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Statistical Modeling of the Determinants Driving the Electricity Demand in Jordan

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ABSTRACT The paper introduces a statistical model that connects the electrical demand in Jordan with several determinants that have a direct impact on the electrical consumption and load profile during the study period from 2007 to 2020. The period was selected as it is characterized by several global events that directly impacted Jordan's economy and energy sustainability in Jordan, such as the Arab spring protests, the civil war in Syria, and the global financial crises. Many determinants that are used in the regression analysis imply the ambient temperature, day of the week, population, gross domestic product (GDP), oil price, and technological factors related to renewable energy projects. Results show that temperature and population positively impact the demand, whereas GPD, population, oil prices, and renewable energy negatively impact the electricity demand. The results obtained from backcasting regression analysis for the hourly 4745 data set covering 13 years period reveals reasonable error metrics with MAE, MAPE, and RMSE values of 134, $\mathbf{6.3\%}$ and $\mathbf{2.76\%}$, respectively. The government must encourage investments to exploit and explore the massive potential of available energy resources such as oil, natural gas, oil shale, and uranium to resolve the problems related to the high global oil prices and high dependency on imported energy. Also, it is required to enable the transition from fossil fuels to renewable energy through financial incentives and tax exemption to encourage investments in clean energy, rebuild a new traffic system showing the volatile electricity prices, which are still unknown and finally remove obstacles and facilitate the ongoing projects, reaching a state of stakeholder buy-in engaging with the projects.

INDEX TERMS Determinants, electricity demand, oil prices, GDP, Jordan.

I. INTRODUCTION

THE electricity demand in Jordan is affected by several climatic and non-climatic factors. The energy prices, income per capita, Gross National Product (GNP), import and export values, oil prices, demographic (population), technological factors, and the conversion from fossil fuel to renewable energy are the main factors that control the load profile in Jordan. The increment in temperature above or below a specific limit may cause a shifting in the maximum peak load occurrence from evening hours to daytime hours or from daytime to evening hours due to the intensive use of heating, ventilation, and cooling systems by residential users. It is expected that the demand increase with the growth of the economy and population. At the same time, it decreases as oil price increase and electricity tariffs. A conversion from fossil fuels which is the most common method of electricity generation today to electricity generation from renewable resources is another factor that will affect the load profile in Jordan.

The understanding of load variations in any country is the first step toward accurate load forecasting. The period from 2007 to 2020 is crucial as many global issues affecting Jordan's energy market took place. The period was characterized by several locals, regional, and international events directly impacting the country's economy and development. The events implied the global financial crisis in 2008—the Arab Spring protests in 2011, the Syrian civil war in 2011, and the following years. During the civil war in Syria, hundreds of thousands of refugees came to stay in Jordan permanently, and the need for energy resources increased dramatically, causing an extra burden on the Jordanian economy [1], [2]. Moreover, Jordan's population has grown from 5 Million in 2005 to 9.6 million in 2015 [3]. Therefore, the government needed to take some actions to encourage the private sector and domestic customers to invest in the clean energy sector to make electricity available and sustainable at the lowest cost.

The emphasis of this paper is to implement multiple linear regression (MLR) to perform the backcasting of the electricity demand in Jordan based on several independent variables. The linear regression was employed in this research due to its ability to provide high accuracy with several independent variables that imply social, weather, income, cost of living, Brent oil price, international economic crises, electricity tariff, and demographic and technological factors related to the electricity consumption in Jordan. The main factors considered in the analysis are the differential daily temperature index in cold and hot weather, the day of the week, annual population, GDP, Brent crude oil price, and technological factors due to the expansion of renewable energy and other related factors.

The paper is organized as follows: Section II and Section III summarize the related work and the indices that directly impact the electricity demand in Jordan during the study period. The analysis of daily load curves (DLCs) and the temperature impact on electricity demand in Jordan during 2007-2020 are presented in Sections IV and V, respectively. The data sources are presented in Section VI. Followed by the statistical model analysis in Section VII. The results and discussion in Section VIII. Finally, the work conclusion and suggestions to enhance the energy sector's issues in Jordan are presented in Section IX.

II. RELATED WORK

Analytical studies are critical studies that power companies in many countries conduct. Such studies aim to identify the load variations over a long time, the behavior of daily load curves (DLC), behavior of load duration curves (LDC), periods of peak load, the variations between daytime and nighttime consumption, and the factors affecting the electricity demand in any country. The results from these studies are used as input for predicting the future profile and load forecast daily, weekly, monthly, and yearly. The accurate load forecast-from the power system planning point of view- can minimize the financial risk, optimize the operational efficiency, enhance the system's stability and reliability and maintain the spinning reserve within a safe limit. For instance, the sectorial electricity demand and load factors variations in Syria are investigated during 1999-2030. It is expected that load factor forecasting will increase from 0.62 to 0.71, and the peak load will increase by 5.3% [4]. The residential consumption in Greece and a proposed method for annual LDC prediction with and without PVs are analyzed [5]. A hybrid approach for modeling the short-term forecasting of electricity loads in French in 1996-2009 is introduced by modeling the overall trend and seasonality of the DLC and modeling the dependence structure across consecutive daily loads via linear regression [6]. A rigorous explanation of several statistical algorithms employed in load forecasting including regression, neural networks, fuzzy logic, and other techniques are discussed [7]. The hybrid multivariate linear models such as ARIMA, SARIMA, and regression-SARIMA models are also discussed by many researchers, mainly when the relationship between the demand and independent variables is linear. These models provide high accuracy, especially for short-term load forecast, and excellent mean absolute percentage error index (MAPE) [8]. The future patterns are predicted based on the past values in ARIMA, whereas in SARIMA, the future patterns are evaluated based on the past values and the seasonality values. The regression-SARIMA model, for example, was employed by several researchers [9] who predict the electricity daily peak demand in South Africa. The same model is presented to predict Australia's weekly peak power demand for a yearly time scale [10].

The factors that affect electricity consumption in any country are also investigated by several researchers elsewhere. The temperature impact on aggregate electricity demand in India was investigated and showed that the demand increases by 11% or further at temperatures above $30°C$ [11]. In Jordan, many studies investigate these factors. Thus the combination of cultural and economic conditions plays an essential role in shaping the load behavior, but the weather conditions remain the primary driver [12]. There are six determinants affecting electricity consumption in Jordan during the period 1986–2015: GDP, climate influences, electricity prices, population, urbanization, the structure of the economy, aggregate water consumption, energy pricing, and technological factors [13], [14], [15], [16], [17]. These determinants are positively related to electricity consumption, except the electricity prices, which are negatively associated with electricity consumption.

Recent analytical studies on the energy sector of Jordan emphasize issues such as energy sustainability and renewable energy potential. Jordan's energy security is historically linked to its relationships with the neighboring countries and is thus susceptible to external shocks and outside political events. Therefore, the main challenges and future aspirations of the energy sector in Jordan are discussed [18]. The impacts of transitioning from fossil fuels to a renewable-dominated energy system on energy security are investigated, showing that Jordan can achieve a 100% renewable energy system by 2050, and such a transition will enhance the energy security level [19]. The challenges of the current energy situation and available renewable energy resources prospective for direct investments in Jordan are presented [20]. The study shows that despite the efforts placed on developing alternative energy resources, the real influence of clean energy is still reasonable at roughly 7% of total energy demand; government initiatives, financial incentives, and tax exemptions are required to encourage investments in clean energy. The current energy situation in Jordan was affected by the penetration of renewable energy, and suggestions for actions for policymakers are introduced [21]. The obstacles facing renewable energy resources development in Jordan can be summarized in financing schemes and the volatile price of electricity.

Thus, the government must remove barriers, facilitate ongoing projects, and encourage technological innovation [22]. Many challenges concerned the energy resources such as lack of local energy resources, high imported energy (97% imports in 2011), and high oil prices (energy imports reported for 16% of GDP in 2011). On the other hand, Jordan has many strong points that make the future energy market optimistic, such as Jordan location, which is transit and can play a significant role in linking the region's oil, gas and electricity networks. Jordan has a vast potential for renewable energy utilization (wind, solar) where solar radiation is 5-7 KWh/m^2 per day and wind speed 7-11 m/s. Finally, Jordan has a vast potential for energy resources (oil shale, uranium) and a potential for oil and gas exploration [23].

III. INDICES AFFECTING THE ENERGY SECTOR IN JORDAN

The most important indices that directly impact the Jordanian economy imply the annual: energy generation, peak load, population, GDP, cruel oil price, and electricity generation from renewable energy projects. These indices are summarized in Table 1. It shows that the annual energy increased from 12787.12 GWh in 2007 to 19850 GWh in 2020, with an overall growth rate of 55.2%. At the same time, the peak load increased from 2130 MW to 3630 MW for the same period, with an overall growth rate of 70.4%. The peak load is usually occurring in summer, particularly in July/August, and sometimes in winter, particularly in December/January, as was seen in 2013 and 2014, respectively. A recession in the percentage growth of GDP from 7.23% in 2008 and 5.02% in 2009 to −1.6% in 2020. This recession caused several economic problems in Jordan, such as increased unemployment rates, cost of living, and reduced industrial sector production. The population of Jordan rose from 6.7 million in 2010 to about 11 million in 2020 [24]. The abnormal population increase was noticed in 2013-2015 with GR % values of 9.4%, 8.6%, and 9.9%, respectively. This increase in population is connected to hundreds of thousands of refugees who crossed the border from Syria starting in 2011 to stay permanently in Jordan. According to UNHCR, the number of Syrian refugees registered in Jordan in 2019 was approximately 655,000 male and female [25]. However, many refugees are still not registered. As a result, the energy needs increased from 3.4% in 2009 to about 7% and 6% in 2011 and 2012, respectively. The GR% rates of peak load were inconsistent with the energy GR % values as the peak load of Jordan is very sensitive to temperature rise or decrease. However, it is strongly affected by population factors due to the expansion of energy use for lighting and other residential and commercial services in the country. A dramatic increase in the average cruel oil price was also observed in the period, particularly during 2010-2014, with a maximum price of $98/ barrel recorded in 2013. Figure 1 presents the Brent crude oil price fluctuations between 1976 and 2022 [26]. During this period, two dramatic increases in oil prices were recorded; the first peak was on July 3, 2008, coinciding with the global financial

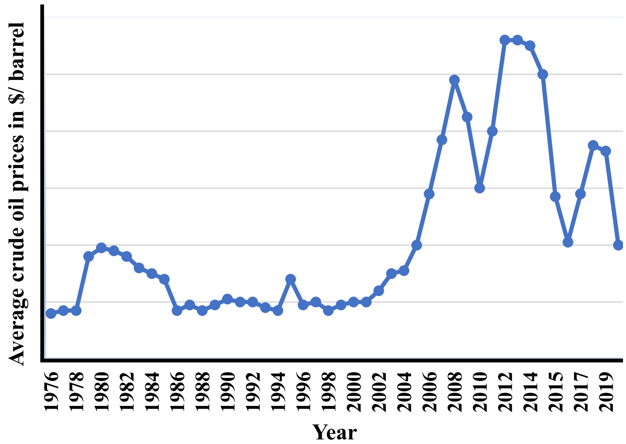

FIGURE 1. Average annual Brent crude oil price ($/ barrel) from 1976 to 2022 [26].

crises in the USA. After that, the oil price exceeded $70/ barrel in January 2007 to $97/ barrel in July 2008. However, it dropped in 2009 to a $63/ barrel value. The second sharp increase was observed in 2012, with a maximum value of $112/ barrel, followed by a steady decrease to a minimum of about $44/ barrel in 2016. Then, a gradual increase reached a maximum of $71/ barrel in 2018, followed by another drop during the COVID-19 crisis in 2020. The second peak in 2012 was coincident with the revolutions of Arab spring in Tunisia, Egypt, Syria, and Libya. Libya is a member of the Organization of Petroleum Exporting Countries (OPEC) and possesses the largest oil reserves in Africa. Before the civil war in February of 2011, Libya exported nearly 1.8 million barrels of oil daily and significant amounts of natural gas [27]. The violence that tore apart the country in 2011, destroying port cities, oil drilling stations, and refineries, profoundly affected the economy [28]. Consequently, the drop in oil prices during 2015 and 2016 helped Jordan to enhance economic consolidation by neutralizing the deficit in gas supplies and reducing energy bills [17].

Renewable energy projects are an essential index for evaluating Jordan's development in the clean energy sector. Table 1 shows how wind, solar, and biomass generation increased from 73.5 GWh in 2007 to 183.9 GWh in 2015 [29]. Jordan will be able to meet 100% of the country's electricity demand by 2050 by using renewable energy resources, saving the treasury $12 billion per year [30]. Also, solar thermal systems were installed in 15% of buildings [30]. Solar thermal systems are expected to be used in 30% of domestic buildings by the end of 2020, according to the government's energy master plan [31]. PV systems used in residential buildings are classified as distribution generation (DGs). Moreover, the penetration of DGs into the distribution network reduces losses since the DGs are closer to the loads, avoiding a considerable amount of power flow from the substation to the loads across several branches [32].

TABLE 1. Annual energy generation, peak load, GDP, population, cruel oil price, and renewable generation resources in Jordan during the period of study.

Year	Energy generation		Peak load		GDP		Population		Average cruel oil price ($/barrel)	Renewable energy (GWh)
	GWh	GR (%)	MW	GR (%)	Billion (JD)	GR (%)	Million	GR (%)		
2007	12787		2130 July 29		21.08		6.1		72	73.5
2008	13247	3.59	2141 August 19	0.52	22.59	7.23	6.3	3.2	99.6	74.2
2009	13697	3.4	2208 July 29	3.13	23.72	5.02	6.5	3.2	62.0	68.9
2010	14573	6.39	2544 August 3	15.22	24.27	2.3	6.7	3.1	79.5	72.8
2011	15589	6.97	2660 August 29	4.56	24.93	2.74	7.0	4.4	95.0	65.7
2012	16492	5.79	2770 July 31	4.14	25.54	2.43	7.4	5.7	94.0	65.7
2013	16766	1.66	2975 December 17	7.4	26.21	2.61	8.1	9.4	98.0	63.2
2014	17805	6.2	2900 December 28	-2.52	27.09	3.38	8.8	8.6	93.2	66.6
2015	18639	4.68	3300 August 4	13.79	27.77	2.5	9.6	9.9	48.7	183.9
2016	18506	-0.7	3250 January 25	-1.8	28.3	2.0	9.9	3.1	43.7	925
2017	19444	5.1	3320 July 25	2.2	28.9	2.1	10.2	3.0	54.3	1360
2018	19444	5.1	3320 January 25	2.2	29.46	2.1	10.2	3.0	54.3	1360
2019	19277	5.2	3380 February 8	5.5	30.0	2.0	10.7	1.9	64.3	2200
2020	19850	3.0	3630 January 18	7.4	29.6	-1.6	11.0	2.8	41.9	2900

IV. DAILY LOAD ANALYSIS DURING THE PERIOD OF STUDY

Figure 2 presents the annual DLC curves during the study period from 2007 to 2019. The readings represent the maximum hourly demand in MW. As shown in the figure, the minimum load occurs at around 6:00 AM, the maximum morning peak occurs during 13:00 –15:00, and the maximum evening peak occurs during 16:00-18:00. It is also seen that the annual peak is generally a morning peak in summer, particularly in July / August every year. In the recent years it converted to evening peak that took place in winter particularly in December / January as in seen 2013, 2014, 2018 and 2019 respectively. A noticeable leap in the 2010 and 2015 peak load was observed due to the weather factor and due to economic enhancement as a result of the sharp drop in global oil prices.

Indeed, Jordan exploits the decline in oil prices whenever it happens and during the study period. The minimum prices were recorded in 2008 and 2015 with the values of $38/ barrel and $40/ barrel, respectively. The response of the electricity demand to the weather factor during the hot August and the cold December are presented as shown in

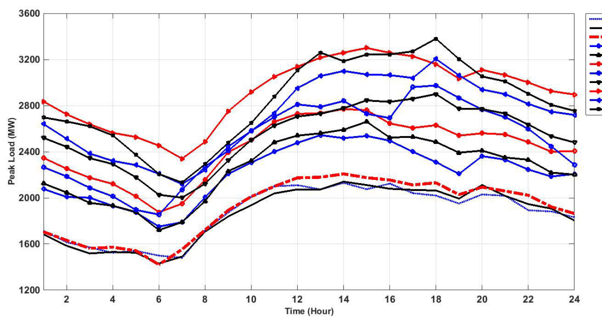

FIGURE 2. Typical annual DLCs for the period 2007-2019 [29].

Figure 3 and Figure 4, respectively. Figure 3 shows that the peak in summer usually occurs during the morning period, particularly between 13:00-15:00, which incidence with high temperatures, whereas in winter, it usually occurs during the evening period, particularly between 16:00-18:00, which is a coincidence with the low ambient temperature. There are many scenarios for electrical consumption. The seasonal energy and electricity consumption pattern typically exhibit

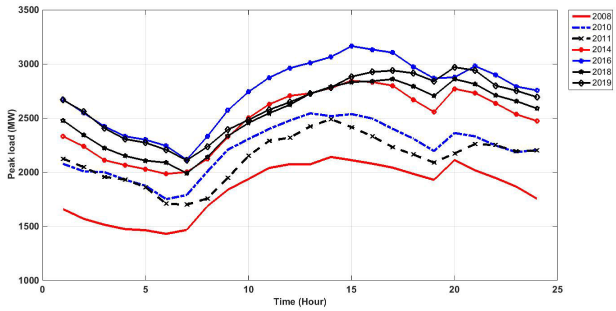

FIGURE 3. The typical DLCs during August for the period 2008-2019 (summer season).

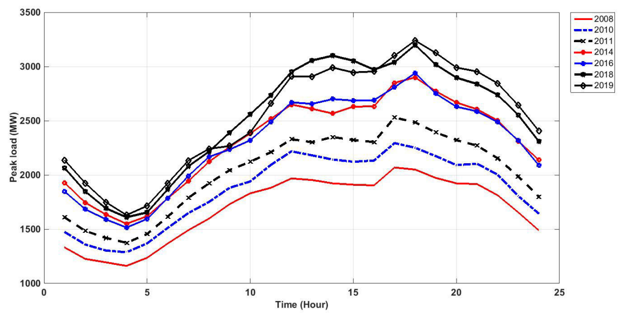

FIGURE 4. The typical DLCs during December of 2008-2019 (winter season).

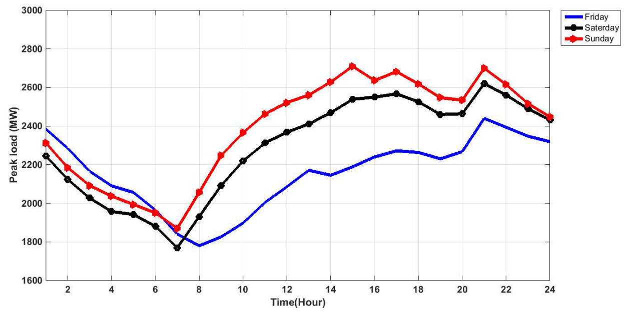

FIGURE 5. Typical load curve taken in 20th, 21st and 22th July 2018 in Jordan.

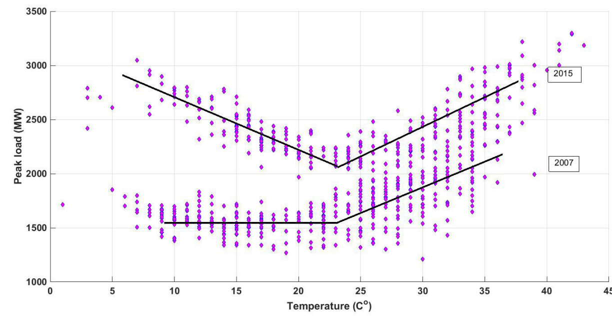

FIGURE 6. The relationship between electricity demand and ambient temperature during the morning in the years 2007 and 2015 in Jordan.

two peaks, one in the winter and the other in the summer, with the summer peak in recent years becoming progressively higher. The impact of rising or lowering temperatures on annual energy demand varies by region [33]. Some studies show that when the temperatures rise above 30°C, demand increases by about 11% [11]. Other studies state that lowering the ambient temperature by 1°C below 15°C increases demand by roughly 17 MW [34].

Based on previous studies made on Jordan's electricity demand and its relation with the social-economic variables [34], it is found that the peak load relied upon the day of the week in Jordan. On Friday which is a public holiday in Jordan where government, private companies, educational institutes, universities, and many other services are off during this day. The historical load profile during this day shows a sharp decrease in the overall demand. A comparison between Friday and Saturday, which is a partial holiday, during which the government and educational institutes are not working, but the private sector is working during this day. Figure 4 presents a DLC sample for three typical days (working day, Friday, and Saturday) in the summer of 2018; a similar profile can also be seen during another period in summer or winter. The figure reveals pronounced depletion on Friday and Saturday compared with Sunday working days. The calculation of energy consumption for the three days shows a significant decrease in consumption by 10% for Friday and 4% for Saturday comparing with working day on Sunday.

V. ANALYSIS OF THE AMBIENT TEMPERATURE IMPACT ON PEAK LOADS

The analysis of the ambient temperature impact on the electricity demand in Jordan shows a noticeable increase in demand when ambient temperature increases above 20°C in summer and below 15°C in winter. A comparison between 2007 and 2015 shows a significant increase in demand when the temperature rises above 20°C in summer and falls below 15°C in winter. The response of the temperature–load profiles nearly takes a V-shape response as shown in Figure 6 and Figure 7, indicating that the peak load increases dramatically during very low and very high ambient temperatures. The V shape was clearly seen in 2015 comparing with 2007 curves, especially during low temperatures in 2015. It is due to technological factors through replacing the old heating systems that depend on gasoline (domenant in 2007) with air-conditioning systems in residential and services sectors, and the worship places, especially in the evening and early morning periods of winter.

VI. DATA SOURCES

Climatic and non-climatic factors are the two types of determinants that have a significant impact on Jordan's energy profile. The climatic factor refers to the ambient temperature, which influences consumption patterns in the summer and winter seasons. The hourly daily peak load in (MW) and the ambient temperature in degree Celsius °C are obtained

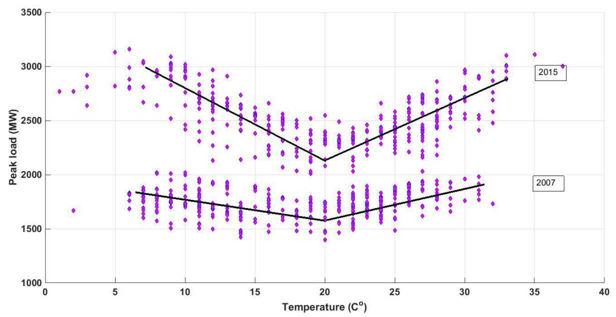

FIGURE 7. The relationship between electricity demand and ambient temperature during the evening in the years 2007 and 2015 in Jordan.

from the electricity operation and control center of National Electric Power Company (NEPCO) in Amman south. The site owns the largest main substation, 400/132/33 kV, that interconnects the power grid of different regions of Jordan. Three main temperature readings that are recorded daily include (1) temperature at the time of daytime peak (2) temperature at the time of evening peak, and (3) temperature at the time of minimum. Table 2 presents a sample of the data obtained from NEPCO.

In contrast, the non-climatic factor refers to socioeconomic factors such as population, day of the week, the high cost of oil that affects Jordan's economy, GDP, electricity prices, tariffs, and technological factors. The technological factor is strongly connected with the expansion of renewable energy use starting in 2013, replacing conventional fossil fuel sources. The data used in the analysis are hourly–daily and cover 13 years from 2007-2020. The annual population of Jordan is obtained from different sources: The Jordan department of statistics, the U.N. refugee agency (UNCAR), and the Worldometers information website [3], [24], [25]. The Brent oil prices are taken from different websites, such as UK Brent crude oil price changes since 1976 [26]. The Jordanian economy metrics such as GDP in market price, per capita GDP, and average inflation CPI index for Jordan are obtained from sources such as Jordan's ministry of finance, NEPCO annual reports in 2021 [29], and the U.S. embassy in Jordan in numbers [35].

VII. STATISTICAL REGRESSION MODEL

MLR is a statistical modeling tool used to find the correlation between the dependent and independent variables. The data obtained from various sources are arranged in EXCEL for regression analysis. The data, as shown in Table 3, implies the time in a day, load in MW as a dependent variable, and X_1 to X_8 parameters as independent variables where X_1 is the absolute differential temperature (ΔT) above $20°C$ in summer and below $15°C$ in winter, the value of ΔT in the table is calculated based on $|T - 20°C|$ in summer and $|T - 15°C|$ in winter, respectively. X_2 is a dummy variable to represent Friday where 1 is given for Friday and 0 for other days, X_3 is a dummy variable to represent Saturday where 1 is provided for Saturday and 0 for other days, X_4 is a dummy variable to represent the public holiday where 1 is given for public holiday and 0 for other days. X_5 is the annual population growth rate is above 3.2% baseline, and 0 for the remaining days. A significant increase in population was observed in the period 2011-2015. X_6 is the GPD growth rate decreases below an average of 6%. Table 1 shows a significant decline in the annual GDP growth from a 6% average from 2007-2009 to about a 2.6% constant rate during 2010-2015 and 1.3% for 2016-2020. X_7 is the oil price above \$70/ barrel baseline (particularly in 2011-2014). Finally, X_8 is the generation from renewable energy (wind, solar, and biomass) above $187 MWh/$ day and 0 for the remaining days.

Table 3 presents the parameters that are used in the analysis. The table is a portion of a long Excel sheet consisting of 4745 rows where The scenarios for selecting the optimal set of data are:

- $T_1(k)$ is the date.
- $T_2(k)$ is the daily load in MW varies from 1380 MW on January 1, 2007 to 2416 MW on December 31, 2019.
- $T_3(k)$ is the differential temperature (ΔT).
- $T_4(k)$ is Friday dummy variable 0 or 1.
- $T_5(k)$ is Saturday dummy variable 0 or 1.
- $T_6(k)$ is the public holiday dummy variable 0 or 1.
- $T_7(k)$ is the percentage increase of population above the baseline 3.2%.
- $T_8(k)$ is the percentage decrease in GDP below the baseline of 6%.
- $T_9(k)$ is the percentage increase of oil price above the baseline \$70/ barrel.
- $T_{10}(k)$ is the renewable energy generation above $187 MWh/$ day baseline

The weight of these factors is investigated based on the multiple linear regressions (MLR) model of Microsoft Excel represented by:

$$\hat{y} = b_o + b_1 X_1 + b_2 X_2 + \cdots + b_i X_i + \epsilon \tag{1}$$

where $\hat{y}$ is the dependent load variables (MW), X_1, X_2, X_i are the dependent variables that affect the load, $b_o, b_1, \ldots b_i$ are the unknown regression coefficients and ϵ is the residual of observations or the mean square error value. The regression analysis shows the correlation between the dependent and independent variables. The R-square value in the regression output summary tells us how much variation is explained by the model, where 0.1 R-square means that your model explains 10% of the variation within the data, so the greater R-square, the better the model. Multiple R is the square root of R^2. The R-square is given by:

$$R^2 = 1 - \frac{\sum_{i=1}^{n} (y_i - \hat{y}_i)^2}{\sum_{i=1}^{n} (y_i - \overline{y_i})^2} \tag{2}$$

where y_i is the actual load in MW; $\hat{y}_i$ is the estimated load in MW and $\overline{y_i}$ is the average value of y_i in MW. The numerator in equation (2) represents the regression sum of squares

TABLE 2. **Sample of data implies ambient temperature, min. and max. load readings, and time of occurrence of min. and max. loads periods as obtained from NEPCO.**

Date	Load (MW)			Ambient temperature ^oC			Time of occurrence		
	Min. load	Max. morning peak	Max. evening peak	Min. load	Max. morning peak	Max. evening peak	Min. load	Max. morning peak	Max. evening peak
Jan. 1, 2019	1600	2490	2936	6	14	11	4:37 am	11:58 am	17:23 pm
Jan. 2, 2019	1530	2680	3040	4	14	11	3:51 am	14:00 pm	17:11pm

TABLE 3. **A sample of dependent and independent variables that are used in the analysis.**

Date	Dependent variable	Independent variables							
	MW	ΔT	Fri.	Sat.	HD	Pop	GDP	Oil price	RG
	Y	X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8
Jan. 1, 2007	1380	5	0	0	1	6.1	0	2	0
Jan. 2, 2007	1455	6	0	0	1	6.1	0	2	0
Jan. 3, 2007	1530	5	0	0	1	6.1	0	2	0
Jan. 4, 2007	1620	6	0	0	1	6.1	0	2	0
Jan. 5, 2007	1505	8	1	0	0	6.1	0	2	0
Jan. 6, 2007	1790	9	0	1	0	6.1	0	2	0
Jan. 7, 2007	1800	8	0	0	0	6.1	0	2	0
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮
Dec. 27, 2019	2910	8	1	0	0	10.7	-4	0	2013
Dec. 28, 2019	2930	3	0	1	0	10.7	-4	0	2013
Dec. 29, 2019	2600	1	0	0	0	10.7	-4	0	2013
Dec. 30, 2019	2660	0	0	0	0	10.7	-4	0	2013
Dec.31, 2019	2410	1	0	0	0	10.7	-4	0	2013

(SS in Excel) is given by:

$$SS = \sum_{i=1}^{n} (y_i - \hat{y}_i)^2 \tag{3}$$

The error indices such as root mean square error (RMSE), mean absolute (MAE) and the mean absolute percentage error (MAPE) can be obtained by [36]:

$$RMSE = \frac{\sqrt{\sum_{i=1}^{n} (\hat{y}_i - y_i)^2}}{n} \tag{4}$$

$$MAE = \frac{1}{n} \sum_{i=1}^{n} |y_i - \hat{y}_i| \tag{5}$$

$$MAPE = \frac{1}{n} \sum_{i=1}^{n} \left| \frac{y_i - \hat{y}_i}{y_i} \right| \times 100\% \tag{6}$$

where n in the equation is the number of observations, the F-test is a hypothesis test based on Fisher and Snedecor's F-distribution under the null hypothesis [37]. The test is performed when it is unknown whether the two populations have identical variance. The F-distribution test value is obtained by dividing the regression SS by residuals SS as shown in

$$F = \frac{\frac{Reg(SS)}{(k-1)}}{\frac{Res(SS)}{(n-k)}} \tag{7}$$

where Reg (SS) is the regression sum of squares, Res (SS) is the residuals sum of squares, n is the number of observations, and k is the number of independent variables. In regression analysis, the p-value tells about the F-statistic hypothesis testing of the fit of the intercept-only model, and our model is equal. Thus, if the p-value is less than the impact level (usually 0.05), the model fits the data well. A t-test in regression is an inferential statistic used to define if there is a considerable difference between the means of two groups. A large t-score implies that the groups are different, while a small t-score demonstrates that the groups are similar [38]. A high R-square and low p-value is the best scenario, meaning that the model explains many variations within the data and is significant.

TABLE 4. **The output summary of the statistical regression for 13 years (2007-2019).**

Multiple R	0.874871				
R square	0.765399				
Adjusted R square	0.764872				
Standard error	175.305				
Observations	4745				
ANOVA					
	df	SS	MS	F	Significance F
Regression	9	4.02×10^8	44639837	1452.56	0
Residual	4737	1.23×10^8	30731.84		
Total	4746	5.25×10^8			

VIII. RESULTS AND DISCUSSION

Table 4 shows the output summary of the statistical regression model for the data presented in Table 3. The table shows a strong correlation between independent and dependent variables with multiple R and R^2 values of 0.8748 and 0.7653, respectively. The results demonstrate that all eight variables have a p-value of less than 0.05 ($typically \leq 0.05$), indicating that they are statistically significant. A p-value of less than 0.05, according to Simplypsychology [39]. As there is less than a 5% probability, it implies strong evidence opposed to the null hypothesis, that the null hypothesis is correct and the results are random. As a result, the null hypothesis is denied, and the alternative hypothesis is accepted. The average of the lower 95% and upper 95% confidence levels are represented by the coefficients of each independent variable. A 95% confidence interval is a set of values (upper and lower) that can be 95% particular and contains the population's true mean.

The results in Table 5 reveals that three of the eight variables have a positive impact on demand, which are: the base load, temperature, and population, whereas the remaining

TABLE 5. The weight of variables of the statistical regression model for 13 years (2007-2019).

Item	Coefficients	Standard error	t-state	P-value	Lower 95%	Upper 95%
Base load (MW)	1748.321	68.97606	17.91011	4.54×10^{-69}	1100.137	1370.6
Temperature	30.65119	0.78726	38.93401	$1.6\times^{-281}$	29.10773	32.19466
Friday	-251.647	8.044064	-31.2835	$2.1\times^{-192}$	-267.418	-235.876
Saturday	-34.5054	8.044049	-4.28956	$1.83\times^{-05}$	-50.2762	-18.7346
Public holiday	-279.004	15.55518	-17.9364	$2.93\times^{-69}$	-309.501	-248.507
Population	287.4545	22.59052	12.72456	$2.17\times^{-36}$	243.1645	331.7445
GDP	-52.9518	10.48551	-5.05	$4.61\times^{-07}$	-73.5092	-32.3944
Oil price	-81.0634	12.13194	-6.68182	$2.68\times^{-11}$	-104.849	-57.2781
Renewable energy	-77.1239	11.14454	-6.92033	$5.22\times^{-12}$	-98.9734	-55.2744

variables have a negative impact on electricity demand. The results reveal that the base load, which represents the intercept with the y-axis, is around 1748 MW, the impact of ambient temperature above $20°C$ in summer and below $15°C$ in winter increases the daily demand by about $30MW/1°C$, and that annual population increase from 3.2% baseline in 2007-2010 to about 10% in 2011-2019 (Table 1) increases the daily load by about $287MW/$ day. The table also shows that the demand fell by about 250, 34, and $280MW/$ day each Friday, Saturday, and holiday, respectively. The sharp drop in the GDP of Jordan from an average of 6% in 2007-2009 to an average constant value of 2.1% in 2010-2019 (Table 1) resulted in a considerable reduction in demand by about $52MW/$ day. The results also reveal that during 2011-2014 and 2018, an increase in oil prices above \$70/ barrel caused a considerable drop in demand by roughly 81 $MW/$ day. The rise in oil prices has negatively influenced the economy throughout this period. The reduction in oil prices in 2015-2017 helped Jordan's economic consolidation by neutralizing the deficit in the gas supply and lowering energy bills, but it did not enhance the economy too much, where GDP is still in the range between $2.0 - 2.5\%$. Finally, the expansion of renewable energy production began particularly in 2015. These projects are considered distribution generators (DGs) fixed at end users and helped the power producers to minimize their production based on fossil fuel sources, causing a reduction in the overall peak load of the country. Thus, the regression analysis shows the negative impacts of renewable energy projects on demand. In 2015, renewable resource generation rose to about 3 times above the average generation during 2007-2014, which was about 69.3 $GWh/$ year to about 184 GWh, followed by a sharp increase in 2016-2020, as shown in Table 1. This increase reduces the overall peak load from conventional sources by about $77MW/$ day.

Based on the analysis in Table 5, the daily electricity demand in MW is modeled based on

$$\hat{y}(t) = 1748 + 30.65\,X_1 - 251.6\,X_2 - 34.5\,X_3 - 279X_4 + 287X_5 - 52.9\,X_6 - 81X_7 - 77.1\,X_8 + \epsilon \tag{8}$$

where X_1 is the daily differential temperature. X_2-X_4 are (0 or 1) dummy variable based on the day. X_5-X_8 are variable

TABLE 6. MAE, MAPE, and RMSE error indices obtained from backcasting load estimation.

Statistical error metrics	Value
MAE	134.25
MAPE	6.36 %
RMSE	2.76 %

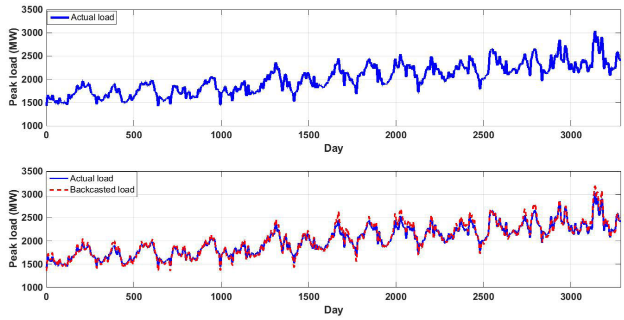

FIGURE 8. Actual vs. backcasted morning peak load in the study period.

based on the reference baseline 3.2% for population, 6% for GDP, $\$70/barrel$ for fuel prices, and 187 $MWh/$ day for solar energy. The analysis for the hourly 4745 data set covering 13 years period reveals reasonable percentage error obtained from the error metrics MAE, MAPE, and RMSE, respectively, as shown in Table 6. The actual versus backcasted results are shown in Figure 8. The trend shows that the backcasted load follows the actual load. The spikes in the peak load are most probably due to ambient temperature, where the peak load in Jordan is very sensitive to hot /cold weather. The impact of temperature rise was reported by many researchers [11], [15], [31].

It is crucial to increase the role of renewable energy technologies where future actions from policymakers should be taken to attain their maximum utilization potential [21]. Installing PVs in the distribution network reduces the losses since it is closer to the loads and saves a large amount of power flow from substations to loads through many branches [32]. Based on the literature that was made on Jordan's energy sector [21], [22], the government should implement several procedures to reduce energy bills and the consequences of high oil prices and high reliance on imported energy, such as: allowing investments to using the massive potential of available energy resources such as uranium and oil shale, exploration of oil and natural gas, as Jordan has significant oil and natural gas potential, a transition from fossil fuels to renewable energy (solar, wind, and biomass) by providing financial incentives and tax exemptions, maximizing the wind energy potential utilization as wind speeds in Jordan range from 7 to 11 m/ s, removing obstacles, facilitating ongoing projects, and achieving stakeholder buy-in in project engagement and finally introduce a new traffic system considering the volatile electricity prices—finally, supporting technical innovation and novel electricity-saving technologies, such as inverter-based AC systems, LED, greenhouse technology, and smart power boards, during peak summer and winter.

IX. CONCLUSION

This paper aims to investigate and model the electricity load development in Jordan during the period of study from 2007 to 2020 based on MLR statistical modeling tool. The study period was characterized by several global events directly impacting Jordan's economy, such as global financial crises and Arab spring anti-government protests in several Arab countries. The main determinants controlling the load profile are the daily differential temperature, the day of the week, annual population, GDP, Brent crude oil price, and technological aspects due to the expansion of renewable energy are used in analysis. Results of MLR show that the peak load of Jordan is very sensitive to the ambient temperature, where the ambient temperature above $20°C$ in summer and below $15°C$ in winter increases the daily demand by about $30MW/1°C$. The increase in population above a baseline increases the demand by $287MW/$ day. The drop in GDP during the study period accompanied a reduction in the demand by about $53MW/$ day. A significant decrease in the load was also observed on Friday, Saturday, and holidays, where during these days, the demand dropped by 251, 34, and $279MW/$ day, respectively. Finally, a decrease in generation from power plants was also observed due to renewable energy penetration, particularly in 2015. The results obtained from backcasting regression analysis for the hourly 4745 data set covering 13 years period reveals reasonable percentage error metrics with MAE, MAPE, and RMSE values of 134, 6.3% and 2.76% respectively. Policies are required to minimize the problems related to the high oil prices that directly impact Jordan's electricity demand and GDP. The switch from fossil fuels to renewable energy, exploration of oil and natural gas, and exploitation of the enormous potential of available energy resources such as oil shale and uranium are required by the government to solve the high energy bills and encourage productivity in Jordan

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REFERENCES

[1] W. Alshoubaki and M. Harris, "The impact of Syrian refugees on Jordan: A framework for analysis," *J. Int. Stud.*, vol. 11, no. 2, pp. 154–179, Jun. 2018, doi: 10.14254/2071-8330.2018/11-2/11.

[2] A. Alshwawra, "Impact of regional conflicts on energy security in Jordan," *Int. J. Energy Econ. Policy*, vol. 10, pp. 45–50, Feb. 2020.

[3] (2021). *Department of Statistics of Jordan*. [Online]. Available: http://dosweb.dos.gov.jo/

[4] A. Hainoun, "Construction of the hourly load curves and detecting the annual peak load of future Syrian electric power demand using bottom-up approach," *Int. J. Electr. Power Energy Syst.*, vol. 31, no. 1, pp. 1–12, Jan. 2009, doi: 10.1016/j.ijepes.2008.09.006.

[5] K.-N.-D. Malamaki, I. Konstantinidis, and C. S. Demoulias, "Analytical evaluation of the annual load duration curve of domestic prosumers," in *Proc. IEEE Manchester PowerTech*, Jun. 2017, doi: 10.1109/PTC.2017.7981183.

[6] H. Cho, Y. Goude, X. Brossat, and Q. Yao, "Modelling and forecasting daily electricity load curves: A hybrid approach," *J. Amer. Stat. Assoc.*, vol. 108, no. 501, pp. 7–21, 2013. [Online]. Available: http://stats.lse.ac.uk/q.yao/qyao.links/paper/edf02.pdf

[7] S. A. H. Soliman and A. M. Al-Kandari, *Electrical Load Forecasting: Modeling and Model Construction*. Amsterdam, The Netherlands: Elsevier, 2010.

[8] L. Alhmoud and Q. Nawafleh, "Short-term load forecasting for Jordan power system based on NARX-ELMAN neural network and ARMA model," *IEEE Can. J. Electr. Comput. Eng.*, vol. 44, no. 3, pp. 356–363, 2021, doi: 10.1109/ICJECE.2021.3076124.

[9] D. Chikobvu and C. Sigauke, "Regression-SARIMA modelling of daily peak electricity demand in South Africa," *J. Energy Southern Afr.*, vol. 23, no. 3, pp. 23–30, Aug. 2012.

[10] A. Eshragh, B. Ganim, T. Perkins, and K. Bandara, "The importance of environmental factors in forecasting Australian power demand," *Environ. Model. Assessment*, vol. 27, no. 1, pp. 1–11, 2022.

[11] S. Harish, N. Singh, and R. Tongia, "Impact of temperature on electricity demand: Evidence from Delhi and Indian states," *Energy Policy*, vol. 140, May 2020, Art. no. 111445.

[12] A. Almuhtady, A. Alshwawra, M. Alfaouri, W. Al-Kouz, and I. Al-Hinti, "Investigation of the trends of electricity demands in Jordan and its susceptibility to the ambient air temperature towards sustainable electricity generation," *Energy Sustainability Soc.*, vol. 9, no. 1, pp. 1–18, 2019, doi: 10.1186/s13705-019-0224-1.

[13] S. K. Al-Bajjali and A. Y. Shamayleh, "Estimating the determinants of electricity consumption in Jordan," *Energy*, vol. 147, pp. 1311–1320, Mar. 2018, doi: 10.1016/j.energy.2018.01.010.

[14] M. G. Fikru and L. Gautier, "The impact of weather variation on energy consumption in residential houses," *Appl. Energy*, vol. 144, pp. 19–30, Apr. 2015.

[15] B. W. Ang, H. Wang, and X. Ma, "Climatic influence on electricity consumption: The case of Singapore and Hong Kong," *Energy*, vol. 127, pp. 534–543, May 2017.

[16] J. Chai, Y. Zhou, T. Liang, L. Xing, and K. K. Lai, "Impact of international oil price on energy conservation and emission reduction in China," *Sustainability*, vol. 8, no. 6, pp. 1–17, 2016.

[17] A. Tahtamouni, F. Al Qaisi, and U. Fendi, "The effect of oil price falling on the Jordanian economic System," *Int. J. Econ. Financial Issues*, vol. 7, no. 5, pp. 282–289, 2017.

[18] S. Sandri, H. Hussein, and N. Alshyab, "Sustainability of the energy sector in Jordan: Challenges and opportunities," *Sustainability*, vol. 12, no. 24, p. 10465, 2020, doi: 10.3390/su122410465.

[19] A. Azzuni, A. Aghahosseini, M. Ram, D. Bogdanov, U. Caldera, and C. Breyer, "Energy security analysis for a 100% renewable energy transition in Jordan by 2050," *Sustainability*, vol. 12, no. 12, p. 4921, 2020.

[20] G. A. Rumman, A. I. Khdair, and S. I. Khdair, "Current status and future investment potential in renewable energy in Jordan: An overview," *Heliyon*, vol. 6, Feb. 2020, Art. no. e03346.

[21] E. S. Hrayshat, "Analysis of the renewable energy situation in Jordan," *Renew. Sustain. Energy Rev.*, vol. 11, no. 8, pp. 1873–1887, 2007.

[22] J. O. Jaber, F. Elkarmi, E. Alasis, A. Kostas, "Employment of renewable energy in Jordan: Current status, SWOT and problem analysis," *Renew. Sustain. Energy Rev.*, vol. 49, pp. 490–499, 2015.

[23] M. Elsagheer, "Energy situation in Jordan," Ministry Planning Int. Cooperation Jordan, Amman, Jordan, IEEJ Rep. 1, 2013. [Online]. Available: https://eneken.ieej.or.jp/data/5020.pdf

[24] Worldometers. (2021). *Jordan Population*. [Online]. Available: https://www.worldometers.info/world-population/jordan-population

[25] UNHCR. (2021). *The UN Refugee Agency Website*. [Online]. Available: https://www.unhcr.org/jo/
[26] *UK Brent Crude Oil Price*. [Online]. Available: https://www.statista.com/statistics/262860/uk-brent-crude-oil-price-changes-since-1976/
[27] R. Goncalves. (Oct. 21, 2011). *Libya's Economy Post-Gaddafi*. Ricardo's Business (Blog). Accessed: Feb. 16, 2012. [Online]. Available: http://www.sbs.com.au/news/blogarticle/125103/RICARDO-S-BUSINESS-Libya-s-economy-post-Gaddafi
[28] A. Torchia and S. Al-Khalidi. (Jan. 17, 2012). *Insight: In Arab Spring, Economic Gain Might Trump Pain*. United States Edition. Accessed: Feb. 16, 2012. [Online]. Available: http://www.reuters.com/article/2012/01/17/us-arabspring-economies-idUSTRE80G0CH20120117
[29] *National Electric Power Company*, NEPCO, Nallur, Tamil Nadu, 2020.
[30] J. R. Steiner, *Energy Security in Jordan*. Monterey, CA, USA: Naval Postgraduate School, 2015.
[31] EcoMENA. (2016) *Solar Energy in Jordan*. [Online]. Available: http://www.ecomena.org/solar-energy-jordan/?goback=.gde-2144331-member-118073788
[32] K. Balamurugan, D. Srinivasan, and T. Reindl, "Impact of distributed generation on power distribution systems," *Energy Proc.*, vol. 25, pp. 93–100, Jan. 2012, doi: 10.1016/j.egypro.2012.07.013.
[33] D. C. Enrica, E. Lanzi, and R. Roson, "The impact of temperature change on energy demand: A dynamic panel analysis," Univ. Ca' Foscari Venice Fondazione Eni Enrico Mattei, Tech. Rep. 46, 2007.
[34] M. A. Momani, "Factors affecting electricity demand in Jordan," *Energy Power Eng.*, vol. 5, no. 1, pp. 50–58, 2013.
[35] *US Embassy in Jordan, Jordan in Numbers*. Accessed: Jul. 15, 2014. [Online]. Available: https://jo.usembassy.gov/wp-content/uploads/sites/34/09-2022-Date
[36] L. Alhmoud, R. A. Khurma, A. M. Al-Zoubi, and I. Aljarah, "A real-time electrical load forecasting in Jordan using an enhanced evolutionary feedforward neural network," *Sensors*, vol. 21, no. 18, p. 6240, Sep. 2021, doi: 10.3390/s21186240.
[37] Wikipedia2. (2021). *F-Distribution*. [Online]. Available: https://en.wikipedia.org/wiki/F-distribution
[38] Investopedia. (2021). *T-Test Fundamental Analysis*. [Online]. Available: https://www.investopedia.com/terms/t/t-test.asp
[39] Simply psychology. (2019). *Statistical P-Value*. [Online]. Available: https://www.simplypsychology.org/p-value.html

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