Research Article

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# Daily load curve prediction for Jordan based on statistical techniques

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**Abstract:** The article proposes a mathematical prediction model for daily load curves (DLCs) in Jordan from 2023–2050. The historical hourly peak loads based on the growth rate statistical method in 1994–2020 and the annual forecasted peak loads during the morning and evening periods taken from the long-term load forecast (LTLF) study of National Electric Power Company (NEPCO) during 2022–2050 are employed in the prediction model. The results show that the actual hourly growth rates, the annual forecasted growth rates, and the hourly peak loads in the reference year 2022 are the main input variables used in the prediction formula. The LTLF study conducted by NEPCO employs various sophisticated methods depending on the end-user sectorial electricity consumption that imply an econometric approach, market survey, and Gomprtz extrapolation techniques. The peak load in Jordan relies upon several climatic and nonclimatic variables, implying the ambient temperature, gross domestic product, income, demographic, urbanization, electricity tariff, average oil prices, and other factors related to technology and new aspects of energy saving and space heating/cooling systems, the DLC in Jordan is variable and changing from year to year. The proposed model considers a variation in the future DLC and suggests three different scenarios of DLC's prediction based on the time occurrence of the peak load: the first is the daytime peak occurrence scenario, the second is the evening peak occurrence scenario, and finally is the daytime and evening peaks may be close to each other.

**Keywords:** DLC, Gompertz extrapolation, econometric approach, market survey, growth rate approach

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## 1 Introduction

The electricity consumption pattern is an essential indicator of the development of any country. It is a mixture of climate and nonclimate variables that include gross domestic product (GDP), income per capita, import and export values, electricity prices, population, urbanization, water consumption, technology, and factors related to policy change and environmental factors [1–3]. The positive contribution of urbanization and economic growth to electricity consumption was investigated by many researchers [4–6]. In the study by Ubani [5], factors such as water consumption, electricity price, and distance to the power station were also examined, and they had a relation with consumption despite low meaning. The electricity consumption to environmental degradation due to $CO_2$ emission was also investigated [7,8]. The factors affecting residential electricity consumption in Taiwan were examined by Chen [9]. They show that GDP, employment rates, residential space, and the implementation of energy labeling schemes significantly affect residential electricity consumption. The analysis shows that air conditioners consume the most significant portion of electricity, with 1470 kWh for each household representing 26.81% of total consumption except for lighting.

The electricity consumption in Jordan during 2018 has steadily increased, where households consume the most significant portion [10]. The current consumption pattern in Jordan during 2022 shows that the households consumed 46% of electricity, industries 22%, water pumping 16%, commercial activities 14%, and street lighting consumes the remaining 2% of total consumption. One of the main problems facing the interconnected power system of Jordan is the abnormal increase in the peak loads due to high and low ambient temperatures during summer and winter, respectively [11–14]. The weather factor was also examined by several researchers elsewhere [15–17]. In the study by Yi-Ling et al. [15], the winter-to-summer peak variations due to the urban residential heating and cooling demand was examined during the period 2003–2007 in Shanghai were examined. The base temperature of electricity enhancement was observed when the daily temperature was below $10^\circ C$

in winter and above 22 °C in summer. In the study by Cartalis et al. [16]. The decrease of ambient temperature by 1 °C below the mean value causes an increase in the energy consumption required for heating by 10% during winter. However, the increase of ambient temperature by 1 °C above the mean value causes an increase in the energy required for cooling by 28.4% during summer. In the study by Pardo et al. [17], a transfer function intervention model is developed for forecasting daily electricity load from cooling and heating degree days.

Load analysis studies are essential planning studies that aim to identify current and future consumption patterns during all periods. Power companies seek an accurate electricity load forecasting model to minimize financial risk, maximize operational efficiency and reliability, and ensure an uninterrupted, reliable, secure, and economical electricity supply. The quality of forecast methods mainly depends on the available historical data and knowledge about the factors influencing the energy demand. The study by Behmiri et al. [18] classified the load forecast into four categories: very short-term (from a few minutes to one hour ahead), short-term (from one hour to a few days ahead), medium-term (from a few days to a year head), and long-term (from one year to several decays a head). Yadav et al. [19] discussed the techniques that are being used in conducting electricity load forecast studies, such as multiple linear regression, exponential smoothing, iterative reweighted least-squares, adaptive load forecasting, stochastic time series, auto-regressive moving average with extra input (ARMAX) models based on genetic algorithms, adaptive neuro-fuzzy inference system (ANFIS), and expert systems [20–22]. The implementation models strongly rely upon selecting of influential external factors affecting the electricity demand. The socio-economic factors are excluded from short-term demand forecasting, where the atmospheric, seasonal, and other short-term dependent variables are considered [23]. The future power profile for countries differs due to demographic and economic factors. The future power demand profile will be completely different from that of today for many reasons, namely, improved building insulation, new comfort levels and management scenarios in dwellings, and possible widespread integration of electrical heating systems that will replace old installed systems using fossil fuels, e.g., photovoltaic modules with battery [24].

Several studies deal with predicting daily load curves (DLCs) [25,26]. For instance, Cho et al. [25] proposed a hybrid approach for the modeling short-term forecasting of DLC curves. Two building blocks of their approach are (1) modeling the overall trend and seasonality by fitting a generalized additive model to the weekly averages of the load and (2) modeling the dependence structure across consecutive daily loads via curve linear regression. Shang et al. [26] proposed a novel model based on data mining and deep learning. Data preprocessing implies normalization of historical load and fuzzification of influencing factors (meteorological factors, data types, and economy) based on the Pearson correlation coefficient, and then kernel fuzzy c-means modified by particle swarm optimization algorithm clusters the DLCs. Caro and Juan [27] proposed a new approach to predict the short-term load variations applied to 10 main Spanish islands based on initial Reg-ARIMA forecasting models. In the study by Alfares and Nazeeruddin [28] proposed a model of the DLC forecast for residential electricity usage based on a time series and stochastic regression framework in which the observed DLC is represented in terms of a set of periodic smoothing-spline basis functions, with the basis function coefficients evolving according to a linear Gaussian state-space model that incorporates level shifts, day of the week and holiday adjustments, and weather effects, as well as the dynamic price-incentive effects mentioned earlier. This article introduces a technique for the DLC forecast up to 2050 in Jordan based on the growth rate (GR) technique. The actual growth rates between 2007 and 2022 were used to forecast the DLCs. The analysis is based on two scenarios of peak occurrence: morning peak in summer and evening peak in winter, as shown in the procedure. Section 2 presents the load development and conversion of peak occurrence in Jordan. Section 3 discusses the long-term electricity demand forecast in Jordan, followed by Section 4, which presents the DLC prediction technique and result discussion followed by conclusions and recommendation in Section 5.

## 2 Load development and conversion of peak occurrence in Jordan

The peak period occurs when the demand for electric power increases and the loads rise to the highest limit in the Jordanian electrical system. During this period, loads of some subscribers are subject to a special tariff to be applied called the monthly maximum load tariff. The monthly maximum load is the highest load rate per half hour in kilowatts during the peak period. Based on historical data on peak load occurrence in Jordan, the peak load may occur during either morning or evening periods in either summer or winter. The maximum morning peak is usually during 13:00–15:00, whereas the maximum evening peak is during 16:00–18:00 [12]. Figure 1 presents the time series of the raw data of the morning and evening peak load in MW during the 2014–2022 study period. The smoothed peak loads are also held in each sub-plot for better presentation. The data are obtained from the electricity operation and control center of the National Electric Power Company (NEPCO) in Amman; the data in Figure 1 are taken every 1-hour time interval. As shown in Figure 1(a), the seasonality of the morning peak forms a W-shape response with a maximum load most of the time occurring in summer, particularly from June to August every year. Figure 1(b) shows the seasonality of the evening peak that also forms a W-shape response with maximum load occurs in winter, particularly December-to-February every year. The growth of electricity demand from year to year is shown in this figure. The minimum peak in the year is usually seen during the equinox and vernal each year besides summer. In Jordan's case, the fluctuation of air conditioning load due to seasonal changes can still be the main reason for the seasonal peak and valley load difference.

Samples of annual DLCs during 3 years, namely, 1997, 2010, and 2019, respectively, are presented in Figure 2. As shown in the figure, the recorded peak load in 1997 was 971 MW, took place on October 15, while in 2010, the recorded peak load was 2,544 MW, took place on August 3, and in 2019, the recorded peak was 3,260 MW, which took place on February 7. A comparison between the curves indicates a modification in the load response and conversion in peak

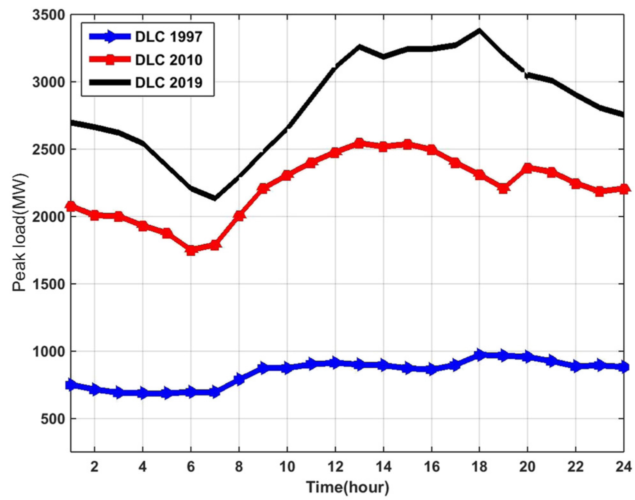


**Figure 2:** Jordan's DLCs in the years 1997, 2010, and 2019, respectively.

load occurrence from evening to morning or morning to evening. Based on the historical data of NEPCO during the last three decades, two main conversions were recorded: the first conversion was from evening to morning. It took place in the year 2000, and it continued until 2013. The second conversion was from the morning to evening period, which took place in the year 2013 and maintained until the present.

Table 1 presents the peak load readings in Jordan during the 1995–2022 period in both morning and evening.

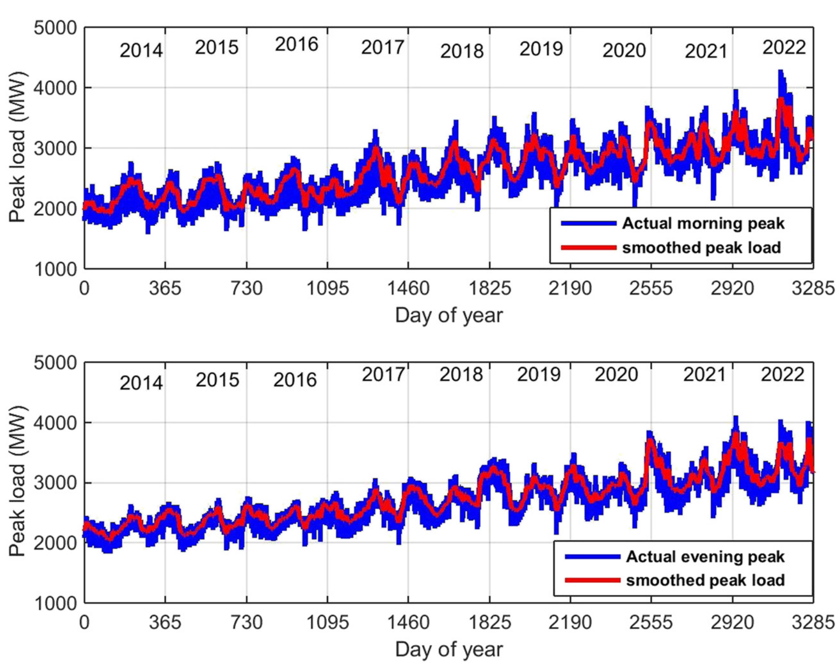


**Figure 1:** The morning and evening peak load variation during the period of study [29].

**Table 1:** Jordan's morning and evening peak load during the 1995-2022 period [29]

| Year | Peak load (MW) | | Year | Peak load (MW) | | Year | Peak load (MW) | | Year | Peak load (MW) | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Morning | Evening | | Morning | Evening | | Morning | Evening | | Morning | Evening |
| 1995 | 842 | 862 (Sep. 13) | 2002 | 1,370 July 31 | 1,310 | 2009 | 2,208 July 29 | 2,131 | 2,016 | 3,180 | 2,208 July 29 |
| 1996 | 895 | 902 (Sep. 28) | 2003 | 1,384 | 1,387 (Aug. 30) | 2010 | 2,544 (Aug. 3) | 2,362 | 2017 | 3,320 (July 25) | 3,220 |
| 1997 | 912 | 971 (Oct. 15) | 2004 | 1,515 (Aug. 27) | 1,471 | 2011 | 2,660 (Aug. 29) | 2,530 | 2018 | 3,100 | 3,205 (Jan. 21) |
| 1998 | 1,020 | 1,020 (Aug. 23) | 2005 | 1,710 (Aug. 8) | 1,665 | 2012 | 2,770 (July 31) | 2,630 | 2019 | 3,260 | 3380 (Feb.7) |
| 1999 | 1,085 | 1,099 (Aug. 23) | 2006 | 1,819 | 1,860 (July 31) | 2013 | 2,840 | 2,975 (Dec. 17) | 2020 | 3,530 | 3,630 (Jan. 19) |
| 2000 | 1,203 (July 31) | 1,188 | 2007 | 2,130 (July 29) | 2,030 | 2014 | 2,845 | 2,900 (Dec. 28) | 2021 | 3540 | 3770 (Dec. 21) |
| 2001 | 1,225 (July 23) | 1,215 | 2008 | 2,141 (Aug. 19) | 2,112 | 2015 | 3,310 (Aug. 4) | 3,160 | 2022 | 3,800 | 4,010 (Jan. 20) |

As shown in the table, the peak load in Jordan developed from 862 MW in 1995 to 4,010 MW in 2022. Before the year 2000, the evening peak was dominant and usually occurred during the August to October months. During the 2000–2012 periods, a conversion from evening to morning peak was observed and took place during the July to August months. From 2013 to the present, another conversion from morning to evening peak was observed where the peak occurs in December, January, and February. Figure 3 shows the differential peak representing the evening peak to Morning Peak during the study period from 1995–2022, as shown in the figure periods where peak load converted from evening to morning and *vice versa*.

Based on Table 1 and Figure 3, from 2000 to 2012, air-conditioning technology became widely used in different utilities including homes and government offices, shops, and malls. During this period, air conditioning is used for cooling rather than heating due to the high cost of heating. From 2012 to the present, and with the invention of inverter or dual-inverter air-conditioning systems and the implementation of these systems for both space heating and cooling in Jordan, a significant reduction in peak load was attained with maximum load reduction potential and optimal economy mainly during evening periods is achieved. However, the implementation of inverter air conditions for space heating in the evening by many end-users caused a conversion from morning to evening peak in winter, as many customers utilize these systems for heating as an alternative to gasoline, which became dominant, especially in the last 5 years until 2022.

The justification of load conversion in Jordan is mainly due to determinates related to climatic and nonclimatic variables that imply weather and technological factors associated with introducing new space cooling/heating methods to be used in both summer and winter as alternatives to gasoline and traditional cooling systems. Moreover, the DLCs' shape in any country can be changed and controlled by implementing demand side management techniques by encouraging energy users to shift their demand needs toward the valley and reduce energy consumption and peak demand. DSM programs such as financial incentives, load scheduling, and energy conservation by many countries [30,31]. In Jordan, foundations such as the Energy and Minerals Regulatory Commission and Ministry of Energy and Mineral Resources implement several DSM technologies and strategies with recommendations to the end-users to be applied, such as the usage of efficient appliances and lights, commercial load scheduling, restricting residential appliance use, price incentives and tariff structure, community involvement, and finally, consumer education and village committees [32]. Researchers such as Eissa [33] show that incentive-based programs such as time-of-use programs

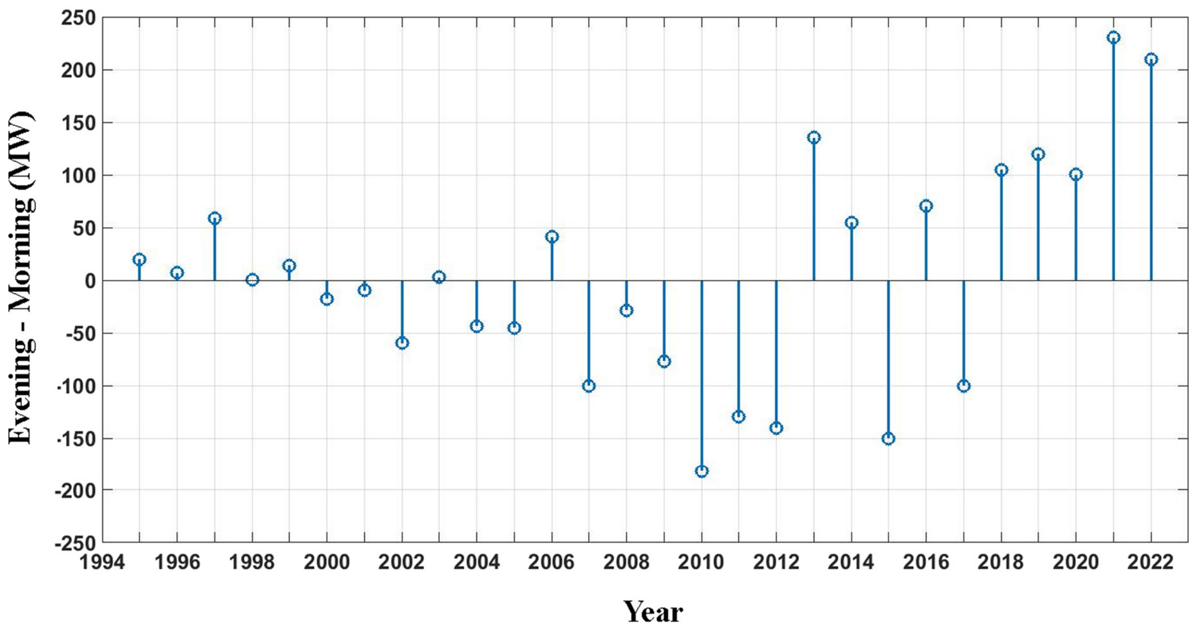


**Figure 3:** The differential peak load (evening peak to morning peak) in the period 1995–2022.

and incentive-based demand response programs applied to industrial and commercial data are better than time-varying retail tariffs. With the application of the time-of-use incentives, load shifting for customers, such as water pumping and industrial loads from peak periods to minimum periods, can change the shape of DLC in Jordan.

It is worth mentioning that during 2021, the total energy consumed by the end-use customers in all sectors is about 17,550 GWh. Most of this energy is consumed by the residential and government sectors (about 45% of total energy purchased), while the minimum consumption was in the street lighting sector with a value of about 2%. The sectorial consumption in 2021 is shown in Figure 4.

## 3 Long-term electricity demand forecast in Jordan

A long-term electricity demand forecast study is the first step in the planning activities of an electrical power system. It is used as input for related power system planning studies, such as the expansion of power generation and power transmission lines. It is also used as input in restructuring the electrical tariffs and other related financial studies. The accuracy and strength of the study rely upon the availability and accuracy of the data input that represents the independent variables affecting electricity demand in the country and upon the methodology and mathematical models employed in conducting this study. In Jordan, the study is conducted in three different directions: medium, high, and low forecast trends [35]. The medium forecast trend represents the realization of the planned aspirations based on normal economic and demographic growth. The high forecast trend represents the high expectations based on optimistic economic and demographic growth expectations. In contrast, the low trend represents the low expectations due to the degradation in the economy, income, productivity, and high cost of living in the country. These trends are used to avoid the ambiguity and uncertainty that may occur in the data input used in forecasting the electricity demand. The forecast study conducted in NEPCO employs the end-user method that subdivides the energy consumption into domestic, commercial, large industrial, medium, and small

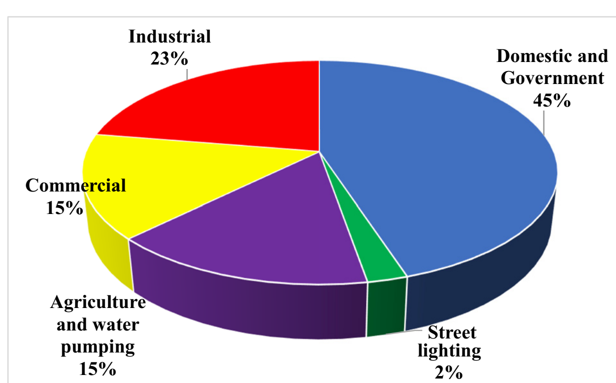


**Figure 4:** Electricity consumption by sector type in the year 2021 [34].

industrial, services, water pumping, and street lighting sectors. Each of these sectors represents a consumption pattern that differs from other sectors in the factors affecting the sector's consumption. The factors affecting consumption in each sector are summarized in Table 2.

The study employs three different cumulative methods for the end-use customers as follows.

## 3.1 The econometric method

The econometric method is used in forecasting the demand for electricity in domestic, commercial, medium, and small industrial, services, and water pumping sectors in small and medium projects. The regression model in its linear form based on historical consumption and influencing factors is presented in equation (1):

$$Y = aX_1 + bX_2 + cX_3 + \cdots + fXn + \varepsilon, \quad (1)$$

where $Y$ is the dependent variable that represents the electricity consumption in GWh, $X_1$, $X_2$, $X3, \ldots, Xn$ are the independent variables coefficients. $a, b, c \ldots, f$ are the regression coefficients, and $\varepsilon$ is the error. The logarithmic regression method is used to calculate the elasticity of demand, which is defined as the ratio of change in demand to the ratio of change in the independent variable, and this can be expressed mathematically in equation (2):

$$\frac{\Delta Y}{Y} = a\frac{\Delta X_1}{X_1} + b\frac{\Delta X_2}{X_2} + c\frac{\Delta X_3}{X_3} + \cdots + f\frac{\Delta X_n}{X_n}, \quad (2)$$

where $\frac{\Delta X}{X}$ is the percentage change in the independent variable, and $\frac{\Delta Y}{Y}$ is the ratio of change in the dependent variable. $a, b, c$, and $f$ are independent variables coefficients. By taking the integral of both sides of the equation and assuming a low rate of the change $\Delta X$ and $\Delta Y$ are small, the regression in logarithmic form is obtained. The effect of all factors should be separated; thus, the multiple regression analysis is used in its logarithmic form, where the flexibility of these factors can be mathematically expressed as in equation (3):

$$\ln(Y) = a\ln(X_1) + b\ln(X_2) + c\ln(X_3) + \cdots + f\ln(X_n). \quad (3)$$

## 3.2 Field survey method

The field survey method is used in forecasting the demand for electric power in the large industries such as cement, phosphates, potash, fertilizers and oil refineries, and large industrial projects under implementation or planned for construction. The method is also used in the water pumping sector for large projects. This method depends on the annual production quantities expected from these projects and the specific amount of consumption per unit of production as in equation (4):

$$Y = aX, \quad (4)$$

where $Y$ represents the forecasted electricity consumption (kWh), $X$ is the production in tons from industrial projects and water production from water pumping projects production, and $a$ is the specific consumption kWh/ton for industries and $\text{kWh/m}^3$ for water projects.

## 3.3 Gempertz extrapolation method

This Gempertz method is used to forecast some factors affecting electricity consumption, such as population and other related factors affecting electricity demand [36]. In our study, this method is suitable for forecasting the electricity consumption in the street lighting sector and the number of households in the domestic sector. This method is considered a modification of the exponential system by making growth dependent on the time factor until saturation is reached. This method is viewed as a modification of the exponential system by making the growth dependent

**Table 2:** Factors affecting electricity consumption in each sector in Jordan [35]

| Sector | Factors affecting consumption |
|---|---|
| Domestic | Per capita income rate, electricity prices, and the sudden increase in the population due to forced migration from neighboring countries witnessing internal wars, such as Syria, Iraq, Yemen, Lebanon, and Libya |
| Commercial | Value added, electricity prices, and number of subscribers |
| Medium and small industries | Value added and number of subscribers |
| Services | Value added |
| Large industries and water pumping | The quantities of production (Ton and $m^3$) and specific consumption (kWh/Ton or $\text{kWh/m}^3$) |
| Street lighting | The number of household subscribers |

on the time factor until the saturation state is reached in infinity and according to equation (5) [37].

$$Y = \alpha e^{\beta e^{\delta t}}, \tag{5}$$

where $t$ is the time in years, $Y$ is the dependent variable representing the forecasted value at $t$ time, $\alpha$ is the saturation level at $t = \infty$, and $\beta$ and $\delta$ are equation constants <0. The previous equation can be converted from exponential form to linear form to be used in the regression analysis of historical as in equation (6).

$$\ln\left(-\ln\left(\frac{Y}{X}\right)\right) = \beta + \delta t. \tag{6}$$

The end-user electricity consumption forecast per sector extracted from the techniques presented in Section 4 is summarized in Table 3.

The total end-use electricity consumption in GWh is referred to the generation bus by adding the amounts of losses in the distribution and transmission power grid, according to equation (7):

$$E_{\text{Gen}} = \frac{E_{\text{Con}}}{(1 - E_{\text{loss}}(\%))}, \tag{7}$$

where $E_{\text{Gen}}$ is the forecasted generated energy (in GWh), $E_{\text{Con}}$ is the forecasted end-use electricity consumption (in GWh) and $E_{\text{loss}}(\%)$ is forecasted average losses in distribution, overhead transmission lines, and power plant auxiliaries. These values are estimated between 2 and 3% for transmission loss, 9 and 10% for distribution loss, and 6 and 7% for power plant auxiliaries. The losses in the transmission and distribution networks are estimated based on load flow programs and some mathematical methods. The historical information, including the difference between the purchased and sold energy, the future expansions in the network, and expected demand and operational plans information, are used as input. The same procedure is followed in calculating the maximum peak load of the electrical system at the generation bus, while the loss ratio is not the same as the values used in equation (7). However, it is dependent on it because there is a correlation between them. The following applied equation shows the relationship between the percentage of losses in the distribution networks associated with the maximum load and the average annual losses in these networks as in equation (8) [35].

$$P_{\text{loss}}(\%) = \frac{E_{\text{loss}}(\%)}{(c + (1 - c) \times \text{LF})}, \tag{8}$$

where $c$ is the coefficient obtained from regression and it is found to be 0.3 for Jordan's power system, and LF is the load factor of the electrical system (assumed to be 0.7 in Jordan case). The future losses in the transmission networks at the time of the maximum load are predicted based on PSSE or DIgSILENT load flow programs, considering future additions and expansions. The electricity demand forecasts made in NEPCO take more than one projection to avoid deviation in the estimated loads. The deviation is due to several sources, such as method errors and errors in estimating influencing factors affecting each sector's electricity consumption, such as demographic and GDP factors. Thus, medium, high, and low three projections are taken. The medium projection represents the continuity of development with normal growth in the electricity consumption factors. The high projection represents the optimistic view, and the low projection represents the pessimistic view. Table 4 presents the medium annual energy and peak load projection from 2023–2050. The table shows a moderate growth rate of 2–3% for both energy and peak load. The analysis assumes that a peak load with the same value may occurs during the morning or evening periods, particularly between 13:00 and 15:00 for the morning peak and 18:00 and 20:00 for the evening peak. Figure 5 presents the forecasted energy and peak load in three directions: medium low, and high projections. A percentage of ±3% was assumed for high and low projections.

**Table 3:** The end-use electricity consumption forecast per sector up to the year 2050 in GWh

| Year | Domestic and Government | Industrial | Commercial | Agriculture and water pumping | Street lighting | Total |
|---|---|---|---|---|---|---|
| 2023 | 8766.472 | 4421.561 | 3027.067 | 2932.784 | 432.117 | 19,580 |
| 2025 | 9237.032 | 4658.898 | 3189.551 | 3090.207 | 455.312 | 20,631 |
| 2030 | 10414.1 | 5252.58 | 3595.994 | 3483.991 | 513.332 | 23,260 |
| 2035 | 11591.17 | 5846.261 | 4002.438 | 3877.775 | 571.35 | 25,889 |
| 2040 | 12768.25 | 6439.94 | 4408.881 | 4271.559 | 629.373 | 28,518 |
| 2045 | 13945.32 | 7033.624 | 4815.324 | 4665.343 | 687.393 | 31,147 |
| 2050 | 15122.39 | 7627.305 | 5221.767 | 5059.127 | 745.413 | 33,776 |

**Table 4:** The end-use electricity consumption forecast per sector up to the year 2050 in GWh

| Year | Energy (GWh) | GR (%) | Pek load (MW) | GR (%) |
|---|---|---|---|---|
| 2018(act) | 18,913 | | 3,205 | |
| 2019(act) | 19,273 | 1.90 | 3,380 | 5.46 |
| 2020(act) | 19,194 | 0.417 | 3,630 | 7.40 |
| 2021(act) | 19,719 | 2.73 | 3,770 | 3.86 |
| 2022(act) | 20,460 | 3.75 | 4,010 | 6.37 |
| 2023 | 21,080 | 3.03 | 4,092 | 2.04 |
| 2025 | 22,131 | 2.46 | 4,313 | 2.66 |
| 2030 | 24,760 | 2.27 | 4,963 | 2.85 |
| 2035 | 27,389 | 2.04 | 5,635 | 2.57 |
| 2040 | 30,018 | 1.85 | 6,270 | 2.16 |
| 2045 | 32,647 | 1.69 | 6,980 | 2.17 |
| 2050 | 35,276 | 1.56 | 7,642 | 1.83 |

## 4 The DLC prediction technique and results

Based on the electricity demand forecast study (medium projection) summarized in Table 4 and Figure 5, respectively, the DLCs are predicted based on the following procedure:

(1) Determine the hourly historical growth rate GR (t)% over a real period from 2007–2022 by equation (9):

$$\mathrm{GR}(t)\% = \left(\frac{P(t_n)}{P(t_o)}\right)^{\frac{1}{n}} - 1, \tag{9}$$

where GR($t$)% is the hourly growth rate over the period, $n$ is the number of years ($n$ = 15); $P(t_n)$ is hourly peak load at the end of the period (year = 2022), and $P(t_o)$ is hourly peak load at the beginning of the period at (year = 2007). The equation produces a matrix of 24 rows and 365 columns (8,760 values), 24 h/day and 365 days/year.

(2) Smooth the real $\overline{\mathrm{GR}(t)}$% by moving average for three consequence readings on a day, the day before, and the day after as shown in equation (10):

$$\overline{GR(t)}\% = \frac{\mathrm{GR}(t-1) + \mathrm{GR}(t) + \mathrm{GR}(t+1)}{3}, \tag{10}$$

where $\overline{\mathrm{GR}(t)}$% is the hourly growth rate obtained by the moving average, and $t$ is the time.

(3) Determine the forecasted hourly peak load $P_f(t)$ by using equation (11):

$$P_f(t) = (k(t) \times \mathrm{GR}_f\% + 1)^{(f-n)} \times P_n(t), \tag{11}$$

where $P_f(t)$ is the 8,760 forecasted hourly peak load set in $f$-year, $n$ is the reference year that, is 2022 in this work, *k(t)* represents the ratio of hourly smoothed rates to annual growth rate over the real n-period given by equation (12):

$$k(t) = \frac{\overline{\mathrm{GR}(t)}(\%)}{\mathrm{GR}_a(\%)}, \tag{12}$$

where $\mathrm{GR}_a$ is the annual growth rate over the real $n$ period, and the value of $k(t)$ is slightly close to 1. It is an

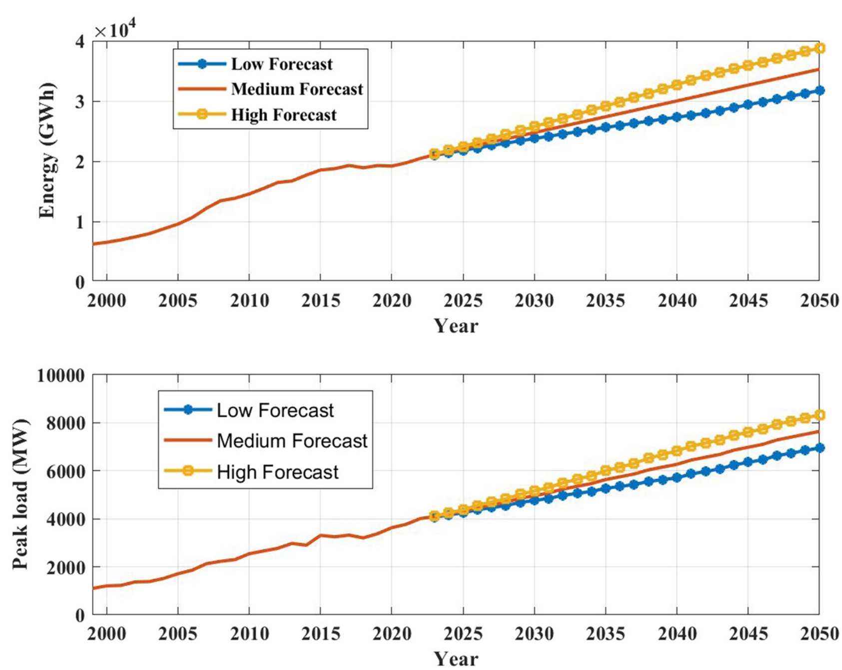


**Figure 5:** The forecasted energy and peak load at generation bus for the period 2023–2050 in three directions low, medium, and high forecast.

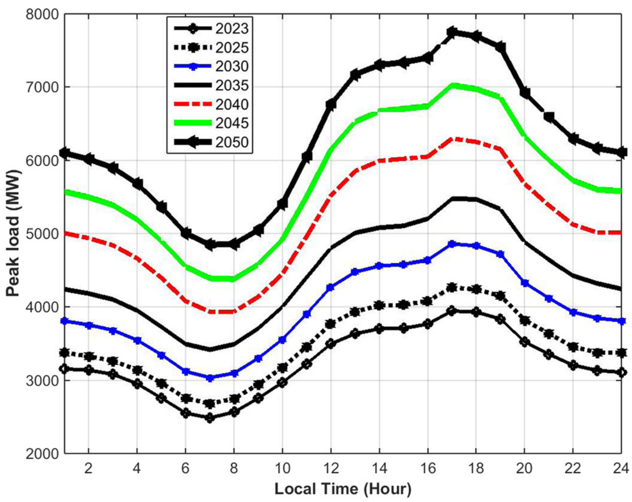


**Figure 6:** The DLC with evening peak occurrence.

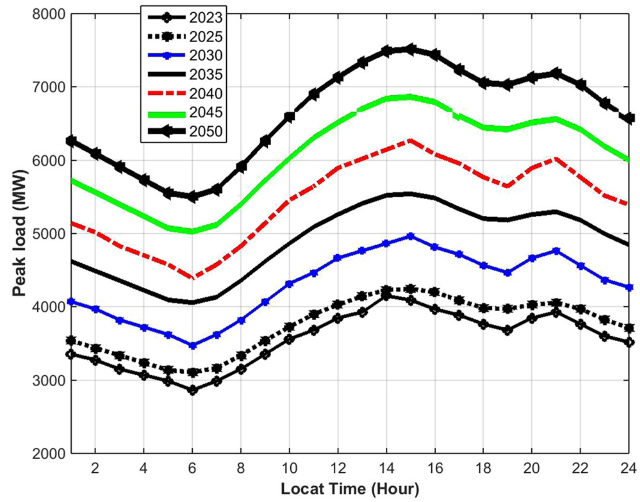


**Figure 7:** The DLC with morning peak occurrence.

essential variable as it considers the seasonality from year to year and adjusts the total energy to be the same as the forecasted values in Table 4.

The $GR_f(t)\%$ value in equation (13) represents the annual growth of the forecasted peak concerning the reference $n$-year peak, and it is given by equation (13)

$$GR_f\% = \left(\frac{P_f}{Pn}\right)^{\frac{1}{(f-n)}} - 1. \quad (13)$$

For example, the value of $GR_f\%$ for the year 2050, where the expected $P_f$ in the year 2050 is 7642 MW, concerning 2022, where $P_n$ in 2022 is 4,010 MW, and $(f-n) = 28$ years is 2.3%.

(4) Forecast the annual energy in the f-year in GWh by summing the predicted hourly peak loads using equation (14)

$$\text{Energy}(t) = \sum_{n=1}^{n=8,760} P_f(t). \quad (14)$$

The values obtained in equations (11) and (14), should be slightly normalized to ensure that they are not exceeding the forecasted values of Table 3 (for instance, 35,276 GWh and 7,642 MW in the year 2050). Based on historical data for DLCs in Jordan, three possible scenarios for peak occurrence took place: the first scenario is that peak load is a daytime peak around 14:00 LT in summer as in the period 2000–2012, the second scenario is that both morning and evening peak loads are almost equal as in DLC's of 1996, 1998, and 2003, respectively and finally the evening peak is higher than morning peak took place in winter around 17:00 as in the period 2013–2022. Based on these scenarios and the procedure mentioned in Section 5, equations (9)–(14) for the DLC prediction, Figures 6 and 7 show the DLC for the period 2023–2050.

## 5 Conclusion

This article presents the load development and variations in Jordan during the 1994–2022 period, emphasizing the peak load conversion from the evening to the morning period and justifying this conversion. It also introduces the determinants affecting the electricity demand methods in Jordan and the variability of these determinants during the last three decades in Jordan. The future DLC is an essential indicator in any country's power system planning, reflecting the load variations connected with economic and demographic growth expectations. Thus, based on the growth rate statistical method, the article proposes a mathematical model for predicting the DLCs in Jordan in the period 2023–2050. The historical hourly peak loads in the period 1994–2020 and the annual forecasted peak loads during the morning and evening periods taken from the long-term load forecast (LTLF) study of NEPCO during 2022–2050 are employed in the prediction model. In the prediction technique, the actual hourly growth rates, the annual forecasted growth rates, and the hourly peak loads in the reference year 2022 are the main input variables used in the prediction formula (i.e., $k(t)$, $GR_f$, and $P_n(t)$ coefficients in the equation). The LTLF conducted by NEPCO employs various sophisticated methods depending on the end-user sectorial electricity consumption that imply an econometric approach, market survey, and Gomprtz extrapolation techniques.

The peak load in Jordan relies upon several climatic and nonclimatic variables, implying the ambient temperature, GDP, income, demographics, urbanization, electricity tariff, average oil prices, and other related factors related to technology and new aspects of energy saving and space heating/cooling systems, and the DLC in Jordan is variable and changing from year to year. The proposed model considers a variation in the future DLC and suggests three different scenarios of DLC's prediction based on the time occurrence of the peak load: the first is the daytime peak occurrence scenario, the second is that the evening peak occurrence scenario, and finally is the daytime and evening peaks may be close to each other.

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