming to predict future electricity consumption in Turkey. They used electricity energy production and consumption data of Turkey for the analysis. The results obtained were then compared with regression analysis techniques and the available estimates given by the Ministry of Energy and Natural Resources in Turkey[3].

Ghosh and Das[4] focused on the monthly forecast of electricity demand for Maharashtra, India. The study used multiplicative seasonal autoregressive integrated moving average (MSARIMA) method for analysis. The results did not suggest any major changes for the forecasted period, thus following the same trend with the seasonal variation[4].

Guerrero and Berumen[5] used information provided by the consumers along with historical electricity-consumption data to forecast short-term electricity consumption in Mexico. The study used univariate time-series models for analysis.

Panklib *et al.*[6] forecasted electricity consumption using ANN and multiple linear regression in Thailand. ANN gave more accurate results than the regression models. The basis of comparison of performance was coefficient of determination, mean absolute percentage error and root mean square error.

Rao and Ghosh[7] forecasted the monthly peak demand of electricity in India. They evaluated the monthly peak demand forecasting performance given by the Central Electricity Authority (CEA), Government of India (GoI), using trend method and then compared it with their predictions made using MSARIMA. The results showed that

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the MSARIMA model was more accurate than the CEA model[7].

Sigauke and Chikobvu[8] predicted the peak electricity demand in South Africa using time-series model. The study used hourly electricity data of 10 years for the forecast.

Data and methodology

In this study, we collected historical sector-wise electricity consumption data from 'energy statistics' reports in 2020, 2018 and 2009 by the National Statistical Office, Ministry of statistics and programme implementation, Government of India. The data was collected for the years between 1970 and 2018 (Figure 1).

For sector-wise modelling of electricity consumption simple regression analysis was used to find the relationship between dependent and independent variables, and thereby the future values of dependent variables. We analysed the past and present data to establish the relationship between electricity consumption and period (1970–2018). The advantage lies in the simplicity of the analysis and the forecast is based on the available data.

Four types of regression models were used, viz. linear, logarithmic, power and exponential. Modelling was done for electricity consumption for each sector. Each regression model generated a modelling equation and their respective R^2 values were estimated. Microsoft Excel was used for modelling. The derived equations were then used for predicting the future values of electricity consumption by each sector. Also, their corresponding errors were estimated.

Table 1. Equations of four regression models

Regression type	Equation	R^2
Linear regression model	$y = 7663.7x - 48{,}788$	0.7382
Logarithmic regression model	$y = 93121 \ln(x) - 133{,}936$	0.4369
Power regression model	$y = 10319x^{0.775}$	0.7436
Exponential regression model	$y = 25564e^{0.0557x}$	0.9575

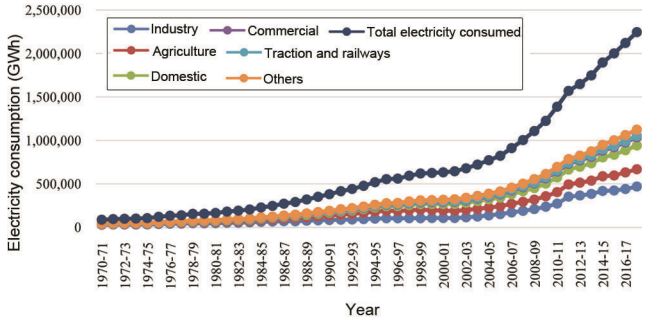

Figure 1. Actual electricity consumption (GWh) by sectors (1970–2018).

Modelling electricity consumption

For each sector, i.e. industry, agriculture, domestic, commercial, traction and railways, others and total electricity consumed, regression analysis was carried out. The regression models with the highest R^2 and lowest mean absolute percentage error (MAPE) values was selected.

For instance, regression analysis for the industrial sector is explained below. The analysis includes plotting of data, finding the best-fit line and calculating errors. Table 1 shows the equations of the four regression models along with their R^2 values. Table 2 shows the errors of the four regression models which give the best-suited model based on MAPE values. Figures 2–5 show the trendline of each model.

R^2 is the coefficient of determination used to find the most suitable model. A higher R^2 suggests better accuracy. MAPE is the average of the ratio of absolute error to actual value of historical data. The regression model having the lowest MAPE value was selected. Smaller values of MAPE suggest better prediction. Table 3 shows the results of regression analysis for each sector. The table indicates that all the sectors show better results

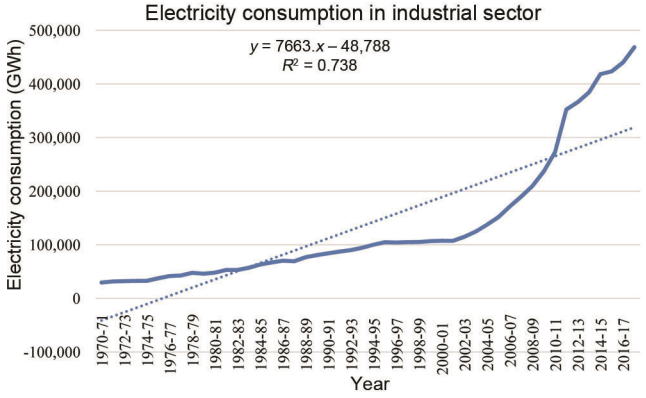

Figure 2. Linear regression model.

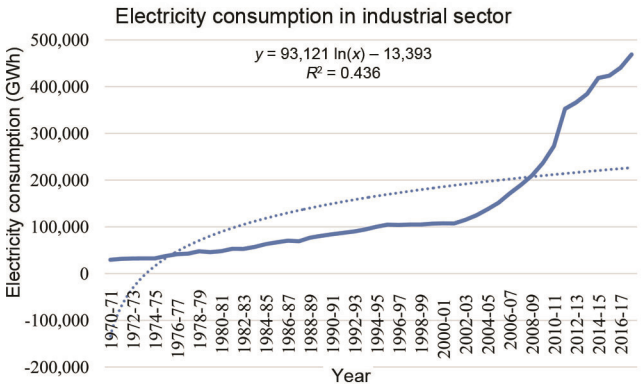

Figure 3. Logarithmic regression model.

Table 2. Errors generated in various regression models

Regression type	ME	MAE	Mean absolute percentage error (MAPE)	Mean square error
Linear	–1504	51,817.45	0.5086	3,977,114,600.36
Logarithmic	–3480	72,586.70	0.6772	8,212,915,242.76
Power	20,063	52,057.04	0.3055	7,469,379,663.86
Exponential	6421	24,003.41	0.1267	1,586,613,084.59

Table 3. Results of regression analysis

Sectors	Type of regression model selected	Equation of selected model	MAPE	R^2
Industry	Exponential	$y = 25564e^{0.0557x}$	0.1267	0.9575
Agriculture	Exponential	$y = 6642.6e^{0.0773x}$	0.2345	0.9312
Domestic	Exponential	$y = 3704.2e^{0.0935x}$	0.1137	0.9903
Commercial	Exponential	$y = 2132.1e^{0.0796x}$	0.0600	0.9950
Traction and railways	Exponential	$y = 1352.1e^{0.0555x}$	0.0563	0.9920
Others	Exponential	$y = 1578.2e^{0.0779x}$	0.0527	0.9959
Total electricity consumed	Exponential	$y = 40776e^{0.0686x}$	0.0664	0.9932

Table 4. Forecasted electricity consumption (GWh) by sectors

Year	Industry	Agriculture	Domestic	Commercial	Traction and railways	Others	Total electricity consumed
2018–19	391,696	293,302.2	361,755	105,373	20,515.1	71,764.1	1,175,553
2019–20	414,132	316,873.8	397,211	114,104	21,685.8	77,578.1	1,259,026
2020–21	437,854	342,339.7	436,142	123,558	22,923.4	83,863	1,348,427
2021–22	462,934	369,852.2	478,888	133,795	24,231.6	90,657.2	1,444,175
2022–23	489,451	399,575.8	525,824	144,880	25,614.5	98,001.7	1,546,723
2023–24	517,487	431,688.2	577,361	156,884	27,076.3	105,941	1,656,552
2024–25	547,129	466,381.3	633,948	169,883	28,621.5	114,524	1,774,180
2025–26	578,469	503,862.5	696,082	183,958	30,254.9	123,802	1,900,161
2026–27	611,604	544,356	764,305	199,200	31,981.5	133,832	2,035,087
2027–28	646,637	588,103.8	839,215	215,704	33,806.7	144,674	2,179,594
2028–29	683,677	635,367.4	921,467	233,576	35,736	156,395	2,334,361
2029–30	722,838	686,429.5	1,011,781	252,929	37,775.4	169,065	2,500,119
2030–31	764,242	741,595.1	1,110,946	273,885	39,931.2	182,762	2,677,647
2031–32	808,019	801,194.3	1,219,831	296,577	42,210.1	197,568	2,867,781
2032–33	854,302	865,583.2	1,339,387	321,150	44,619	213,574	3,071,415
2033–34	903,237	935,146.7	1,470,661	347,758	47,165.3	230,877	3,289,509
2034–35	954,975	1,010,301	1,614,801	376,571	49,857	249,581	3,523,090
2035–36	1,009,676	1,091,495	1,773,069	407,772	52,702.3	269,801	3,773,256
2036–37	1,067,511	1,179,214	1,946,849	441,557	55,710	291,659	4,041,187
2037–38	1,128,659	1,273,983	2,137,661	478,142	58,889.3	315,288	4,328,142
2038–39	1,193,309	1,376,368	2,347,174	517,758	62,250	340,830	4,635,474
2039–40	1,261,662	1,486,981	2,577,222	560,656	65,802.6	368,443	4,964,628

for the exponential regression model. The MAPE value for all sectors lies between 0.05 and 0.23. Whereas R^2 has a range 0.93–0.99, which shows good relationship between electricity consumption and year. Both MAPE and R^2 suggest better prediction accuracy.

Forecasting sector-wise electricity consumption

The results were analysed for each sector and the predicted values, i.e. future values of electricity consumption by each sector were estimated.

Table 4 shows the forecasted sector-wise electricity consumption in India from 2018 to 2040. All the sectors show increase in their trend.

Industrial sector

Figure 6 shows the increasing trend of the industrial sector from 2018–19 to 2039–40. In the year 2020–21, electricity consumption in the industrial sector would be 437,854 GWh which will further increase to 722,838 GWh in 2029–30. The increase till year 2039–40 will result into 1,261,662 GWh electricity consumption.

Agricultural sector

Figure 7 shows an increase in electricity consumption in the agricultural sector for the next 20 years. A total of 342,339.7 GWh electricity will be consumed till 2020–21. In the coming 10 years, i.e. in 2030–31, electricity consumption in the agricultural sector will increase to 741,595.1 GWh, and to 1,486,981 GWh in 2039–40.

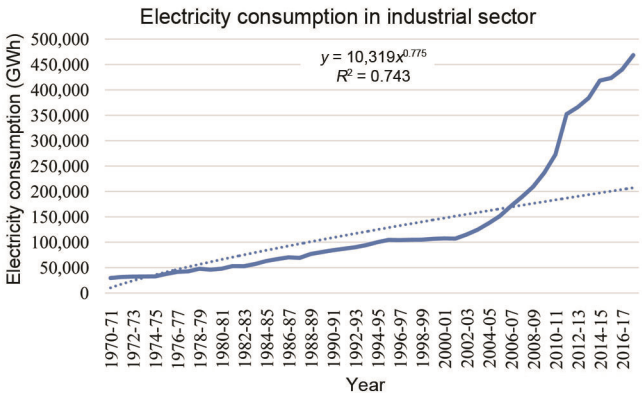

Figure 4. Power regression model.

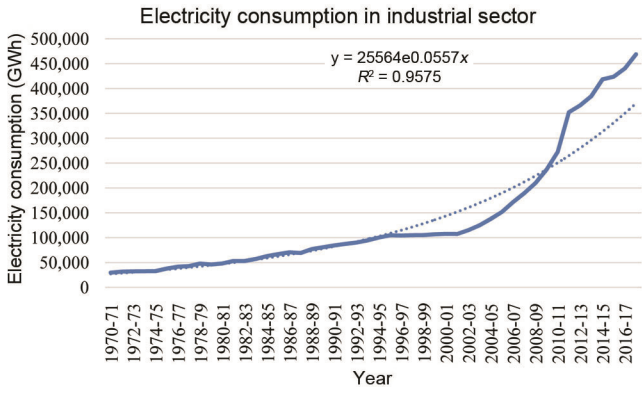

Figure 5. Exponential regression model.

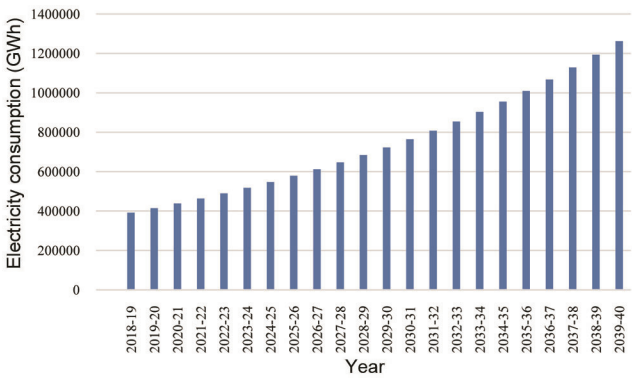

Figure 6. Forecasted electricity consumption (GWh) for industrial sector (2018–2040).

Domestic sector

For the domestic sector (Figure 8), electricity shows an increasing trend in consumption in the next 20 years, from 397,211 GWh in 2019–20 to 2,577,222 GWh in 2039–40.

Commercial sector

As shown in Figure 9, electricity consumption will increase from 123,558 GWh in 2020–21 to 273,885 GWh

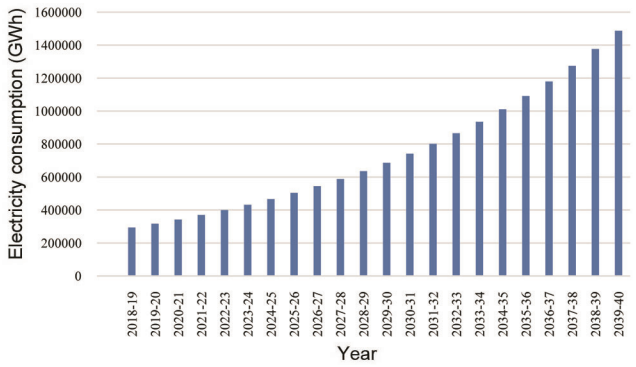

Figure 7. Forecasted electricity consumption (GWh) for agricultural sector (2018–2040).

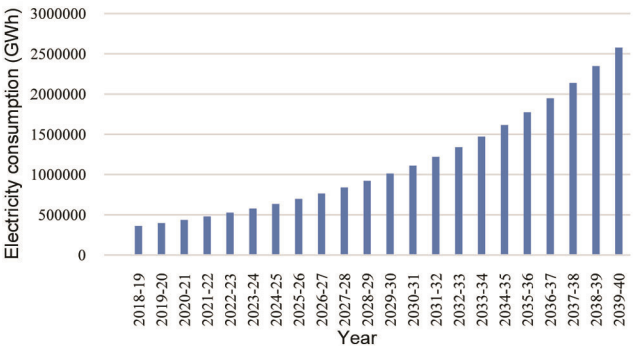

Figure 8. Forecasted electricity consumption (GWh) for domestic sector (2018–40).

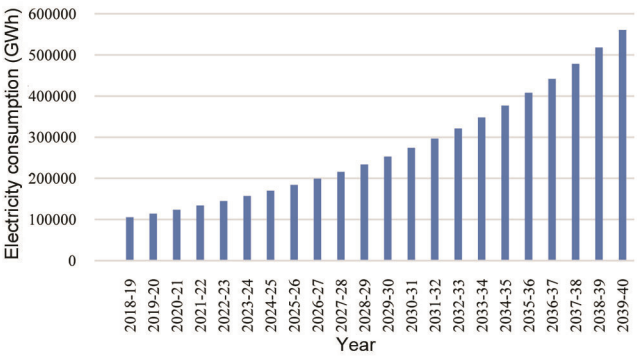

Figure 9. Forecasted electricity consumption (GWh) for commercial sector (2018–40).

Table 5. Category-wise forecast of electricity consumption (GWh)

Category	2019–20			2021–22		
	Central Electricity Authority	Predicted	Difference	Central Electricity Authority	Predicted	Difference
Domestic	333,356	397,211	63,855	386,790	478,888	92,098
Commercial	112,630	114,104	1474	128,888	133,795	4907
Industries	341,492	414,132	72,640	386,450	462,934	76,484
Others	109,818	77,578.1	–32,240	122,081	90,657.2	–31,424
Total	1,144,579	1,259,026	114,447	1,300,486	1,444,175	143,689

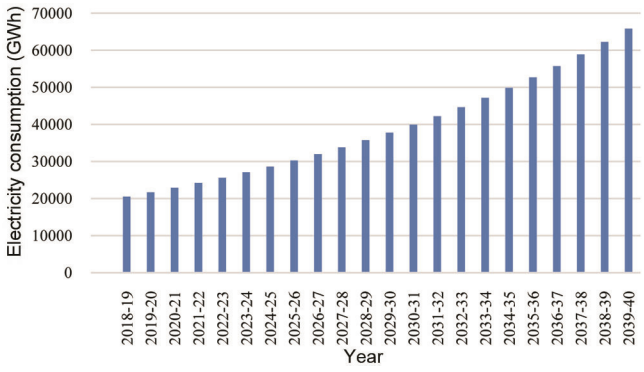

Figure 10. Forecasted electricity consumption (GWh) for traction and railways sector (2018–40).

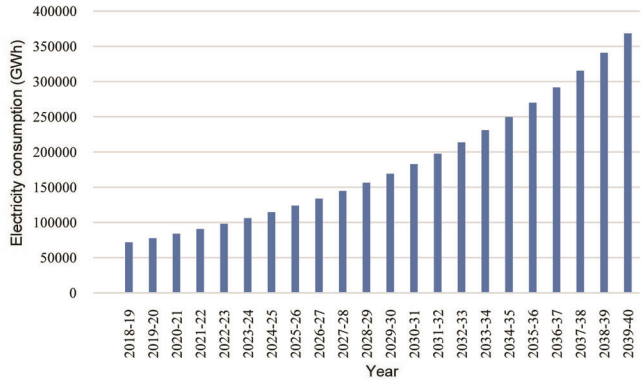

Figure 11. Forecasted electricity consumption (GWh) for other sectors (2018–2040).

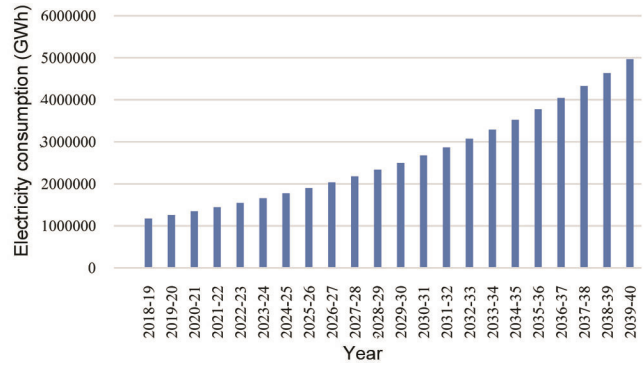

Figure 12. Forecasted total electricity consumption (GWh; 2018–2040).

in 2030–31. Similar trend will follow in the next 10 years, thus increasing the electricity consumption in the domestic sector to 560,656 GWh.

Traction and railways sector

Figure 10 shows the increasing future trend in the traction and railways sector. In 2020–21, electricity consumption will be at 22,923.4 GWh which will increase to 39,931.2 GWh in 2030–31. Further, the consumption of electricity will increase to 65,802.6 GWh in 2039–40.

Other sectors

Figure 11 shows an increase in the consumption of electricity in other sectors. The electricity consumption will increase from 77,578.1 GWh in 2019–20 to 169,065 GWh in 2029–30. In 2039–40, electricity consumption will increase to 368,443 GWh.

Total electricity consumed

As observed from Figure 12, the total electricity consumption shows an increasing trend from 1,259,026 GWh in 2019–20 to 2,500,119 GWh in 2029–30. This will further increase to 4,964,628 GWh in 2039–40.

Validation of obtained results

Validation of the present study was done by comparing the available forecasted data published by the CEA in report titled 'Growth of electricity sector in India from 1947–2019' published in May 2019. Since the forecast published by the GoI is for the years 2019–20 and 2021–22, comparison could be done only for these two years. Also, the CEA data were available only for five sectors, namely industry, domestic, commercial, others and total electricity consumed, out of seven being forecasted in this study. Table 5 shows forecasted values by both CEA and the present study.

Figure 13 shows the comparative analysis of forecast presented by CEA and this study. It can be seen that the increasing trends of both forecasts match well. However,

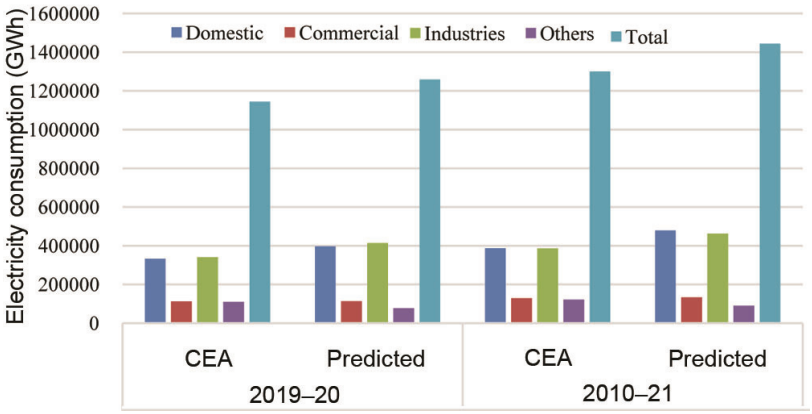

Figure 13. Comparative analysis of forecast with Central Electricity Authority data.

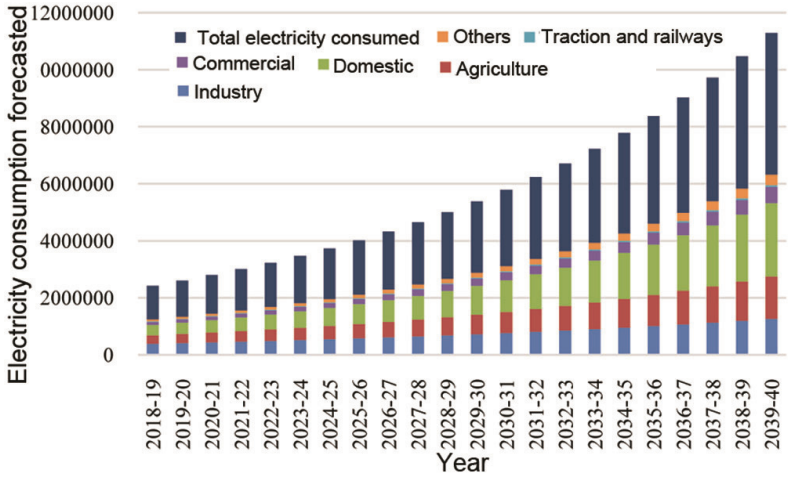

Figure 14. Forecasted sector-wise electricity consumption.

as shown in Table 5, there is a slight difference in the values.

Conclusion

In the present study, forecasting models are developed for electricity consumption by different sectors in India. This study will be helpful to energy planners to prepare for the demand in electricity in various sectors in the next few years. Also, it will be useful for the development of the required electricity infrastructure. The main conclusions of the study are summarized below.

- The coefficient of determination for all the selected regression models is higher than 0.93, thus indicating high reliability of the models for the sector-wise electricity consumption forecasting.
- The proposed models have small values of MAPE, which suggests that they can be successfully used as a forecasting tool for electricity consumption.
- The study reveals that among the various regression models, the exponential regression model shows the best forecasting performance.

Future studies should focus on the forecasting of electricity consumption using other methods, including ANN, programming, time-series models, etc. They can also include other important variables such as GDP, population and others affecting electricity consumption.

Figure 14 shows the forecasted sectorwise electricity consumption. In 2018–19, the industrial sector shows an electricity consumption of 391,696 GWh, which will increase to 1,261,662 GWh by 2040. Whereas, the agricultural sector shows the consumption of 293,302 GWh in 2018–19 and 686,429 GWh in 2029–30, which will increase to 1,486,981 GWh in 2039–40. In the domestic sector, 361,755 GWh was consumed in 2018–19, which will increase to 2,577,222 GWh in 2039–40. The commercial sector will show an increase to 252,929 GWh in 2029–30 and 560,656 GWh in 2039–40. Railways and traction shows an electricity consumption of 20,515 GWh

in 2018–19 which will rise to 65,802 GWh in 2039–40. The 'others' sector shows a consumption of 169,065 GWh in 2029–30, which will increase to 368,443 GWh in 2039–40. The total electricity consumption in 2018–19 was 1,175,553 GWh, which will show an exponential increase to 4,964,628 GWh in 2039–40.

The results of the present study show that there will be an exponential increase in electricity consumption of all sectors. To cope with this demand, energy manufacturers and developers should increase the infrastructure and production of electricity. While increasing production, focus should be given to the fact that maximum energy should be generated using renewable energy sources such as solar power, wind power, etc. This will help in the conservation of non-renewable energy sources such as coal, natural gas, etc. Thus, the present study will help policymakers in designing and developing future energy policies related to the consumption and production of electricity in India.

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