Strategic Forecasting of Electricity Demand Using System Dynamics Approach

Salman Ahmad Akhwanzada and Razman Mat Tahar

***Abstract*—Electricity has become an important source of energy in human society. The enormous use of electricity necessitates a mechanism to predict the future demand. Forecasting models provide that mechanism. They facilitate decision makers in keeping a balance between supply and demand, thus strategically managing the supply system A simulation based on system dynamics methodology is developed for demand forecasting. The variables used are population and per capita consumption of electricity to forecast electricity demand. The forecasting horizon of the model is 11 years from 2011 to 2022. Malaysia is used as a case study. The simulation model estimates that at the current rate of consumption and population growth there will be a need of 151.05 terawatt-hour of electric energy in year 2022. It is found that that by using simulation, a fairly accurate forecast can be obtained.**

***Index terms*—Electricity, long-term forecasting, system dynamics, artificial neural networks.**

I. Introduction

Electricity is considered the newest and the most efficient form of secondary energy. It plays an important role in the economic and social development of a country and consequently in the standard of living of people [1].

The issue of present and future supply of electricity is of equal interest to public, politicians and scientific community [2] In this regard electricity demand predictions are essential. These predictions are employed for studies of capacity expansion, development of a supply strategy, particularly related to fuel diversification, and for revenue analysis and market research. The former studies relate to strategic management level, while the latter, at an operational level. Operational forecasting is more optimization approach [3]. Irrespective of the application level, forecasting proves to an important tool for policy and decision makers in energy sector[4].

Electricity forecast are broadly divided in two categories: short term and long term. Short term forecast are useful in daily operations of a utility companies whereas long term forecast are needed for strategic planning. Planning in electricity sector is very challenging due to following reasons: electricity generation capacity is capital intensive, it takes long period of time in construction, and the commodity cannot be stored in large amounts. Along with this, there is high level of uncertainty involved in planning; change in demand (due to any externality) and liberalization of electricity are among the top causes [5]. Due to this peculiarity of the sector, it is not an exaggeration to say that demand forecasting plays a critical role in of integrated electricity planning process. Reliable forecasts alleviate any shortcoming of electricity supply and demand balance that can jeopardize social and economic well being of the people [6].Our goal, in this paper, is to develop a dynamic simulation model that can be used to forecast total annual electricity demand. We are also aiming to show to prospective researchers that simulations have the capability to make sound forecasts.

At present more than 67% of electricity is generated by fossil fuels [7]. According to World Energy Council, coal reserves are going to last for 128 years, natural gas 54 and oil 41 years, at current production and consumption ratio [8]. Another estimate shows that coal, natural gas, and oil will only last for 107, 37, and 35 years, respectively [9]. The inconsistency in these two estimations highlights the uncertainty in availability of fossil fuels for electricity generation. This premise suggests that electricity generation is going to face major challenges in long-run. Along with fuel availability, the choice of technology and its capacity also very significant role in planning process. Failing to invest in right technology and capacity may cause generating firm lose its competitiveness [10]. In this context, strategic forecasting becomes inevitable while considering sustainability of power generation.

There are myriad of studies done on electricity forecasting using various tools and techniques. Using consumption growth factor, Bodger and Tay [11] used logistic and energy substitution to forecast the electricity demand in New Zealand. Kumar and Jain [12] used three times series models to forecast the energy requirement for India including electricity. A Grey-Markov forecasting model to forecast the electricity supply and demand in China was developed Huang et al., [13]. Electricity consumption and economic growth for Malaysia was studied using econometric approach by [14], also Aman et al., [15] used econometric approach for electricity forecasting steal industry of Malaysia. In artificial intelligence category of forecasting methods Ekonomou [16] used artificial neural network (ANN) for long term electricity forecasting in Greece. In the same artificial intelligence category, a hybrid models for long term electricity forecast were developed by Padmakumari et al.,[17], and Azadeh et al.,[18]. A comparison of different forecasting techniques was presented by Tso et al., [19].

The objective of using simulation models in electricity forecasting is that simulations are mathematically flexible. They have the ability to accommodate any pattern of

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behavior of variables under consideration [20].Many authors are exploring the simulation techniques due to their simplicity and ability to perform wide range of non destructive experiments[21] However, the simulation approach has some drawbacks; one of the being the implementation[22]. This difficulty has been overcomes by advances simulation software in the market, e.g., Arena, Stella, Vensim, Anylogic and many more.

In this paper we employed a different methodology for long term electricity forecast. We used system dynamics simulations for the purpose. Our choice of using system dynamics simulations for forecasting is based on context that simple extrapolation of time series can be misleading. This discrepancy occurs by ignoring the behavioral constructs of the system. In the behavioral construct the relationship between the variables determine the future direction of the system. System dynamics is one such methodology of computer simulation that makes use of the behavioral construct of the systems [23]. Strategic planning in electricity sector can be as long as thirty years [16]The long- term model is used as defined by[24].In this research we have chosen the forecasting window to be 11 years, from 2011 to 2022. The significance of this time period is that it incorporates two Malaysian national planning periods: 2011-2015, and 2016-2020. This long-term forecast can serve as a ground for developing or readjusting new strategies.

II. Electricity Sector of Malaysia

Electricity plays an import role in human's daily life. As population grows, demand for electricity dramatically increases. Fig.1 shows Malaysia's population growth and yearly per person demand of electricity from the period 1976 to 2010.

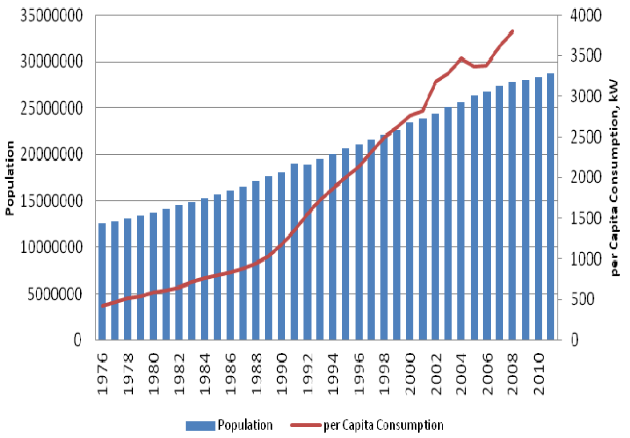


Fig. 1. The Malaysian population and annual per capita consumption

Form Fig. 1 we see that population is increasing at steady rate. The annual population grwoth is 3% [24]. At presnet Malaysia population is around 28,830,389 people [26]. In comparion to population, the per person annual electricty consumption shows a dramatic behvaiour.The per capita demand shows a very steep rise from 1989 onwards. This change is due to 1985 Malaysian shift towards manufactriug from agriculture based economy. Another major shift is in 2008-2009 when the world financial crisis occurred. This had a drmatics influence on export dependant economy of Malasyia. However, since 2009 as the economy recovered so did the per capita consumption of electricty increased.

III. Methods and Materials

A. The System Dynamics Approach

System dynamics methodology was developed by Prof J W Forrester and colleagues around 1950s at MIT Sloan School of Management [23]. It is a computer-oriented approach that makes use of interrelation of variables in a complex setting. This methodology was initially developed for managerial decision making but later has been successfully applied to other areas. Electricity sector is one of them [27].

According to Forrester [28], in system dynamics is focused on a problem. It makes use of ordinary differential equations. Building a system dynamics model is an iterative process making use of causal and feedback relationships. These relationships are built in differential equations, parameters and variables [29]. In simple words system dynamics model consists of stocks and flows connected through auxiliaries depicting a system.

System dynamics methodology has been applied for forecasting in various sectors. Lyneis [30] forecasted the jet aircraft industry and found that the system dynamics forecast perform better than stochastic forecasts. Railway cargo carrying capacity in China was forecasted by [31]. It was found that system dynamics model generated an error of only 2.66%. Air passenger transport volume was forecasted for coming 10 years for China [32]. In Taiwan, [33] forecasted air passenger demand and linked it to the passenger terminal capacity expansion decision. Malla and Kunch[34] used simulation to predicted the diffusion of combined heat and power (CHP) system in Belgium. Dyson and Chang [35] forecasted the amount of solid waste generated in a city of San Antonio, USA to develop a strategy for effective management. Apart from focusing on a forecasting requirement from the model system dynamics has been successfully applied to water resources management [36], environmental management [37], deregulation in electricity industry [38], and shipping port terminal operations [39] to name a few application areas.

B. Model Development

Malaysian electricity sector is used in this research. Malaysia has seen an enormous rise in electricity demand per capita. In this case the system dynamics boundary is the Malaysia electricity sector. No differentiation is made in demand for different sectors of the economy on the premise that breakdown is not required at strategic level; it is fairly simple to get sector demand based on individual sector growth.

Population is one of the major driving forces behind the amount of electricity demand in the country. Population governs various sectors of demand: domestic, industrial, commercial, and agriculture. The total electricity demand subsequently depends upon population [40].

The variables are selected that are pertinent to long term forecast. The variables used in this study are summarized in Table I.

TABLE I: THE MODEL VARIABLES

Factors	Reference
Population	[6],[17],[40],[41],[42]
Per capita demand	[43]
Total electricity demand	[41] ,[44]

Correlations between the variables indicates that the there is a strong relationship between two variables.

TABLE II: CORRELATION MATRIX FOR VARIABLES USED

	Population	Total Demand	Per capita demand
Population	1		
Total Demand	0.966	1	
Per capita demand	0.961	0.943	1

The system dynamics model proposed in this study comprises of one stock and two flow and fours auxiliary variables (for details on please see appendix). The simulation forecasting model is divided in two distinct sub-models. They are, "Population dynamics sub-model" and "Electricity demand sub-model". The interaction of these two sub-models forecast the total electricity demand. Figure 2 shows the logical setup of the model. This model has been developed in iThink® simulation package.

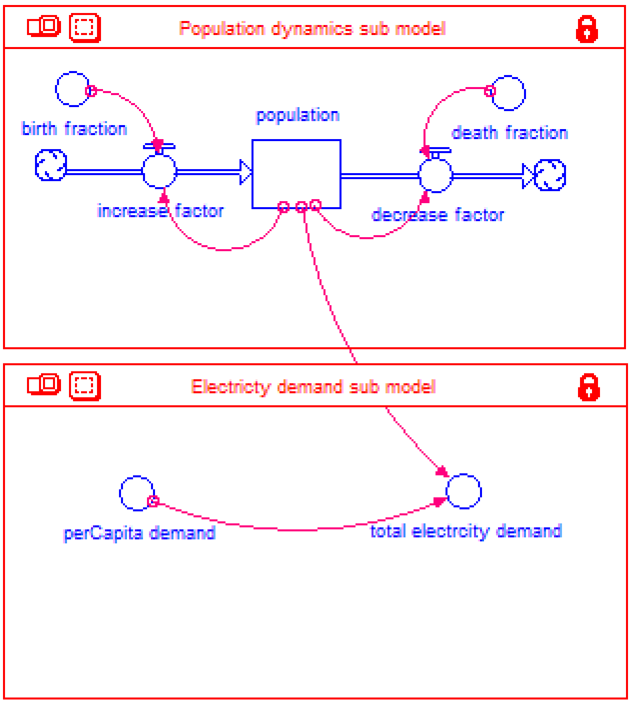


Fig. 2. The system dynamics model of electricity demand estimation

C. Mathematical Formulation

The mathematical equations used in the study are given in (1), (2), and (3). The rise or inflows to the "population" consist of births (increase factor) while deaths (decrease factor) is responsible of outflows or decrease in from "population". Based on these dynamics the "population", at any time (t) in the study area is calculated using (1).

$$P(t) = P(t - dt) + (If - Df) \times dt \quad (1)$$

where,

P(t) Population at time 't',

P(t− dt) Population at previous time step,

If Number of births in time, dt, and

Df Number of death in time, dt

"Per capita demand" is another socio-economic factor that drives "total demand" in the model. This variable is calculated based on the historic trend of "per capita demand". Equation (2) is the mathematical formulation of it.

$$PCD(t) = 1484.4 \times TIME\text{^}0.2991 \quad (2)$$

where,

PCD(t) per Capita demand at time 't'

Finally in the model, (3) provides the "total electricity energy demand".

$$TED = PCD(t) \times P(t) \quad (3)$$

where,

TED Total electricity demand at time't'.

The variables and parameter initial values and units users are given in Table III below.

TABLE III: THE MODEL PARAMETER VALUES AND UNITS

Factors	Value	Units
Population	19,503,000.0	people
Birth fraction	23.1 births per 1000 people	people/year
Death fraction	5 deaths per 1000 people	ratio
Increase factor	Population*Birth fraction	ratio
Decrease factor	Population * death fraction	people/year
Per capita demand	1484.4 * TIME^0.2991	kilowatt-hour

The model is calibrated to 1993 data. All data used in this study is from World Development Indicators of World Bank.

D. Model Validation and Accuracy

We adopted two distinct approaches of building confidence in our proposed model. The reason being that the face validation is of less importance than the structural correctness of the simulation model [45]. The first approach is being the traditional check of accuracy approach using statistical tests, while second one is using a completely different methodology to validate our results. In the latter approach we use a multilevel perception artificial neural network (MLP ANN). PASW version 18 was used for ANN based validation.

The schematic of a MLP feed-forward ANN is show in Fig. 3. It consists of three layers: an input, a hidden, and an output layer.

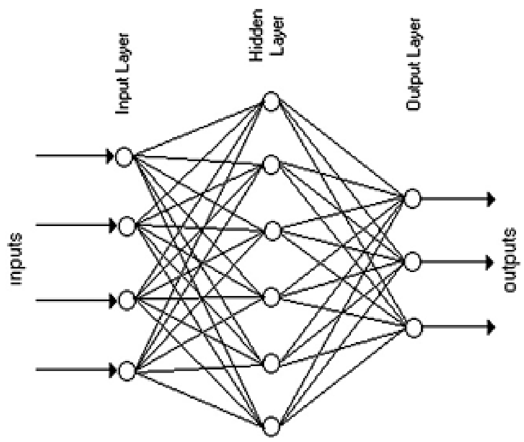


Fig. 3. A MLP feed forward neural network

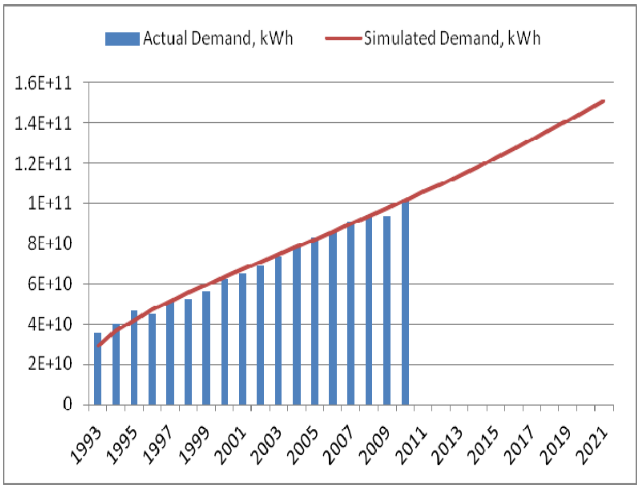


Fig. 4. Compariosn of actual and estimated demand

IV. Results and Discussion

The simulated results of total electric energy demand are shown in Table IV. In Fig. 4 we see that the simulated data shows close match with the actual data in the 1993 and 2010 time period. The simulation model forecast that the total electricity energy demand from 2011 will rise from 105 terawatt-hour to 151.02 terawatt-hours in 2022. This is an increase of around 4% per annum. Per annum percentage rise in demand is less than from what [46] had predicted. Their estimate was 5 to 7.9% till 2024. The reason for this difference is in the approach of forecasting methodology adopted. However, it is worth mentioning that both the estimates are close to one another.

TABLE IV: Actual and Forecasted data of Electrical Consumption, kilowatt-hours

Year	Actual total demand	Simulated total demand
1993	35,603,000,000.00	28,950,253,200.00
1994	40,104,000,000.00	36,449,685,357.24
1995	46,609,000,000.00	42,108,136,772.55
1996	45,177,000,000.00	46,961,130,872.11
1997	51,204,000,000.00	51,372,142,327.54
1998	52,525,000,000.00	55,515,484,373.15
1999	55,961,000,000.00	59,489,629,445.88
2000	62,350,000,000.00	63,356,328,318.59
2001	64,954,000,000.00	67,157,275,005.24
2002	68,802,000,000.00	70,922,245,376.02
2003	73,483,000,000.00	74,673,477,131.90
2004	78,804,000,000.00	78,428,205,596.33
2005	83,219,000,000.00	82,200,218,172.35
2006	85,956,000,000.00	86,000,852,168.23
2007	91,189,000,000.00	89,839,660,136.96
2008	94,393,000,000.00	93,724,867,935.44
2009	93,822,000,000.00	97,663,698,820.57
2010	102,311,000,000.00	101,662,608,261.86

A. Results Accuracy

A low value of mean error (ME) as compared to mean absolute error (MAE) can be distracting at first sight. This is because ME is can be influenced by large value of negative and positive errors. This biasness in ME is overcome by MAE. But MAE is unable to provide ant useful information about the forecasting method. However, we resolved to a better statistic, mean absolute percentage error (MAPE). In our case the MAPE value is only 5%. To develop more confidence in forecasting system Thile's U statistic is used [47]. This static brings the forecasting accuracy between 0 and 1 [43]. A closer value of U statistic to zero signifies a better forecasting system. For our simulation based forecasting system, it is 0.03. The forecasting errors statistics are summaries in Table V.

TABLE V: Simulated Model Forecast Evaluation

Statistic	Definition	Value
Mean Error	1/T $\sum_{t=1}^{T} e_t$	549,959.55
Mean absolute error	1/T $\sum_{t=1}^{T} \lvert e_t \rvert$	2,097,034,911
Mean absolute percentage error	1/T $\sum_{t=1}^{T} * 100 * \lvert {}^{e_t}/_{y_t} \rvert$	5%
Theil's U statistic	$\frac{\sqrt{\frac{1}{T}\sum_{t=1}^{T}(y_t - f_t)^2}}{\sqrt{\frac{1}{T}\sum_{t=1}^{T} y_t^2} + \sqrt{\frac{1}{T}\sum_{t=1}^{T} f_t^2}}$	0.03

where $e_t = y_t - f_t$ is, error = actual – forecast

B. Results validation

The validation of simulation forecast was done using ANN as mentioned in section III. The architecture of MLP ANN used in this study is given in table VI. This architecture was chosen based on a number of iterations performed on the basis of error minimization in ANN.

TABLE VI: The Final MLP ANN Model Architecture

Structure	Learning Rule	Transfer function
1 hidden layer	Gradient descent	Input: Hyperbolic tangent
2 neurons in hidden layer		Output: Identity

From Fig. 5 we can see that system dynamics simulation model output is very close to MLP ANN model.

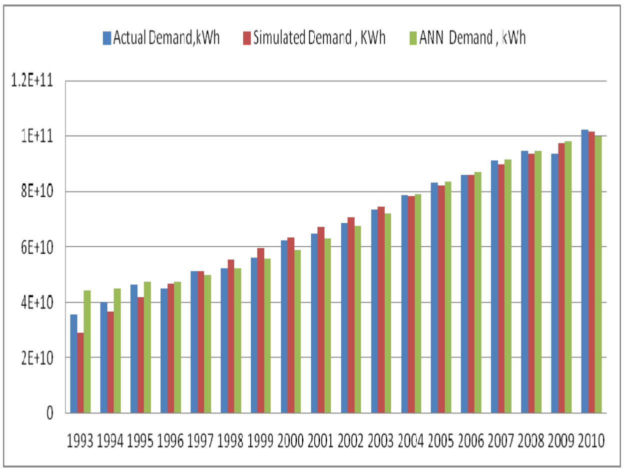


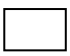
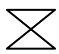
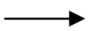
Fig. 5.Compariosn simulation and ANN model with actual data

V. CONCLUSION

The present study has explored the potential of simulation model in electricity demand forecasting for Malaysia. For a 11 years forecasting horizon, the results clearly indicate that values forecasted by simulation model are fairly close to the real values. Simulation models can be a viable alternative to project the future electricity requirements. Normally, energy consumption pattern has rising trend for most of the countries. Therefore, simulation models because of their flexibility have potential for wider application. These models are less demanding in terms of data as compared to econometric and artificial intelligence models. They can be very helpful and supplementary to frame suitable energy policy.

APPENDIX

SYSTEM DYNAMICS BUILDING BLOCKS

Building block	Symbol	Description
Stock		Accumulation of quantity over time
Flow		Attached with stock. It increases of decreases the stock level.
Auxiliary		Connects stocks and flows through equations.
Converter		Links different building blocks.

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