Okoboi and Mawejje *Energy, Sustainability and Society* (2016) 6:29
DOI 10.1186/s13705-016-0094-8

Energy, Sustainability and Society

ORIGINAL ARTICLE

Open Access

Electricity peak demand in Uganda: insights and foresight

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Abstract

Background: Availability of reliable energy supply plays a critical role in the social, economic, and cultural transformation of society. The Uganda electricity sector has suffered long standing supply side constraints that resulted in suppressed demand and outages. Recent developments, including the completion of the 250 MW Bujagali project in 2012, have resulted in sustained growth in peak demand. However, this growth in peak demand appeared to stagnate by 2013. This study examines the recent trends as well as forecast the medium term path of electricity peak demand in Uganda.

Methods: This study uses descriptive data exploration analysis and polynomial functions augmented by empirical estimations of structural break equations to account for the observed trends in electricity peak demand. The study applies the double exponential forecasting model to forecast total peak electricity demand.

Results: The results show that the recent surge in electricity peak demand is due to increased electricity exports. Moreover, the results show a shift in electricity demand from peak to nonpeak time-of-use, possibly due to changing consumption patterns in the industrial sectors.

Conclusions: The study draws two major conclusions. First, the growth in Uganda's electricity demand in general and peak demand in particular has not stagnated as such but rather partially shifted from peak to nonpeak time-of-use zone. Second, electricity exports have contributed to growth of electricity peak demand. Importantly, higher electricity exports need to be considered in line with the system capacity given the current electricity spinning reserves of Uganda are less than 15 % of Uganda current installed capacity.

Background

Availability of reliable energy supply is critically important for economic growth, poverty reduction, and the social and cultural transformation of society [1–3]. Deficient electricity infrastructure curtails social and economic development [4]. Proper energy planning ensures the sustainable development of energy systems that meet the growing energy demands. Electricity peak load modeling and forecasting is an important aspect of energy sector planning and management [5]. Electricity peak demand refers to the highest amount of electricity that an electrical system must supply to all its customers at any given time, in any one period such as a month [6, 7]. Peak demand occurs when the demand for electricity sharply increases (spikes) in magnitude compared to a normal trend. The spike in demand can be short-lived or last for a longer period.

Demand for electricity generally follows a cycle throughout the day.[1] The cycle is such that total demand is at peak between 19 and 23 h, declines from 24 h reaching the lowest level at 05 h. This load profile reflects strong industrial demand for electricity which accounts for 62 % of electricity consumption in Uganda. The share of electricity demand by the different categories of consumers, including industrial, commercial, and domestic consumers, and export is shown in Fig. 1. This demand at any given point in time of the day closely mirrors the consumption patterns in the various sector categories. For example, an industrial facility that switches on more machines at the start of a production shift, such as in the morning at 8 am, or even an office complex switching on the central air conditioning system in the early morning. In such circumstances,

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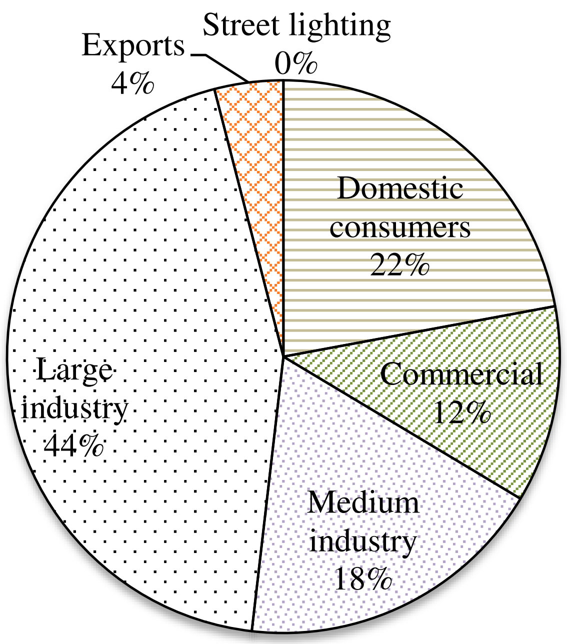


Fig. 1 Distribution of electricity demand in 2015

electricity demand may spike culminating into temporary or sustained peak demand.

Unmet electricity peak demand that outstrips infrastructure generation, transmission, and distribution capacities stresses networks and may result in short-term drop in voltage leading to outages [8]. Unmitigated electricity outages have significant undesirable social and private impacts [9–14].

The Uganda electricity sector has suffered long standing supply side constraints that resulted in suppressed demand and outages [15]. Recent developments, including the completion of the 250 MW Bujagali project in 2012, have resulted in sustained growth in peak electricity demand, culminating into spikes in total peak demand in June 2012 (518 MW) and December 2012 (544 MW) as shown in Fig. 2.

However, growth in peak demand appeared to stagnate by 2013, averaging 493 MW. This apparent stagnation in peak demand concerned stakeholders, including government, especially given the ongoing efforts to increase electricity generation that have primarily focused on exploiting hydropower by expediting the construction of the 183 MW Isimba and 600 MW Karuma Hydro Power Projects whose expected completion dates are 2017 and 2019, respectively.

Despite these concerns, studies on electricity peak demand have attracted little attention. Okoboi and Mawejje [16] have attempted to account for this stagnated peak electricity demand by examining the impact of adoption of power factor correction technology. Other studies have evaluated the possible role of renewable energy—such as solar—as a substitute for grid supplied electricity [17, 18]. Despite these efforts, however, more analysis is required to fully understand the dynamics of electricity peak demand in Uganda. This is even more important considering that the country has prioritized electricity generation as critical for greater economic performance and social transformation [19].

Against this background, this paper examines the recent trends in electricity peak demand in Uganda as well as forecast the medium term path of peak demand. We decompose the trend in electricity peak demand, in particular at transmission level, to try to establish the underlying drivers of the trend. Specifically, this paper considers the following objectives: (1) examine the trend of peak demand; (2) assess the significance of electricity exports in total peak demand; (3) examine the likely shift in domestic electricity consumption from peak to other (shoulder and

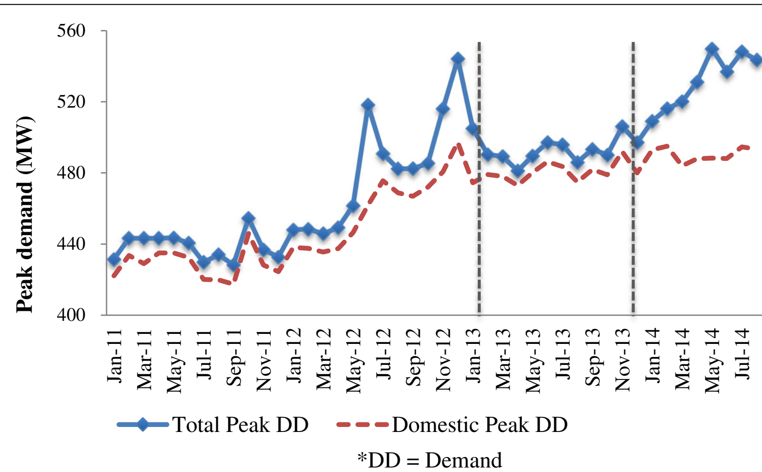


Fig. 2 Trend of Uganda's electricity peak demand, 2011–2014

off-peak) time-of-use (TOU) zones; (4) examine the relationship between industrial production and domestic electricity peak demand; and (5) forecast the medium term path of electricity peak demand in Uganda.

Using descriptive data exploration analysis and polynomial functions augmented by empirical estimations of structural break equations, we show that the recent surge in electricity peak demand is due to increased electricity exports. Moreover, we show a shift in electricity demand from peak to nonpeak time-of-use, possibly due to changing consumption patterns particularly in the industrial sector.

The remainder of this paper is organized as follows: The "Context" section provides the context with regard to the Uganda electricity sector. The "Methods" section introduces the methods used in the analysis. Results are presented and discussed in the "Results and discussion" section. The "Conclusions" section provides the conclusions and recommendations.

Context

Uganda is one of few African countries that fully unbundled the electricity sector, devolved the role of government in the sector, and allowed private sector participation. The reforms in Uganda's electricity sector were motivated by a quest to improve overall sector efficiency [20, 15]. The general idea behind the reforms in the electricity sectors across many countries, including in sub-Saharan Africa, was that private sector participation would enable increased supply of reasonably priced and reliable electricity [21]. Recent detailed discussions of the electricity sector reforms in Uganda can be found in [15] and [22]. The timeline of Uganda's electricity sector reforms is shown in Table 1.

Table 1 Timeline of Uganda's electricity sector reforms

Dates	Reforms
June 1999	Government approves the power sector restructuring and privatization strategy
November 1999	The new electricity Act is passed
April 2000	The Electricity Regulatory Authority becomes operational
March 2001	The Uganda Electricity Board is unbundled and three companies created and registered namely: UEGCL, UETCL, and UEDCL
May 2001	Concessions for generation and distribution are advertised
November 2002	Concession for generation awarded to Eskom Enterprises
February 2003	Appointment of the Rural Electrification Board to oversee the Rural Electrification Trust Fund (RETF)
2005	UMEME awarded concessionaire to operate for 20 years to purchase electricity in bulk from UETCL and distribute it along low voltage electricity lines to individual customers

Source: Karekezi et al ([21])

In general, the performance of Uganda's electricity sector has improved greatly, albeit slowly, since the reform period. With a generation capacity of 867 MW and available capacity of some 600 MW against peak demand for electricity estimated at 550 MW, Uganda now has surplus electricity. Consequently, periods of load shedding have greatly reduced, and new connections and access have accelerated. The completion of the 250 MW Bujagali plant, the 9.5 MW plant at Buseruka, and the 3.5 MW plant at Nyagak coupled with the completion of a number of mini-hydroplants has provided great reprieve to the Uganda electricity industry and for the first time in over three decades Uganda has enough electricity to satisfy peak demand. This has led to the decommissioning of two of the emergency thermal plants. In addition, the 9.5 MW bagasse co-generation project at Lugazi Sugar Cooperation of Uganda Limited (SCOUL) was completed raising total installed capacity from about 540 MW in 2005 to 870 MW by 2015 (Table 2).

To date, the generation capacity eclipses the pre-reform installed capacity—a milestone that only a few African countries have managed [15].

In a bid to save the scarce available resources and instead focus attention on securing future electricity supply, the Government scrapped subsidies to the electricity

Table 2 Installed electricity capacity in MW 2010–2015

Plant name	2010	2011	2012	2013	2014	2015
Hydroelectricity						
Nalubale	180	180	180	180	180	180
Kiira	200	200	200	200	200	200
Kasese Cobalt Company Ltd	9.9	9.9	9.9	9.9	9.9	9.9
Kilembe Mines	5	5	5	5	5	5
Bugoye Tronder	13	13	13	13	13	13
Mpanga	18	18	18	18	18	18
Ishasha	6.5	6.5	6.5	6.5	6.6	6.6
Buseruka	–	–	9	9	9	9
Bujagali	–	–	250	250	250	250
Kisizi	0.3	0.3	0.3	0.3	0.3	0.3
Nyagak	–	–	3.5	3.5	3.5	3.5
Thermal generation						
Jacobsen Namanve	50	50	50	50	50	50
Electromaxx Tororo	20	20	20	20	50	50
Aggreko Kiira	50	50	–	–	–	–
Aggreko Mutundwe	50	50	–	–	–	–
Bagasse co-generation						
Kakira sugar works	12	12	12	12	12	12
Kinyara sugar works	4.5	4.5	4.5	4.5	4.5	4.5
Lugazi SCOUL	–	–	9.5	9.5	9.5	9.5

Source: Electricity Regulatory Authority and Uganda Bureau of Statistics consumers in 2012. Subsequently, generation projects such as Karuma (600 MW), Ayago (600 MW), and Isimba (183 MW) have been earmarked for immediate construction.

Other potential projects expected to start in the medium term include Oriang 380 MW and thermal generation (100 MW) from the oil refinery. However, despite all these positive developments, Uganda's electricity sector is still small. Installed capacity, at 867 MW, is only approximately half of Kenya's 1600 MW and Tanzania 1509.85 MW. Peak demand at 550 MW is only a third of Kenya's 1500 MW and a half of Tanzania's 1000 MW (Fig. 3).

Developments in distribution

The reforms in Uganda's electricity sector necessitated the pursuit of a private sector-led industry. The Uganda electricity distribution network, formerly managed under the Uganda Electricity Board (UEB)—a government parastatal—was concessioned to Umeme Limited in 2005 under a 20-year lease contract. In a bid to speed up rural electrification, a few small distribution companies and cooperatives were granted licenses to distribute electricity in some of the most remote areas of Uganda. Consequently, the distribution network has been expanded with investments made by both the private sector and the Rural Electrification Agency (REA). The list of companies currently distributing electricity in Uganda is provided in Table 3.

Electricity access and consumption

Despite the developments in the electricity industry, Uganda has recorded slow progress in ensuring that majority of rural Ugandan households have access to electricity. Per capita electricity consumption is estimated at 75 kWh and is one of lowest in the world with unequal access rates for rural and urban households [23]. Figure 4 shows the regional comparison of electricity consumption per capita.

At the national level, 14 % of all households have access to electricity. This represents a remarkable improvement from 7.5 % in 1999 when the reforms started. However, while the urban electrification rate is 40 %, the rural electrification rate is much lower: in 2014, a whopping 95.6 % of all rural households did not have access to electricity on the national grid (Fig. 5).

In addition, consumption per connection is not only low but declining with new connections and the commercial and financial performance of rural electricity distribution companies is, therefore, not sustainable (Fig. 6).

In addition to social and cultural barriers, the major constraints to rural electrification are problems with rural isolation, power theft, insufficient supply, and the high costs that have inhibited rural communities from gaining access to electricity. Consequently, Uganda still compares unfavorably with its region neighbors with regard to household access to electricity. Indeed, Uganda's electrification rate of 14 % is lower than that of Kenya which stands at 29 % and Tanzania which is 16 % (Fig. 6).

Reliability of electricity supply

The provision of reliable and affordable electricity is very important for economic growth and business competitiveness. As discussed earlier, Uganda has made some progress towards ensuring the adequate availability of electricity. However, many businesses continue to report the reliability of electricity supply as the top obstacle for doing business in Uganda [24]. Data from the World Bank (2013) enterprise surveys shows that the average

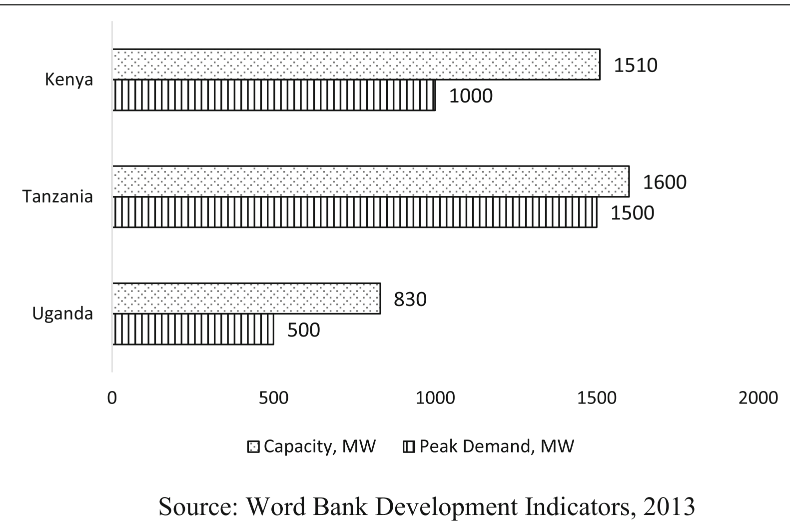


Fig. 3 Regional comparison of peak demand, MW

Table 3 Distribution companies in Uganda

Distribution company	Status
Umeme	Umeme inherited customers that were once served by UEB and was leased the UEDCL assets under a 20-year concessional arrangement and controls 97 % of the distribution market in Uganda.
Ferdsult	Ferdsult operates and maintains a rural electricity distribution network concessionaire under a 10-year agreement with the Rural Eelectrification Agency. Areas of operation include the districts of: Kibaale, Kyenjojo, Rukungiri, Kanungu, Ntugamo, Isingiro, Rakai, and Masaka. Ferduslt pioneered the pre-paid metering system in Uganda and currently serves about 10,000 consumers.
West Nile Electricity Company (WENRECO)	WENRECO operates an off-grid distribution network in the Northwestern districts of Arua, Paidha, Nebbi, Koboko, Maracha, Zombo, and Yumbe. The company operated the 3.5 MW Nyagaka HPP and served about 4000 customers by March 2013.
Bundibugyo Energy Coop. Society (BECS)	BECS runs the distribution concessionaire in Bundibugyo district since 2009. Accordingly, BECS took charge of electricity distribution, grid maintenance, and managing the revenue from power consumers. Currently, BECS serves about 1500 customers.
Pader - Abim Energy Cooperative	Serves about 1500 customers in Pader, Abim, and Agago districts.
Kilembe Investments Limited (KIL)	KIL runs a 10-year concessionaire to distribute and sell electricity in the Districts of Kasese, Rubirizi, and surrounding areas. The license runs for 10 years and is renewable. Currently KIL serves about 2000 customers on the pre-payment system. KIL intends to introduce solar energy for users in isolated areas.
Kygegwa Rural Electricity Cooperative Society	

Source: Electricity Regulatory Authority and Mawejje et al. [15]

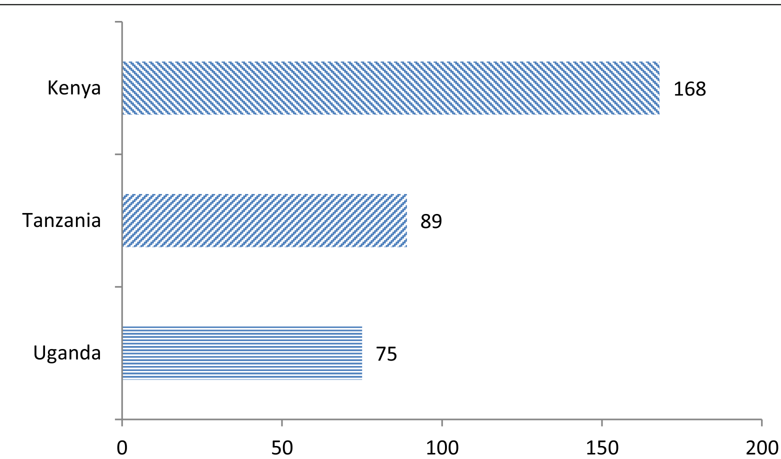
duration of a typical electricity outage is longer (6.8 h) than the sub-Saharan Africa average (4.6 h) and associated losses are larger (Table 4). Consequently, many businesses have invested in backup generators with deleterious consequences for investments in productive capital and scale economies [11].

In line with industry best practices, the Electricity Regulatory Authority (ERA) has promoted new initiatives such as prepaid metering and aerial bundle conductors (ABC) to enhance energy use efficiency and reduce peak demand at low voltage level. In addition, the Government has partnered with the distribution companies to distribute free energy saving bulbs to electricity consumers as a demand side management (DSM) option to shave-off peak demand.

With regard to sector regulation, ERA has continued to pursue incentive-based regulation as an effective DSM option to mitigate the forecasted growth in peak demand until the planned small renewable energy resources under the GETFIT Project are expected to be commissioned between 2017 and 2018 start supply power to the grid.

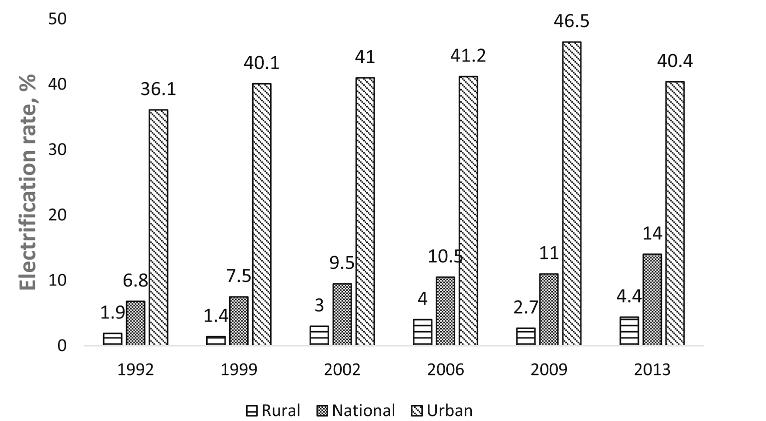
Tariff determination

Electricity tariff determination in Uganda follows the automatic adjustment mechanism introduced by the sector regulator in 2012. The inputs into the tariff computation include exchange movements (Uganda shilling against the US dollar), the fluctuations in oil prices on the international market as well as local inflation levels. In addition,



Source: Word Bank Development Indicators, 2013

Fig. 4 Regional comparison of electricity consumption per capita, kWh



Source: Uganda Bureau of Statistics, Uganda National Household Survey Datasets

Fig. 5 Trends in electrification levels, %. Source: Uganda Bureau of Statistics, Uganda National Household Survey Datasets

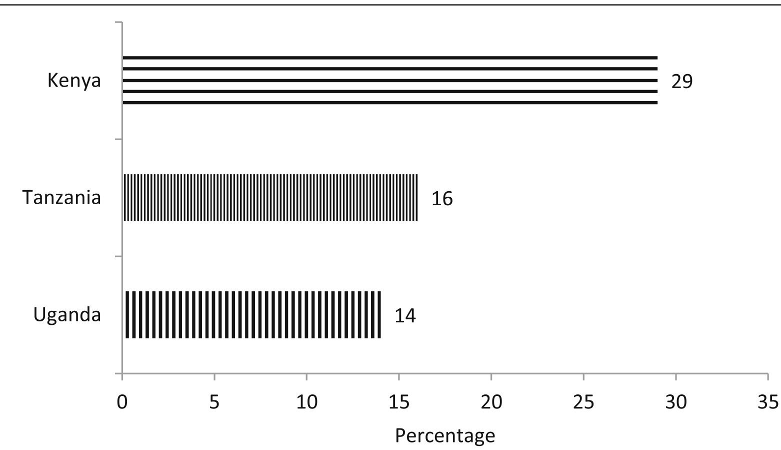
the end-user tariffs are differentiated by time of use for some consumer categories. Time-of-use metering is available for the following categories: large industrial consumers, medium industrial consumers, and commercial consumers. The different load patterns and corresponding time are shown in Table 5. Essentially, time-of-use metering is meant to improve efficiency in electricity consumption by offering lower tariffs during off-peak and shoulder times. This is intended to incentivize increased consumption at nonpeak times. For example, the currently peak tariff is 20 % above shoulder tariff and off-peak is 20 % less shoulder tariff.

Methods

The data

The data used in this study is from three sources, namely: Uganda Electricity Transmission Company Limited (UETCL), Umeme Limited, and Uganda Bureau of Statistics (UBOS). System data on power and energy purchases from electricity generation companies, sales to distribution companies, and imports and exports from and to Kenya, Tanzania, Rwanda, and Democratic Republic of Congo was obtained from UETCL. Distribution data on energy sales to different customer categories (Domestic, Commercial, Medium and Large Industries, and Street Lighting) at different time-of-use (TOU) periods was obtained from Umeme Limited. The proxy for industrial production—the Index of Industrial Production (IOP)—was obtained from UBOS. The data from UETCL and Umeme are monthly and span the period January 2011 to August 2014. The data from UBOS are quarterly and span the period 2011Q1 to 2014Q1.

The descriptive statistics of the variables used in the analysis are presented in Table 6. All analyses except for



Source: Word Bank Development Indicators, 2013

Fig. 6 Regional comparison of access to electricity, %. Source: Word Bank Development Indicators, 2013

Table 4 Extent of electricity challenges in Uganda

Indicator	Uganda	Sub-Saharan Africa	All countries
Number of electrical outages in a typical month	6.3	8.3	6.3
Duration of a typical electrical outage (hours)	6.8	4.6	2.6
Losses due to electrical outages (% of annual sales)	6.3	4.4	2.6
Average losses due to electrical outages (% of annual sales)	11.2	7.3	4.7
Percentage of firms owning or sharing a generator	52.2	48.0	34
Proportion of electricity from generator, %	8.4	14.2	8.1
Days to obtain an electrical connection (upon application)	18.1	29.0	30.9
Percentage of firms identifying electricity as a major obstacle	26.8	43.6	34.0

Source: World Bank Enterprise Survey Data

objective 4 are based on 45 monthly data points (January 2011 to August 2014) observations. The analysis for objective 4 is based on 13 quarterly (Q1 2011 to Q1 2014) data observations.

The descriptive statistics indicate that between January 2011 and August 2014, the registered system electricity peak demand has ranged between 428 and 550 MW with average peak demand of 482 MW. The energy losses average 3.6 % of total purchases at transmission system level while at distribution level (Umeme Limited), energy losses average 26 % of purchases from the system operator.

To improve the efficiency of the results from the analysis, the data were transformed into natural logarithms and the econometric analysis involved robust and bootstrapped standard errors where applicable.

Estimation methods

The study adopted a number of estimation methods for the analysis as detailed below:

a) Trend and descriptive statistical analyses were used to examine the trends of peak demand;
b) Bootstrapped linear regression models were used to assess the significance of electricity exports in total peak demand. Bootstrapped methods were adopted because they basically replicate the observations to the desired level and improve the efficiency of the estimates especially where the sample is relatively small [25].

With regard to bootstrapped linear regression modeling, Eqs. (1) and (2) below were estimated.

Table 5 Time-of-use patterns

Load pattern	Time (h)
Peak	18.00–24.00
Shoulder	06.00–18.00
Off-peak	24.00–06.00

$$tp_i = \beta_0 + \beta_1 \mathrm{ex}_i + \beta_2 \mathrm{umeme}_i + \beta_3 \mathrm{other}_i + \beta_4 \mathrm{loss}_i + \varepsilon_i \quad (1)$$

$$tp_i = \beta_0 + \beta_1 \mathrm{ex}_i + \beta_2 \mathrm{upk}_i + \beta_3 \mathrm{uop}_i + \beta_4 \mathrm{ush}_i + \beta_5 \mathrm{other}_i + \beta_6 \mathrm{loss}_i + \varepsilon_i \quad (2)$$

Whereby

tp = total peak demand, measured in megawatt (MW);

ex = total electricity exports demand, measured in gigawatt hours (GWh);

umeme = UETCL energy sales (GWh) to Umeme that distributes up to 96 % of electricity generated in Uganda;

other = UETCL energy (GWh) sales to other electricity distribution companies in Uganda that include Uganda Electricity Distribution Company Limited (UEDCL), Ferdsult Engineering Services Limited (FESL), Kilembe Investment Limited (KIL), Bundibugyo Electricity Cooperative Society (BECS), Pader-Abim Community Multipurpose Coperative Society (PACMECS), and Kyegegwa Rural Electricity Cooperative Society (KRECS);

loss = energy losses (as a percentage total energy sales by UETCL—the system operator) experienced at transmission level;

upk = UETCL energy sales to Umeme at peak (18:00–23:00 h) TOU zone;

opk = UETCL energy sales to Umeme at off-peak (23:00–05:00 h) TOU zone;

ush = UETCL energy sales to Umeme at shoulder (05:00–18:00 h) TOU zone;

ε = error term representing any other factors not included in the equation but may have an impact of peak demand; and

β = parameters to be estimated while $i = 1, 2,\ldots, n$ is the number of observations from first to the last (n).

UETCL energy sales to Umeme are disaggregated into peak, off-peak, and shoulder TOU zone sales in Eq. (2). The disaggregated data was included to examine the differentiated effects of individual TOU sales—particularly peak sales—on total peak demand.

Table 6 Descriptive statistics of the variables

Variable	Unit of measure	Obs	Mean	Std. dev.	Min	Max
Total peak demand	MW	44	482.00	36.82	428.35	549.63
Domestic peak demand	MW	44	462.45	26.30	417.37	497.20
Total energy purchases	GWh	44	241.93	21.50	198.93	283.58
Total generation	GWh	44	238.78	21.76	194.94	282.05
Total imports	GWh	44	3.15	1.02	1.53	5.99
System peak demand	GWh	44	65.18	6.81	45.99	73.55
Shoulder demand	GWh	44	113.48	8.23	93.27	128.04
Off-peak demand	GWh	44	47.14	3.61	36.52	53.44
System nonpeak demand	GWh	44	160.62	11.64	129.79	181.48
Umeme purchases	GWh	44	221.43	18.98	175.78	252.53
Other distributor purchases	GWh	44	2.05	0.52	1.13	2.91
Total purchases by distributors	GWh	44	223.48	19.39	177.31	254.97
Total exports	GWh	44	9.78	3.99	6.38	24.92
UETCL total sales	GWh	44	233.26	21.89	184.66	273.54
System energy loss	%	44	3.62	1.15	0.16	7.17
Umeme offpeak sales	GWh	40	25.61	2.50	20.33	30.80
Umeme shoulder sales	GWh	40	64.89	6.09	50.28	76.63
Umeme peak sales	GWh	40	28.59	3.08	22.86	33.44
Umeme domestic sales	GWh	40	42.79	4.90	32.68	51.70
Umeme total sales	GWh	40	161.88	15.94	126.16	188.50
Umeme energy losses	%	40	26.47	5.28	15.51	39.98
Index of industrial production	%	13	195.00	10.82	174.75	218.42
Average domestic system peak	MW	13	460.95	25.98	419.08	490.67
Maximum domestic system peak	MW	13	465.58	27.84	420.05	497.20

c) Fractional polynomial functions were estimated to determine the likely shift in domestic electricity consumption from peak to other (shoulder and off-peak) time-of-use (TOU) zones. The advantage with fractional polynomial functions is that they use the full information and search for the optimal functional form within a flexible class of functions [26].

To confirm the robustness of the graphical results from the first method, structural break models stated in Eq. (3) were estimated.

$$\mathrm{pk}_i = \alpha_0 + \alpha_1 \mathrm{np}_i + \alpha_2 d_i + \alpha_3 (\mathrm{np}_i * d_i) + \varepsilon_i \tag{3a}$$

$$\mathrm{pk}_i = \gamma_0 + \gamma_1 \mathrm{np}_i + z_i \text{ ; for the period January 2011 to December 2012} \tag{3b}$$

$$\mathrm{pk}_i = \delta_0 + \delta_1 \mathrm{np}_i + w_i \text{ ; for the period January 2013 to August 2014} \tag{3c}$$

Whereby

pk = system peak demand, measured in gigawatt hours (GWh);

np = system nonpeak (shoulder and off-peak) demand (GWh);

d = the dummy variable; $d = 1$ if time period is January 2011 to December 2012, and $d = 0$ if time period is January 2013 to December 2014.

np*d = interaction term between the explanatory variable (np) and the dummy variable (d);

ε, z, and w = errors terms for the respective equation specifications above; and

α, γ and δ = parameters to be estimated while $i = 1, 2, \ldots, n$ is number of observation from first to the last (n).

When the coefficients of dummy variable (α_2) and interaction term (α_3) in Eq. (3a) are statistically significant, it implies that the magnitude of the peak-nonpeak slope (change in peak demand arising from a unit change nonpeak demand) for the period January 2011 to December 2012 and the January 2013 to August 2014 period is different. The actual magnitudes of the slopes are reflected in the coefficients γ_1 and δ_1 of Eqs. (3b) and (3c), respectively. To verify that the slopes of Eqs. (3b) and (3c) are different and hence there may be a shift in peak demand, the Hausman F test of equality of coefficient of two regression models [27] has been estimated.

d) GLM and fractional polynomials were used to estimate the relationship between industrial production and domestic electricity peak demand. With respect to the GLM, the estimated model is stated in Eq. 4.

$$\mathrm{dpk}_i = \mu_0 + \mu_1 \mathrm{iop}_i + \varepsilon_i \tag{4}$$

Whereby

dpk = domestic average or maximum peak demand, measured in GWh;

iop = index of industrial production, which measures (as percentage) performance of the industrial sector in current quarter compared to previous quarter given the base period.

μ = parameters to be estimated while $i = 1, 2, \ldots, n$ is number of observations from first to the last (n).

ε = error term representing any other factors not included in the equation but may have an impact of peak demand; and

under the graphical fractional polynomials method, a scatter and predicted trend of average and maximum domestic peak demand against index of industrial production (IOP) are plotted using quarterly data transformed into natural logarithms.

e) The double exponential smoothing methods were applied to the predicted values of total peak demand derived from the estimated Eq. (1) to predict the medium term path of electricity peak demand.

Following the Holt-Winters formulation, in this paper, the double exponential forecasting model used to forecast total peak demand is stated as in Eqs. (5a)–(5c).

$$C_t = \alpha y_t + (1-\alpha)(C_{t-1} + T_{t-1}) \tag{5a}$$

$$T_t = \beta(C_t - C_{t-1}) + (1-\beta)T_{t-1} \tag{5b}$$

$$F_{t+1} = C_t + T_t \tag{5c}$$

Whereby

y_t = actual total peak in time t;

α = constant-process smoothing constant;

β = trend-smoothing constant;

C_t = smoothed constant-process value for period t;

T_t = smoothed trend of total peak demand for period t;

F_t = forecast total peak demand for period $t + 1$;

t = current time period; and

$t - 1$ = previous time period.

Results and discussion

Trends in electricity peak demand

Following the relatively stable electricity peak demand in 2013, many stakeholders in Uganda's ESI expected the trend of peak demand to remain stable or even decline in 2014. These expectations were based on a 2014 review of end-user TOU tariff weighting factors that were increased from 10 to 15 % during peak TOU zone and downwards from −10 to −15 % during off-peak TOU zone compared to shoulder TOU zone.

Results from the 9-month trend of the peak demand in 2014 show that peak demand has consistently increased in 2014 compared to 2013 as indicated in Fig. 1. In May 2014, peak demand reached 550 MW thereby surpassing the highest record of 544 MW attained in December 2012. A comparison of the total peak demand to domestic demand suggests that the recent upsurge of total peak demand may be associated with increased exports of energy by UETCL given that 2014 domestic peak demand remained fairly and comparable to that of 2013.

Effect of electricity exports on total peak demand

In a bid to understand the drivers of peak demand, some stakeholders have pointed at the possibility of Uganda's power exports to Kenya, Tanzania, Rwanda, and Democratic Republic Congo as being a key driver given that most of the exports are at peak TOU zone. That is, the time at which UETCL dispatches most of energy exports is largely in the evening, between 18 to 23 h, which coincides with Uganda's peak TOU zone (Fig. 7).

As stated in the background, one of our objectives of this study was to examine the magnitude and impact of energy exports on the peak demand. The results of this analysis are contained in Table 6.

Table 6 presents the bootstrapped regression of total peak demand against UETCL disaggregated energy sales to domestic and export markets. In the first regression, domestic sales are disaggregated into sales to Umeme Limited, that is, the major distributor with about 96 % share of the domestic markets; other distributors; and UETCL technical losses. In the second regression, energy sales to Umeme are further disaggregated by TOU—that is, peak, shoulder, and off-peak sales.

Starting with the robustness of the results, Wald chi^2 results in Table 7 for both regressions 1 and regression 2 are robust and the models explain up to 78 % (adjusted R^2) of relationships between the total peak demand and the explanatory variables.

Increase in energy exports, sales to Umeme and sales to other distributors by UETCL, has a statistically

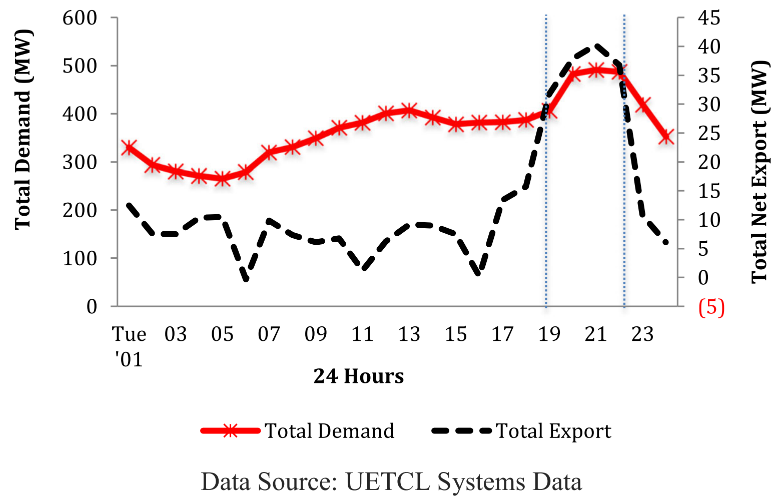


Fig. 7 Load profile of total demand and total net export demand on 1st July 2014. Data source: UETCL systems data

significant ($p < 0.01$) impact on peak demand. In addition, an increase in total net exports by 10 GWh has 0.8 % impact on peak demand whereas 10 GWh increase in energy sales to Umeme leads up to 3.5 % increase in peak demand and 10 GWh increase in energy sales to other electricity distributors leads up to 0.9 % increase in peak demand.

To understand the most likely underlying relationship between peak demand and energy exports and sales to Umeme, two polynomial graphs of the estimated relationships are presented in Fig. 8. The polynomial in Fig. 8a (peak demand–export sales) is convex upwards (or concave downwards) given the dotted line that connects the two ends of graph is below the graph while the polynomial in Fig. 8b (peak demand–Umeme sales) is convex downwards (or concave upwards) given the dotted line that connects the two ends of graph is above the graph. The implication of convex upward graphs in Fig. 8a is that more export sales will be required for a unit increase in peak demand compared to the concave upward graph (sales to Umeme) in Fig. 8b. This therefore validates reliability of the results in Table 6.

Table 7 Bootstrapped regression results

Dependent variable = total peak demand				
	Regression 1		Regression 2	
Variables	Coefficient	*z* value	Coefficient	*z* value
Exports (log)	0.08***	4.15	0.08***	4.00
Sales to Umeme (log)	0.35***	3.66		
Peak Sales Umeme (log)			0.13	0.95
Off-Peak Sales Umeme (log)			0.28	1.14
Shoulder Sales Umeme (log)			0.03	0.15
Sales to other dist. (log)	0.09***	3.26	0.08***	2.99
TX energy loss (log)	0.02	1.01	0.02	1.33
Constant	4.03***	8.03	4.13***	7.54
Obs.	44		44	
Replications	105		105	
Wald chi^2	249.13***		330.72***	
R-squared	0.82		0.86	
Adj. *R*-squared	0.80		0.84	
Root MSE	0.03		0.03	

Notes: 1) z values based on bootstrapped standard errors; 2) significance levels: *** = significant at the 1% level, ** = significant at the 5% level, *= significant at the 10% level

In the second regression in Table 6, the results indicate that when UETCL energy sales to Umeme are disaggregated into peak, shoulder, and off-peak sales, there is a positive relationship with peak demand but the relationships are not statistically significant. In the same regression, the coefficients of UETCL energy exports and sales to other distributors have the same magnitude, impact, and statistical significance on peak demand as that in regression 1.

Relationships between electricity peak to nonpeak demand

In an effort to understand the likely causes of the relatively stable peak demand in 2013—which was expected to continue in 2014, some stakeholders in the ESI pointed to the possible shift in energy consumption from peak TOU zone to other (shoulder and off-peak) TOU zones. When there is a shift in energy consumption from peak to nonpeak TOU zones, this implies that on the one hand there would be a decrease in the growth of energy sales at peak TOU and on the other hand an increase in growth of energy sales at nonpeak TOU zone. This change in pattern of peak vis-à-vis nonpeak demand can be observed either at transmission and/or distribution level.

At the transmission level, a change in the pattern of energy sales can be analyzed using the estimated

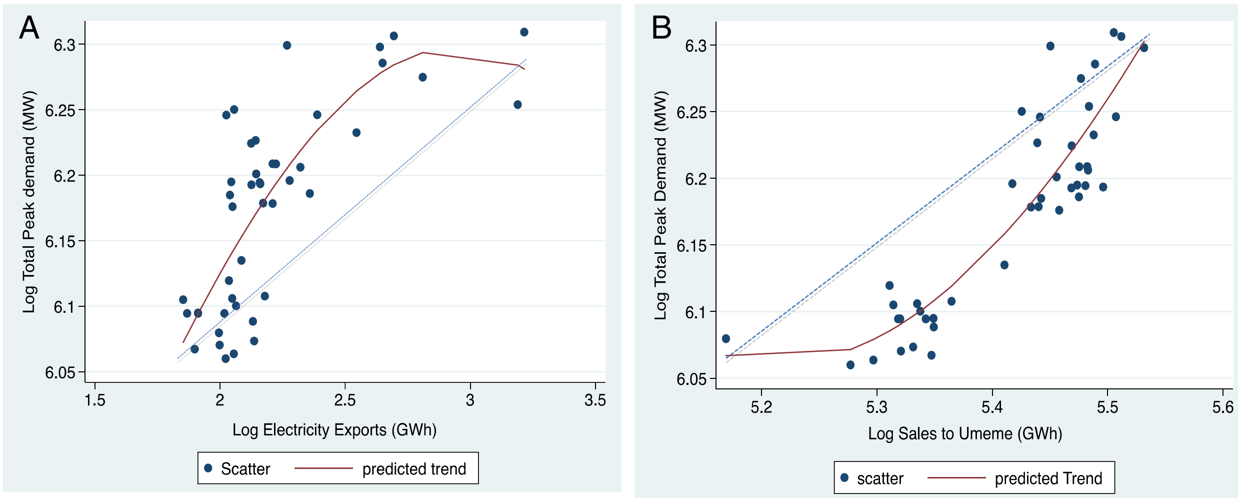


Fig. 8 Polynomials of electricity total peak demand and exports and Umeme sales. **a** Polynomial graph of electricity total peak demand and export sales. **b** Polynomial graph of electricity total peak demand and Umeme sales

fractional graphs for both peak and nonpeak demand (Fig. 9). An alternative method involves examining the change in peak and nonpeak demand patterns by comparing the coefficients from estimated equations relating peak to nonpeak demand before and after the year 2013.

In order to make the robust comparisons, in Fig. 8, actual peak demand data has been multiplied by a scale of 2. The depiction of the graphs in Fig. 8 suggests that in 2011, peak demand declined faster and likewise increased faster in 2012 and for nonpeak demand on the other hand in 2011, declined mildly and as well increased mildly in 2012, leading to some sort of catch-up by peak demand. In the case of peak demand growth in 2013 and 2014, the graph indicates that it was generally linear, positive, and low. On the other hand, growth in nonpeak demand is also linear, positive, and low in 2013 but somewhat doubled in 2014.

Arising from the foregoing explanation of the graphical depiction of the relationship between peak and nonpeak demand before and after January 2013, one can conclude that in 2013 and 2014, there is some observed slight shift in energy demand from peak to nonpeak TOU. To establish reliability of this conclusion, we test if there is a statistically significant difference in the slopes of the curves in Fig. 8 by

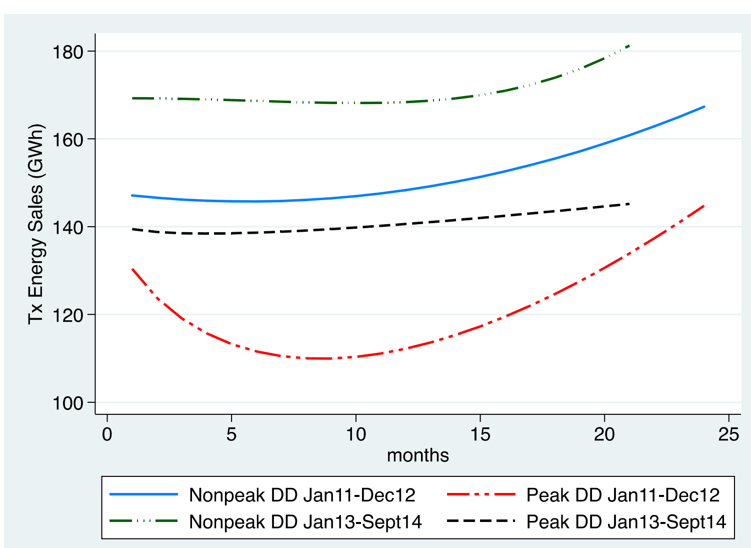


Fig. 9 Fractional polynomials of electricity peak to nonpeak demand

performing an ordinary least square (OLS) estimate the relationship between peak and nonpeak demand including the dummy variable and an interaction term between dummy and explanatory variable to control for the situation before and after January 2013. This regression is presented in Table 8.

Results in Table 8 indicate a strong relationship (adjusted R square = 87 %) between peak and nonpeak demand. The dummy and interaction terms are statistically significant ($p < 0.01$), thereby suggesting that there is a statistically significant difference in the magnitude of the coefficients of the individual regression results that are shown in the lower panel of Table 8.

The coefficient for the first regression is 1.3 while that for the second regression is 0.51. This implies that in the period January 2011 to December 2012, a unit (1 GWh) increase in nonpeak demand was matched by 1.3 GWh increase in peak demand. On the other hand, in the period January 2013 to August 2014, a unit (1 GWh) increase in nonpeak demand was matched only 0.51 GWh increase in peak demand. This therefore suggests that there might be a decline in peak demand in the later period—which demand has shifted to nonpeak TOU zones, given the fact total energy demand has consistently increased in the reference period.

Table 8 Structural break regression of relationship between system peak and nonpeak demand

Dependent variable = peak energy sales			
	Coef.	Std. err.	*T*
Nonpeak energy sales (NP)	1.30***	0.12	10.72
Dummy (*D*)	130.11***	44.74	2.91
Interaction (NP*D*)	−0.79***	0.27	−2.95
Constant	−75.66***	18.38	−4.12
Obs.	44		
F(3, 41)	103.59***		
R-squared	0.88		
Adj. *R*-squared	0.87		
Individual results			
M1_Before Jan 2013 (Jan 2011–Dec 2012)			
	Coef.	Robust std. err.	Z
Nonpeak energy sales (NP)	1.30***	0.10	12.88
Constant	−75.66***	16.01	-4.73
M1_log variance			
Constant	3.65***	0.22	16.88
M2_After Jan 2013 (Jan 2013–Sept 2014)			
Nonpeak energy sales (NP)	0.51***	0.08	6.11
Constant	54.44***	14.06	3.87
M2_log variance			
Constant	1.60***	0.20	7.84

Significance levels: *** = significant at the 1% level, ** = significant at the 5% level, *= significant at the 10% level

To conclude that the coefficients 1.30 and 0.51 from the first (M1) and second (M2) regressions, respectively, are statistically different and hence a shift in peak demand to nonpeak TOU zone in 2013 and 2014, an F-test was performed, with the null hypothesis that coefficients of the dummy variable (D) and the interaction term (NP*D) were jointly zero. That is $D = 0$ and (NP*D) = 0. The results of the test are shown in Table 4, and the statistic is statistically significant at less than 5 % level (Table 9).

The slight shift in electricity consumption from peak to nonpeak TOU zone may be due to the incentive-based regulatory regime offered by the Electricity Regulatory Authority (ERA) to industrial consumers. The incentive regime involves lower tariffs at off-peak TOU and high tariffs at peak TOU. The other incentives and disincentives to industrial consumers of electricity involve Reactive Energy Reward to industrial consumers with efficient energy using equipment and Reactive Energy Charge to industrialists with inefficient power using equipment. The incentives and disincentive above are besides the maximum demand charges[2] that ERA has set for industrialists.

Relationship between industrial production and domestic peak demand

In Uganda, the industrial sector is the largest consumer of electricity, accounting for up to 65 % of total electricity sales (Fig. 1). Accordingly, output growth in the industrial sector has the largest effect on electricity consumption in Uganda [28]. In line with this proposition, a regression of the relationship between the index of industrial production (IOP) and domestic peak demand is presented in Fig. 8 and Table 10.

The polynomial functions in Fig. 10 suggest that there is a somewhat one-to-one relationship between change in IOP and domestic electricity peak demand, much as the deviation of the observations from their mean—as indicated by the scatter seems to be high.

The GLM estimates in Table 10 indicate that the IOP correlates fairly well with average domestic peak demand than with maximum domestic peak demand.

Table 9 *F* test results that $D = 0$ and (NP*D) = 0

F(2, 41)	4.56**
Prob > *F*	0.016

Significance levels: *** = significant at the 1% level, ** = significant at the 5% level, *= significant at the 10% level

Table 10 GLM estimates of the relationship between IOP and domestic peak demand

	Dependent variable	
Parameters	Av. peak (log)	Max. peak (log)
IOP (log)	0.66***	0.58**
Bootstrap std. err.	0.17	0.26
T	3.82	2.21
Number of obs.	13	13
Replications	105	105
Wald chi^2 (1)	14.62***	4.89**
Prob > chi^2	0.00	0.03
R-squared	0.42	0.28
Adj. *R*-squared	0.36	0.22

Significance levels: *** = significant at the 1% level, ** = significant at the 5% level, *= significant at the 10% level

In terms of impact, the results indicate that a 10 % increase in the index of industrial production is associated with 6.6 % increase in average domestic peak demand and 5.8 % maximum domestic peak demand spikes in the country. The results are statistically significant at less than 5 % level. Based on this statistical relationship, we can conclude that industrial production is an important driver of peak electricity demand.

Medium term forecast of total peak demand in Uganda

We forecast Uganda's medium term electricity demand based on predicted values from Eq. 1. The forecast of total peak demand based on predicted peak demand was performed using the double exponential smoothing regime given that the predicted values followed a similar trend (Fig. 11).

The forecast considered three scenarios of Uganda's medium term peak demand as follows: normal growth, accelerated growth that is 5 % above the forecasted normal growth, and suboptimal growth that is 2 % below the forecasted normal growth (Fig. 9). The forecasted normal growth in total electricity peak demand is based on the historical data while the forecasted accelerated growth scenario is based on Uganda Investment Authority (UIA) projections[3] of growth in industries by both local and/or foreign investors in agriculture, construction, and mining especially as the country gears into the development stage of the oil and gas industry.

In the medium term, suboptimal growth in electricity peak demand may materialize if there are significant regional geopolitical risks that may curtail export demand for industrial products. In addition, the completion of energy projects in Uganda's neighboring countries, such as Kenya's Olkaria-Lessos-Kisumu Transmission Lines, may lead a decline in the recent upsurge in Uganda's electricity exports to Kenya (Figure 12 in Appendix). This may to lead to a reduction in electricity peak demand given the previously observed close relationship between electricity exports and peak demand.

Results in Fig. 10 indicate that under the normal growth scenario, electricity peak demand is forecast to rise to 900 MW by January 2021. Under the accelerated growth scenario, our model predicts peak demand to reach an average of 950 MW by January 2021. Finally, under the suboptimal growth scenario,

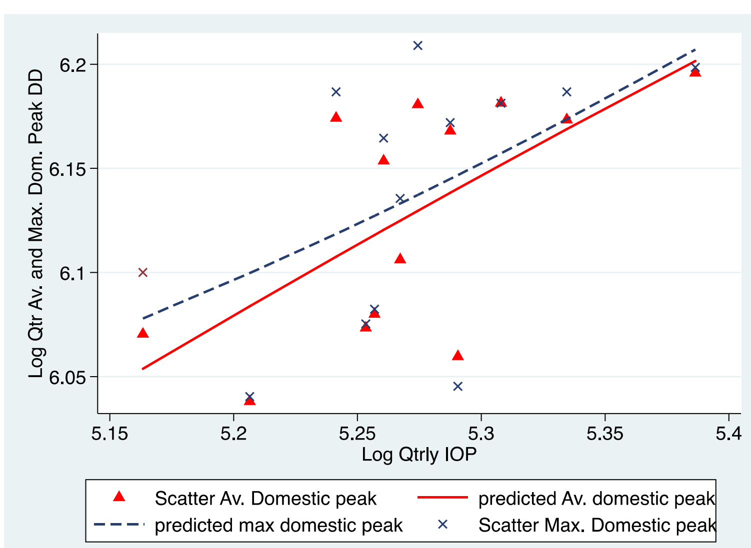


Fig. 10 Relationship between IOP and domestic peak demand

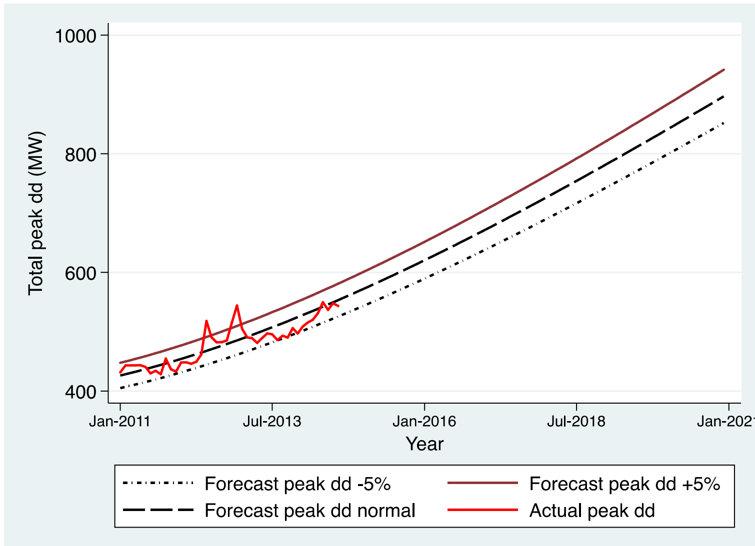


Fig. 11 Six-year forecast of Uganda's peak demand

the model predicts January 2021 peak demand to be 850 MW.

Conclusions

This paper set out to provide insights and forecast in Uganda's electricity peak demand. Specifically, the paper set out to examine the impact of Uganda's energy exports on electricity system peak demand, the impact of industrial production on domestic electricity peak demand, and the likelihood of a shift in electricity peak demand from peak to nonpeak TOU. Furthermore, the paper set to forecast the medium term path of electricity system peak demand up to January 2021.

The study used a combination of descriptive and empirical estimations of structural models. Results indicate that the recent upsurge in Uganda's electricity exports, particularly to Kenya, has had a significant bearing on system peak demand. The results also confirm that there is a positive and significant relationship between the industrial production index and domestic peak demand—given that industrial electricity demand is a derived demand—based on economic activity. In the case of a likely shift in peak demand, the results indicate a slight shift in electricity consumption in 2013–2014 from peak to nonpeak time-of-use zone. Finally, results from the forecast model predict that by January 2021, system peak demand will be in a range of 950 MW (accelerated growth scenario) and 850 MW (suboptimal growth scenario).

These results provide a number of conclusions and implications for policy. First, the growth in Uganda's electricity demand in general and peak demand in particular has not stagnated as such but rather partially shifted from peak to nonpeak time-of-use zone. Second, whereas electricity exports bring additional revenues to the electricity transmission system operator, higher exports need to be considered in line with the system capacity given the current electricity spinning reserves of Uganda are less than 15 % of Uganda current installed capacity of about 870 MW. Increased energy security and sufficiency in the export market is likely to reduce power imports from Uganda. Third, the apparent shift in electricity consumption from peak to nonpeak TOU zone, particularly in the industrial sector, is a step in the right direct direction in so far as it reduces the peak load that is likely to be unsustainable in the near future given the country's spinning reserves.

Endnotes

[1]The load profile for a typical day is shown in Fig. 7.

[2]For additional information on ERA incentive-based tariffs, visit http://www.era.or.ug/index.php/component/content/article/94-general/176-umeme-ltd-tariffs.

[3]For additional information investment projects coming into Uganda, see for example UIA 2013/14 Investment Abstract at: http://www.ugandainvest.go.ug/wp-content/uploads/2016/02/investment_abstract_2013_14_revised_Nove_2014.pdf .

Appendix

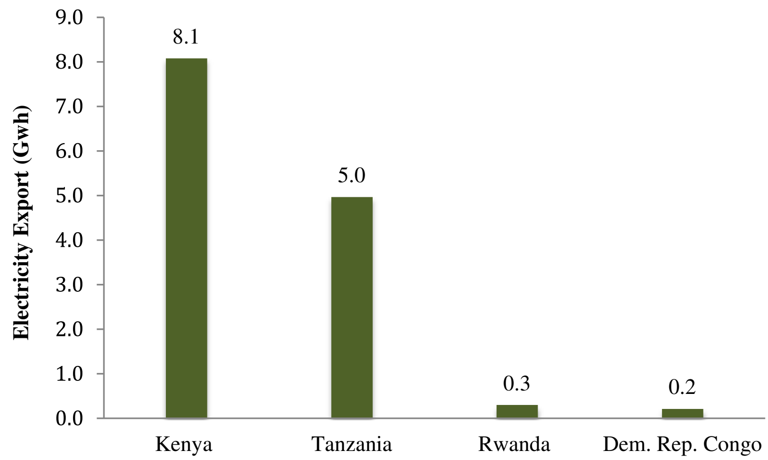


Fig. 12 Uganda's electricity exports to other countries in August 2014

Acknowledgements

This study benefited from insightful discussions and comments from colleagues at the Electricity Regulatory Authority and the Economic Policy Research Centre. We are grateful to two anonymous referees for useful comments.

Authors' contributions

GO conceptualized the study and contributed towards the data analysis. JM contributed towards the drafting of the manuscript and refining the paper. All authors read and approved the final manuscript.

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GO is the Director of Economic Regulation at the Electricity Regulatory Authority. JM is a Research Analyst at the Economic Policy Research Centre with research interests in development, macroeconomics, and natural resources.

Competing interests

The authors declare that they have no competing interests.

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Received: 6 February 2016 Accepted: 19 September 2016
Published online: 10 October 2016

References

1. Oyedepo SO (2012) Energy and sustainable development in Nigeria: the way forward, *Energy*. Sustainability and Society 2(1):1–17
2. Payne JE (2010) A survey of the electricity consumption-growth literature. Applied energy 87(3):723–731
3. Rögnvaldur H (2009) Energy and GDP growth. International Journal of Energy Sector Management 3(2):157–170
4. Calderon C (2008) Infrastructure and growth in Africa. Africa Infrastructure Country Diagnostic, Working Paper 3, World Bank, Washington, DC
5. Alfares HK, Nazeeruddin M (2002) Electric load forecasting: literature survey and classification of methods. International Journal of Systems Science 33(1):23–34
6. Stern F (2013) Peak demand and time-differentiated energy savings cross-cutting protocols, subcontract report no. NREL/SR-7A30-53827, in "The Uniform Methods Project: Methods for Determining Energy Efficiency Savings for Specific Measures". National Renewable Laboratory. http://energy.gov/sites/prod/files/2013/11/f5/53827-10.pdf. Accessed 15 Nov 2014.
7. Gross G, Galiana FD (1987) Short-term load forecasting. Proceedings of the IEEE 75(12):1558–1573
8. Chao H (1983) Peak load pricing and capacity planning with demand and supply uncertainty. The Bell Journal of Economics 14(1):179–190
9. Anderson R, Taylor L (1986) The social cost of unsupplied electricity: a critical review. Energy Economics 8(3):139–146
10. Lee KS, Anas A, Oh GT (1999) Costs of infrastructure deficiencies for manufacturing in Nigerian, Indonesian and Thai cities. Urban Studies 36(12):2135–2149
11. Reinikka R, Svensson J (2002) Coping with poor public capital. Journal of development economics 69(1):51–69
12. Kateregga E (2009) The welfare costs of electricity outages: a contingent valuation analysis of households in the suburbs of Kampala, Jinja and Entebbe. Journal of Development and Agricultural Economics 1(1):1–11
13. Allcott H, Collard-Wexler A, O'Connell SD (2014) How do electricity shortages affect productivity? Evidence from India, National Bureau of Economic Research, Working Papers, No. 19977
14. Fisher-Vanden K, Mansur ET, Wang QJ (2015) Electricity shortages and firm productivity: evidence from China's industrial firms. Journal of Development Economics 114:172–188
15. Mawejje J, Munyambonera E, Bategeka L (2013) Powering ahead: the reform of the electricity sector in Uganda. Energy and Environment Research 3(2): 126–138
16. Okoboi G, Mawejje J (2016) The impact of adoption of power factor correction technology on electricity peak demand in Uganda. Journal of Economic Structures 5(1):1–14
17. Twaha S, Ramli MA, Murphy PM, Mukhtiar MU, Nsamba HK (2016) Renewable based distributed generation in Uganda: resource potential and status of exploitation. Renewable and Sustainable Energy Reviews 57:786–798
18. Twaha S, Idris MH, Anwari M, Khairuddin A (2012) Applying grid-connected photovoltaic system as alternative source of electricity to supplement hydro power instead of using diesel in Uganda. Energy 37(1):185–194
19. Government of Uganda (2015) Second National Development Plan 2015/16–2019/20. National Planning Authority, Republic of Uganda
20. Engurait SP (2005) Power sector reforms in Uganda: status and achievements. International Journal of Global Energy Issues 23(2):110–118
21. Karekezi S, Kimani J, Mutiga A, Amenya S (2004). Energy services for the poor in Eastern Africa Sub Region: energy access study of East Africa. Global

Network on Energy for Sustainable Development. African Energy Research Network.

22. Mawejje J, Munyambonera E, Bategeka L (2012) Uganda's electricity sector reforms and institutional restructuring. EPRC Research Series No. 89, Kampala: Economic Policy Research Centre
23. Mawejje J (2014) Improving electricity access in Uganda. Kampala: Economic Policy Research Centre. Policy Brief No. 43
24. Mawejje J, Nampewo D (2012) Perceptions of Ugandan business executives on the current and expected business economic conditions, EPRC Business Climate Index Issue 1. Economic Policy Research Centre, Kampala
25. Efron B (1979) Bootstrap methods: another look at the jacknife. The Annals of Statistics 7(1):1–26
26. Royston P, Sauerbrei W (2008) Multivariable model-building—a pragmatic approach to regression analysis based on fractional polynomials for continuous variables volume 777. John Wiley & Sons Ltd, Chichester
27. Clogg CC, Petkova E, Haritou A (1995) Statistical methods for comparing regression coefficients between models. American Journal of Sociology 100(5):1261–1293
28. Mawejje J, Mawejje ND (2016) Electricity consumption and sectoral output in Uganda: an empirical investigation. Journal of Economic Structures 5(21):1–16