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# A Bottom-Up Model for Generating Electricity Load Profiles for the Malawi Service Sector

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**Abstract:** Electricity consumption data profiles that include details on the consumption can be generated with end-use models. The load components that can be buildings or appliances can be used to construct the load profiles. In this research, module 2 of MAED has been used to generate electricity consumption data on hourly basis in the service sector of the Malawi economy. The electricity system peak demand has also been generated by including projections of shares in total consumptions from other sectors of the national economy. The model uses input half-hourly data from ESCOM for 2008 as base year. The load curves show that the load pattern in service sector is high between 06:00 and 18:00 h and is low in the evening. This is because most of the public services are closed down during night time. It is also shown that the share of service sector load decreases from 15% in 2008 to 7% in 2025. Consequently the share for service in total consumption is projected to decrease from 22% in 2008 to 11% in 2030 for both business-as-usual and moderate growth scenarios while in the accelerated scenario the share decreases to 12%.

**Key words:** MAED, Malawi, load coefficient, profile, peak demand

## INTRODUCTION

This study reports on efforts to apply model for Analysis of Energy Demand (MAED) energy model in order to generate load patterns for the Malawi electricity system for the service sector. Load data is crucial for planning electricity distribution networks and optimal production capacity (Jukka and Lund, 2006). Accurate information of the consumer loads is important when small scale distributed technologies are optimally sized into the local network or local Demand Side Management (DSM) measures are planned. This knowledge is also useful for planning medium and low voltage networks in the residential, service and industrial areas.

The data that electric utilities typically have on electricity consumption do not contain much information about its nature. The data is normally aggregated consumption of multiple buildings without knowledge about individual buildings (Jukka and Lund, 2006). The fluctuation of electricity consumption concerning an individual building remains unrevealed. Detailed knowledge can therefore be produced with simulation models.

Many studies have been conducted in which electricity demand models have been applied to forecast the demand at utility level (Gross and Galiana, 1987; Hippert *et al.*, 2001; Capasso *et al.*, 1994; Alfares and Nazeeruddin, 2002). In these studies novel methods including fuzzy, logic, genetic algorithms and neural networks have been reported in addition to the traditional econometric models (Urban, 2008). These methods of forecasting are normally used when there is little or no knowledge about consumer details.

End-use models represent bottom-up demand modeling and act as an alternative to the traditional demand forecasting models. According to Jukka and Lund (2006) the accuracy of these models depends on the availability of grass-root level consumer details. An ideal case is to know stock of appliances and their usage patterns in buildings and details about composition of the load being valued. On the other hand, a utility level bottom-up method provides much less detail on the individual consumer level, although it shows more details than the typical electric demand forecasting scheme (Swan and Ismet, 2009).

The main problem with detailed bottom-up models is an extensive need of data about the consumers or their appliances and the buildings in general. Mostly some part of the data is not easily available.

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The purpose of this research is to generate consumer load data projections that can be used to generate electricity consumption data. The method uses module 2 of MAED which converts annual electricity demand (in terms of energy) of each economic sector considered to the demand broken down on an hourly basis.

## MATERIALS AND METHODS

**MAED (Hourly electric power demand module):** This module is used to convert the annual electricity demand (in terms of energy) of each economic sector considered to the demand broken down on an hourly basis, i.e., to the power demand or electric load imposed on the electric power system by the sector being considered. For simplification, module 2 of MAED considers four sectors: household sector, service sector, industry sector and transport sector. These calculations are performed using the various modulation factors which characterize changes in the electricity consumption of each particular hour with respect to the average consumption in order to determine the electric load of a sector in a given hour, day and week of the year from the total annual electricity demand of the sector, the program takes into account the trend of the average growth rate of the electricity demand during the year; the changes in the level of electricity consumption owing to the various seasons of the year (this variation may be reflected on a monthly or weekly basis, depending on the available information); the changes in the level of electricity consumption owing to the type of day being considered (i.e., working day, weekends, special holidays, etc.) and finally, the hourly variation of electricity consumption during the given type of day considered.

The electric load of a given sector in a certain hour, day and week is characterized by one modulation coefficient for each of the above time variations. The multiplication of all these coefficients by the average electricity demand of the sector permits obtaining the power demand of the sector (i.e., the electric load imposed on the generating system by this sector) in the hour considered. Furthermore, the modulation coefficients are known for each hour of the year, execution of the above procedure in a sequential manner permits the calculation of the 8760 values of the electric load for each sector.

After all the hourly electric loads for each sector have been determined, the aggregation of the loads for the same hour produces the hourly values of the total electric load imposed on the power system in the year considered. The representation of these values consecutively on a graph (time vs. load) produces the so-called hourly load curve of the electric power system.

The modulation coefficients previously mentioned can only be obtained from statistical analysis based on past operating experience for the power system under consideration. Various statistical studies of this nature have concluded that for a given sector, these coefficients show very little variation from one year to another (except when certain economic activities aggregated into the sector experience a notably rapid development). In fact, the power systems load curve of a given country is more influenced by the relative contribution of each economic sector to the total electricity demand. A lesser influence on the system load curve is accorded to variations of the various modulation coefficients (i.e., daily, seasonal and hourly) of each individual sector with the years (IAEA, 2006).

**Data description:** Service sector half hourly load data for 2008, the base year were collected from the Electricity Supply Corporation of Malawi (ESCOM). The data were averaged to hourly data. Seasons were defined as follows:

- Pre-winter: warm-wet season (November to April)
- Winter: cool-dry season (May to August)
- Post-winter: hot-dry season (September to October)

Load profiles for representative days in the three seasons were captured by averaging data for all the days in the particular season. These average values were normalized. The normalized values were for working days, Saturdays and Sundays in all the seasons. These values (coefficients) defined the seasonal, daily and hourly patterns for the service sector. These coefficients were used as input into MAED Model Module 2.

### Assumptions

**Socio-economic assumptions:** Three scenarios were built to generate service sector load patterns. These are business-as-usual scenario, accelerated growth scenario and moderate growth scenario. The assumptions for these scenarios are as follows:

**Business-as-usual scenario:**

- GDP growth rate will be at 7% in the next 20 years
- Share of service sector contribution to GDP will increase
- Process of cooking will gradually shift from household to the service sector in later years
- The share of service sector buildings equipped with air-conditioning will increase

**Accelerated growth scenario:**

- GDP growth rate will be at 10% in the next 20 years
- Share of service sector contribution to GDP will increase
- Cooking will gradually move from household to service sector in later years
- There will be high use of air conditioners both in service sector

**Moderate growth scenario:**

- GDP will grow at a moderate rate of 5% in the next 20 years
- Share of service sector contribution to GDP will increase slowly
- More service sector buildings will be equipped with air-conditioning

**Assumptions on the development of the electricity load patterns:** The weekly, daily and hourly load modulating coefficients in the service sector considered in this study have been assumed to remain the same throughout the study period. The same coefficients have also been used in business-as-usual, accelerated growth and moderate growth scenarios. However, it is recognised that some factors may influence the consumption patterns in future. For example, changes in weather patterns due to global warming and climate change may have impact on seasonal variations of electricity consumption by altering air-conditioning requirements (cooling and heating) in the service sector establishments. Such changes cannot be accurately predicted in the long term as such they have not been incorporated.

The only change which has been made in the scenarios that will influence future load profiles is the contribution of other various sectors in the future years. For example, load factors of various clients in the economic sectors are different. Households have lower load factors compared to industry and service sectors. Even within the service sector establishments, rural electrification loads have lower load factors than service sector establishments in the urban areas. This means that if service sector loads are growing at a faster rate than the other sectors, the system peak will tend to increase as compared to the scenario where industrial loads are growing faster.

System losses have been assumed to reduce from 21% in 2008 to 17.8% in 2020 and 15% in 2030. The same targets have been adopted in all the scenarios.

The other initiative being carried out by ESCOM is to promote efficiency in the utilisation of electricity through DSM. This is done through the use of time-of-use tariffs to encourage industries to shift consumption from peak periods to off-peak periods and through the promotion of energy efficient lighting devices. This initiative is expected to change the load consumption pattern in the future. However, this scenario has not been studied since its long-term impact is still uncertain.

## RESULTS AND DISCUSSION

**Historical electricity consumption pattern:** Table 1 shows total electricity consumption, shares of different sectors in total electricity consumption and the corresponding average growth rates for the 20 years from 1989 to 2008. Electricity consumption grew by two and a half times over the 20 years at an average annual growth rate of 5.1% which is almost 1.5 times the corresponding GDP growth rate.

It can be seen in Table 1 that the sectoral pattern of electricity consumption underwent considerable change due to different growth rates experienced in the various economic sectors. This change is mainly in household and industrial sectors. The share of household sector has been steadily increasing from 17.8% in 1989 to 37.5% in 2008 while the share of industrial sector has been decreasing from 59.7% in 1989 to 40.1% in 2008. The share of service sector has almost remained constant. Sectoral growth rates also underwent significant changes in the various time periods considered as can be seen in Table 1.

The large variations experienced in the sectoral growth rates for the 20 years were due to changes in electricity demand determining factors such as economic policies, sectoral economic activity levels, urbanisation, pumped irrigation use of air conditioners and increase in usage of other electric appliances at household level and in service sector establishments. The evolution of these factors will continue to determine growth of electricity and sectoral patterns in the coming years.

Table 1: Electricity consumption from 1989 to 2008

| Items | 1989 | 1994 | 1999 | 2004 | 2008 |
|---|---|---|---|---|---|
| Electricity consumption (GWh) | 476.0 | 639.0 | 844.0 | 964.0 | 1219.0 |
| **Shares (%) by sector** | | | | | |
| Household | 17.8 | 22.5 | 29.9 | 33.8 | 37.5 |
| Service | 22.5 | 24.6 | 20.9 | 22.0 | 22.4 |
| Industry | 59.7 | 52.9 | 49.2 | 44.2 | 40.1 |
| **Average annual growth rates (%)** | | | | | |
| Household | 11.4 | 11.9 | 4.8 | 8.8 | |
| Service | 6.4 | 1.4 | 2.5 | 6.5 | |
| Industry | 8.0 | 0.8 | 1.0 | 3.5 | |
| Total consumption | 8.0 | 4.0 | 3.0 | 6.0 | |

**Evolution of system load factor:** Figure 1 shows the evolution of system load factor for the 20 years from 1989 to 2008. The average system load factor for the 20 years was 65%. The actual annual system load factor has been varying between 60 and 70% except in 2008 when it reached 73%. This very high system load factor in 2008 was because of generation constraints which led to the chopping of the peak demand by load shedding.

**Maximum demand:** Table 2 shows the growth of system demand and the corresponding annual growth rates for 5 years periods in the 20 years. It can be seen that the system demand has been growing at a decreasing rate. This is partly due to the fact that demand is being curtailed due to generation constraints.

**Transmission/distribution losses:** According to ESCOM's sales and generation statistics reports, total system losses for the base year are 21% of energy sent out to transmission grid. Of these, 7% are transmission losses while 14% are distribution losses (both technical and commercial losses).

**Peak load:** Peak load for the base year obtained from the reconstructed load duration curve is 233 MW while the actual peak load for 2008 was 242 MW.

**Load modulating coefficients (by week and by day):** In the MAED methodology, the load curves for various clients in different end-use sectors are constructed using electricity consumption by each client and load modulation coefficients. The load modulation coefficients for the service sector include seasonal coefficients representing the seasonal variation in electricity consumption; daily coefficients accounting for relative weights of each day within the week and hourly coefficients describing the hourly load variation behaviour of the sector.

Table 2: Annual system demand

| | Annual system demand (years) | | | | |
|---|---|---|---|---|---|
| Items | 1989 | 1994 | 1999 | 2004 | 2008 |
| System demand (MW) | 101 | 139 | 188 | 227 | 242 |
| Average annual growth rate (%) | - | 8 | 6 | 3 | 2 |

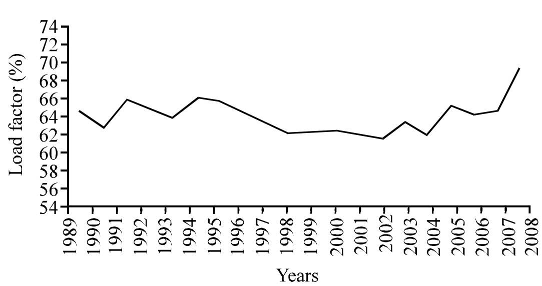


Fig. 1: Load factor

Weekly and daily load modulating coefficients for the service sector are presented graphically. The coefficients were obtained from half-hourly load profile data which was obtained from ESCOM. Profiles for feeders supplying the commercial establishments were used as represented profiles for the sector. The feeders used were single feeders such that they may not be representative of all the clients within the service sector but were still considered reasonable in absence of detailed load profiles.

Figure 2 show seasonal variation in electricity consumption for service sector while Fig. 3 show relative weights of each day within the week. It can be seen from these figures that there is not significant seasonal variations except during weekends. This variation comes from the working pattern of the sugar industry which is one of the major consumers of electricity. During winter the sugar industry crushes the sugarcane using its own electricity which is generated from bagasse. This reduces electricity demand from the national grid. The demand for electricity of the sugar industry picks up in post-winter when they begin to irrigate the sugarcane fields. On a weekly basis, the load pattern is almost the same. Demand levels are not significantly different. However, Sundays have got the lowest demand levels followed by Saturdays and peaks up during working days. The difference

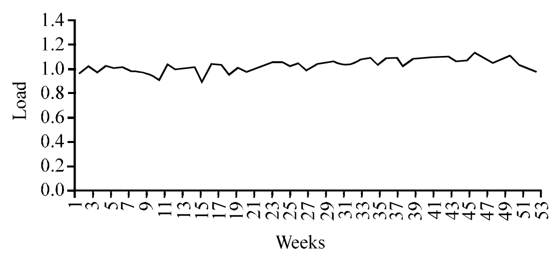


Fig. 2: Seasonal variation of service sector normalised loads

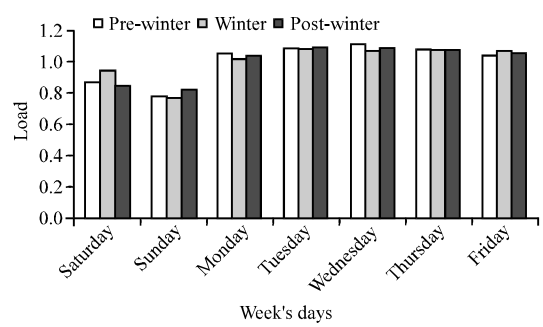


Fig. 3: Relative weights of week days for service sector loads

between Saturday and Sunday is due to some industries and service sector companies that work half day on Saturday and close down on Sunday.

**Hourly load coefficients by day for the service sector:** Hourly coefficients for clients within the service sector were calculated for 3 representative days: Saturday, Sunday and a working day (which is an average of the 5 working days in a week). These coefficients define hourly load variations in a day and the normalised load curves are shown in Fig. 4- 6. There are no significant differences in profile shapes for the service sector and the profiles show significant consumption during the day time (06:00-18:00 h). The load factor is also significantly high.

**Projection of service sector electricity load patterns:** Table 3 shows the service sector share in total consumption including the shares of other sectors. In both business as usual and moderate growth scenarios, the share for service decreases from 22% in 2008 to 11% in 2030 while in the accelerated scenario the share decreases to 12%. It can also be observed that in business as usual scenario of industry and household shares grow, the latter growing from 38% in 2008 to 45% in 2030 while the former grows from 40% in 2008 to 44% in 2030. The share of industry in the accelerated scenario grows from 40% in 2008 to 55% in 2030 while that of household decreases from 38-33%. In the moderate scenario, the share of household increases from 38% in 2008 to 56% in 2030 while that of industry decreases from 40-33%.

Using the load modulating coefficients as discussed in the preceding section, assumptions made on system losses and sectoral shares as shown in Table 3, the projected system peak demand for all the scenarios is shown in Table 4.

In the business as usual scenario, the system peak demand increases from 233-4274 MW in 2030 at an average growth rate of 14% per annum. For accelerated scenario, system peak demand increases from 233 MW in 2008 to 5352 MW in 2030 at an average growth rate of 15% per annum while in the moderate scenario, peak demand increases from 233 MW in the base year to 3622 MW in 2030 at an average growth rate of 13% per annum.

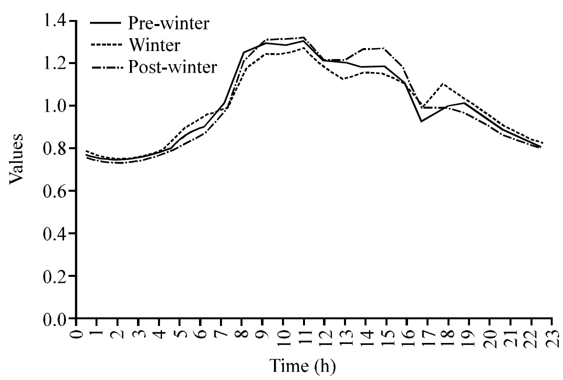


Fig. 4: Hourly load co-efficients for Saturday for the service sector

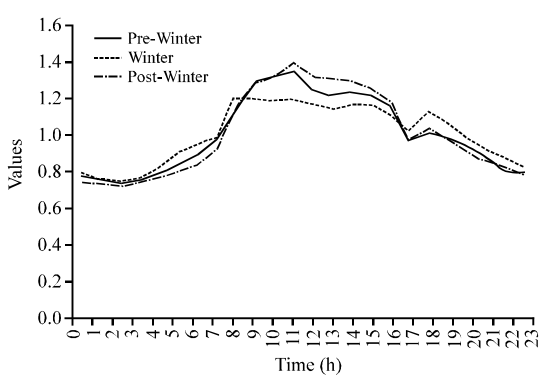


Fig. 5: Hourly load co-efficients for Sunday for the service sector

Table 3: Consumption shares by sector (%)

| Scenario | Client | 2008 | 2015 | 2020 | 2025 | 2030 |
|---|---|---|---|---|---|---|
| Business as usual scenario | Industry | 40 | 37 | 39 | 42 | 44 |
| | Household | 38 | 48 | 48 | 46 | 45 |
| | Service | 22 | 15 | 13 | 12 | 11 |
| Accelerated scenario | Industry | 40 | 41 | 45 | 50 | 55 |
| | Household | 38 | 44 | 41 | 38 | 33 |
| | Service | 22 | 15 | 14 | 12 | 12 |
| Moderate scenario | Industry | 40 | 33 | 33 | 33 | 33 |
| | Household | 38 | 52 | 54 | 56 | 56 |
| | Service | 22 | 15 | 13 | 11 | 11 |

Table 4: Projected peak demand (MW)

| Years | Moderate scenario | Business as usual scenario | Accelerated scenario |
|---|---|---|---|
| 2008 | 233 | 233 | 233 |
| 2015 | 700 | 740 | 789 |
| 2020 | 1257 | 1374 | 1532 |
| 2025 | 2141 | 2425 | 2847 |
| 2030 | 3622 | 4274 | 5352 |

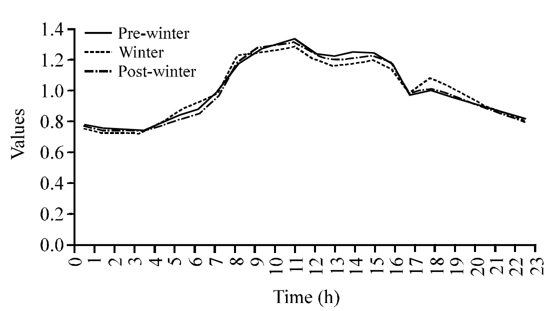


Fig. 6: Hourly load co-efficients for a working day for the service sector

The system load factor decreases from 67.5% in the base year to 60.94, 64.65 and 57.47% in business as usual, accelerated and moderate scenarios, respectively.

## CONCLUSION

An attempt has been made to generate projections of electricity load profiles for the service sector using module 2 of MAED. The electricity system peak demand has been generated by including projections of shares in total consumptions from other sectors of the national economy. Due to changes in the composition of energy demand the load curves may undergo some changes in future. The expected increase in air conditioning, mining and rural electrification loads will also have an effect on future load curves. It is therefore necessary to do further analysis of sectoral as well as sub-sectoral load patterns to estimate power distribution of the different sectors for future years.

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