Electricity and Water Demand Behavior in Kuwait

MICHAEL WOOD[1] AND OSAMAH A. ALSAYEGH[2]
[1]Ministry of Electricity and Water
[2]Kuwait Institute for Scientific Research
KUWAIT
osayegh@kisr.edu.kw http://www.kisr.edu.kw

Abstract: - This paper presents a Kuwait-specific electricity and water demand behavior model. The demand model is developed based on historic data of oil income, gross domestic product (GDP), population and electric load and water demand over the past ten years (1998-2009). The analysis shows that there is a strong association between the electric power (as a dependent parameter) and Kuwaiti population and GDP (as independent parameters); water consumption and Kuwaiti population; non-Kuwaiti population and GDP; and GDP and oil income; electricity and water demand and future mega projects (housing, petrochemical, infrastructural projects). The model was run under three oil income scenarios (high, base, and low). The model is utilized to simulate the demand from 2010 to 2030.

Key-Words: - Demand forecast, economic diversification, GDP, macro model, and oil price

1 Introduction

Decision-making, planning, and strategy development in the electricity and water production sector are based on mid- to long-term forecast of electric load demand. In the case of Kuwait where the main source of potable water is from seawater desalination, the forecast must also include water demand. Therefore, the sector production strategy development is based on the demand analysis under different socio-economic, technological, and demographic development scenarios. Moreover, future demand forecasting is also an important tool for electric transmission and distribution networks planning.

Demand forecasting results are attained through the simulation of a model that is run under various scenarios. The model systematically relates the specific electric load and water demands to the corresponding social, economic, and technological factors that affect these demands. There are various demand forecasting methods and the approach and demand drivers are different from one method to another. Depending on the availability of data, time era, socio-political, economic and technological aspects of a country or region, a specific model is developed. In general, there are two main approaches which are the macro and micro demand models. The macro modeling approach, which is also known as the top-down approach, follows an aggregated view of the influence of the economic, demographic and social behavior, on the demand. It relies on econometric modeling techniques, e.g.,[1]. The micro approach, which is also known as the bottom-up or end-use approach, is represented by economic-engineering models in which technology indicator drivers are utilized for the demand model development. Its approach attempts to capture the impact of energy usage patterns of various devices and systems, e.g., [2]. The micro models for electricity demand focus on various uses in the residential, commercial, industrial and agriculture sectors of the economy.

This paper presents a Kuwait-specific electricity and water demand behavior model which is based on [3]. The paper consists of six main sections. The second Section provides general background on the State of Kuwait. The third Section discusses the conventional method that has been used by the country's electric and water utility. The forth Section presents more realistic demand model that describes the influence of the main drivers of the demand. In the fifth Section, the model simulation results are presented. The sixth Section provides concluding remarks.

2 Kuwait: Background and Review

2.1 Geographic and Socio-Economic Preview

The State of Kuwait lies at the north-west corner of the Arabian Gulf, between 28º and 30º latitudes and between 46º and 48º longitudes. Its total land area is

17,818 km^2. Most of the mainland is a flat sandy desert. The weather is characterized by long, hot and dry summers and short, warm and sometimes rainy winters. Dust storms occur frequently with a rise in humidity during late summer. Typical extreme temperature ranges between the winter and summer is 0 ºC to 50 ºC.

About 6% of Kuwait's total area is inhabited. By the end of 2010, the population was estimated to be 3.5 million with annual growth rate of 5.9% for the last 10 years [4]. In 2010, the gross domestic product (GDP) was US dollar 135 billion with growth rate of 4% and it is relatively stable.

2.2 Electricity and Water Supply and Demand Records

The indigenous energy sources are oil and natural gas that are managed (production, manufacturing, exporting and distribution) by a state owned entity, Kuwait Petroleum Corporation (KPC), with its subsidiaries. The electricity and water utility is a state owned and operated plants by the Ministry of Electricity and Water (MEW). MEW is responsible to produce, transmit and distribute electricity and water in Kuwait. The system is solely dependent on oil, oil refined products and gas fuels, which are provided by KPC. The current total installed capacity is more than 12 GW. The current generation inventory technologies include 55% reheat steam, 20% non-reheat steam and 25% open cycle gas turbine plants [5]. The desalination capacity is about 450 million imperial gallon per day (MIGD) that utilizes a multi-stage flash (MSF) systems to produce steam to drive the electrical generators. Currently, number of reverse osmosis systems are being tested for potential future deployment. The electricity and water is massively subsidized (about 95%) by the government.

In Kuwait, the electric energy system serves a typical electric load profile as shown in Fig. 1 (2008 load profile as an example). High temperature during summer seasons, during which maximum temperature can reach higher than 50 ^{o}C, is a key driving force for the high electricity demand. This is mainly due to the widespread use of air conditioning (A/C) systems which are the largest consumer of electricity. A/C systems account for nearly 70% of the annual peak load demand and over 45% of the yearly electricity consumption [6]. Fig. 1 shows the load profile at the hours 04:00, 15:00 and 20:00. These hours are selected to illustrate the load fluctuations and transients throughout the year and in a typical day in which the temperature and society work activities at their minimum and maximum. The load level during summer is approximately twice the base load, e.g., in 2008, the base load was around 4,000 MW and the average summer load was 8,000 MW.

Currently, the base load is around 4,500 MW which is about 40% of the total installed capacity. The average daily difference between the maximum load (at hour 15:00) and minimum load (at hour 04:00) is around 1,000 MW throughout the year. This difference is more than 8% of the total installed capacity. Despite the temperature drop during evenings, the electrical load remains almost the same during afternoons. This can be attributed to inefficient operation of A/C systems in office buildings combined with thermal inertia of these buildings.

2.3 Kuwait Demand Modeling: Related Studies

Long-term demand forecasting is a challenging procedure with respect to the precision of the forecasted demand values. Unprecedented factors (wars, financial crisis, political changes, etc.) that may rise within a country, region or/and the world can radically affect the demand drivers and, hence, influence the demand. Therefore, demand modeling must be carried out periodically to account for such changes. Demand drivers must be reviewed annually for the purpose of retrofitting, adding or/and eliminating of these drivers. Consequently, the demand model structure might further be developed to accommodate such changes. There have been number of studies that modeled Kuwait's electricity demand [7] - [10].

The forecasting error percentage of the above mentioned studies ranges between 6 and 67%. The methods, drivers and data used by the studies were robust and justifiable; however, the main reasons for the projection assessments of some studies being considerably off the actual values include the rise of oil prices after 2005, unexpected rapid development after 2003 (change if Iraqi regime), improvising demographic planning, and random increase and changes in government salaries (About 85% of the local labor force work for the government sector).

There is no robust energy model that can handle unexpected changes in the drivers affecting the demand. The proposed electricity and water model in this paper is not immune from the effect of the unexpected and unprecedented changes in the demand drivers. Hence, it is not claimed that the proposed model would provide a better representation of Kuwait's electricity and water demand. However, it represents the demand under the influence of the actual drive players.

3 Conventional Electricity and Water Demand Forecasting Methodology

The planning of MEW for electricity and water production depends on the expected and prescribed, residential, commercial, and industrial projects. The latest MEW projection profiles of electricity and water are shown in Fig. 2 [10]. The forecasted peak electric load and water productions by 2030 are around 28 GW and 1101 MIGD, respectively. MEW's forecast technique is based on extrapolation, i.e., 8% growth between 2010 to 2015, 6% between 2015 to 2020, and 3% between 2020 to 2030.

Unlike MEW's forecasting method, this paper presents a model that describes the relation between electricity and water demands and several socio-economic drivers. Historic data confirms that GDP has strong influence on the demands. GDP, which mainly depends on oil income, is better predicted than future development projects, which are subject to delays and/or cancelation.

4 Demand Behavior Model

The demand modeling is based on the work developed in [13]. It is important to mention that about 31% of the population are Kuwaitis and 69% are non-Kuwaiti. Breaking down the non-Kuwaiti population further, 16% are labor force in Kuwaiti households, and 53% are household independents. The labor force in Kuwaiti households is found to be GDP/capita dependent and its ratio is 1 to 2 Kuwaitis. Table 1 presents the interrelation between socio-economic parameters and electricity and water consumption. Currently, the Kuwaiti and non-Kuwaiti domestic labor force populations at any year can be estimated as follows,

$$N_K(y) = N_K(y_o)[1+f]^{(y-y_o)} \quad (1)$$

$$N_{HK}(y) = 0.5 N_K(y) F_{GDP}(y) \quad (2)$$

where $N_K(y)$ and $N_{HK}(y)$ are the Kuwaiti and non-Kuwaiti domestic labour force populations, respectively, in year y, y_o is the initial year at which the calculation starts, f is the fertility factor ($0 \leq f \leq 1$). The current fertility factor is 3.1%. $F_{GDP}(y)$ is a GDP factor which is a function of oil revenue and industrial diversification. Further details on the calculation of $F_{GDP}(y)$ is discussed in [10]. The population of the non-Kuwaiti with independent households is calculated over the next 20 years as follows,

$$N_{nK}(y) = N_{nK}(y_o) F_{GDP}(y) \left[1 - \frac{r(y-y_o)}{20}\right] \quad (3)$$

where $N_{nK}(y)$ is the non-Kuwaiti population with independent households, and r is a reduction factor ($0 \leq r \leq 1$) of non-Kuwaiti population over the next 20 years, i.e., 2010 to 2030.

4.1 Electricity Demand Model

The electric load demand can be calculated as follows,

$$P(y) = [P_R(y) + P_{ICG}(y)][1+L] \quad (4)$$

where $P(y)$ is the electricity power demand in year y, $P_R(y)$ is the residential electricity power demand in year y, $P_{ICG}(y)$ is the combined industrial, commercial, and governmental electricity power demand in year y, and L is the loss factor ($0 \leq L \leq 1$) due to power station consumption and transmission and distribution losses. In this study the loss is assumed to be 10%. The residential demand is estimated by,

$$P_R(y) = P_{RK}(y) + P_{RnK}(y) + \sum_{i=y_o}^{y} P_{HP}(i) - S_R(y) \quad (5)$$

where $P_{RK}(y)$ is the Kuwaiti residential electricity power demand in year y, $P_{RnK}(y)$ is the non-Kuwaiti residential electricity power demand in year y, $P_{HP}(i)$ is the electricity power demand for the new housing project in year i, and $S_R(y)$ is the residential electricity savings in year y. The Kuwaiti and non-Kuwaiti residential electricity power demand are approximated by,

$$P_{RK}(y) = P_{RK\_pc}(y_o).F_{GDP}(y)[N_K(y) + N_{HK}(y)] \quad (6)$$

$$P_{RnK}(y) = P_{nK\_pc}(y_o) N_{nK}(y) \quad (7)$$

where $P_{RK\_pc}(y_o)$ and $P_{nK\_pc}(y_o)$ are the electricity power demand per capita for the Kuwaiti and non-Kuwaiti household population average up to year y_O. The residential energy saving in year y, $S_R(y)$, is calculated as follows:

$$S_R(y) = \sum_{i=y_o}^{y} P_R(y_o) S_e(i) + \Delta P_R(i) S_n(i) \quad (8)$$

where $S_e(i)$ and $S_n(i)$ are the savings in existing and new buildings in year i, respectively. These values are defined as product of percentage saving per building times the proportion of increment on

ISBN: 978-1-61804-135-7

which it is implemented. $\Delta P_R(i)$ is the increment of residential electric power demand in year i.

The combined industrial, commercial and governmental electric power demand in year y, $P_{ICG}(y)$, is calculated as follows:

$$P_{ICG}(y) = P_{ICG}(y_o)F_{GDP}(y) + \sum_{i=y_o}^{y} \Delta P_{ICG}(i) \quad (9)$$

where $\Delta P_{ICG}(i)$ is the increment in year i of the industrial, commercial and governmental electricity demand combined.

4.2 Water Demand Model

The same outline that is followed for electricity demand modelling, is used for calculating the water demand, i.e.,

$$W(y) = W_R(y) + W_{ICG}(y) \quad (10)$$

where $W(y)$, $W_R(y)$ and $W_{ICG}(y)$ are the water demand, maximum residential water demand and maximum combined industrial, commercial and governmental water demand in year y, respectively. The maximum residential water demand is determined as follows,

$$W_R(y) = W_{RK}(y) + W_{RnK}(y) + \sum_{i=y_o}^{y} W_{HP}(i) - S_R(y) \quad (11)$$

where $W_{RK}(y)$ is the Kuwaiti residential water demand (MIGD) in year y. The calculated correlation coefficient between the load (MW) and water demand (MIGD) from 1998 to 2010 is 0.97. This strong relation between the load power and water demand is utilized to determine $W_{RK}(y)$ as follows,

$$W_{RK}(y) = C_K \, P_{RK}(y) \quad (12)$$

where C_K is a constant coefficient with the unit MIGD/MW. $W_{nK}(y)$is the non-Kuwaiti residential maximum water demand and is determined as follows,

$$W_{RnK}(y) = C_{nK} \, P_{RnK}(y) \quad (13)$$

where C_{nK} is a constant coefficient with the unit MIGD/MW. $W_{HP}(i)$ is the water demand increment due to housing projects in year i. The savings, $S_R(y)$, in residential consumption due to conservation is calculated as follows,

$$S_R(y) = \sum_{i=y_o}^{y} W_R(y_o)S_{eW}(i) + \Delta W_R(i)S_{nW}(i) \quad (14)$$

where $W_R(y_o)$ is the residential demand in year y_o, $\Delta W_R(i)$ is the increment of residential demand in year i, $S_{eW}(i)$ and $S_{nW}(i)$ are the savings in existing buildings in y_o and new buildings, respectively. These savings parameters are the product of percentage saving per building times proportion of increment.

The maximum combined industrial, commercial and governmental water demand, $W_{ICG}(y)$, is calculated as follows:

$$W_{ICG}(y) = W_{ICG}(y_o)F_{GDP}(y) + \sum_{i=y_o}^{y} W_{ICG}(i) \quad (15)$$

$W_{ICG}(y_o)$ and $W_{ICG}(i)$ are the water quantities in year y_o and the increment due to projects in year i, respectively, of the maximum water demand of the industrial, commercial and government sectors.

5 Simulation Results

The demand behavior model was run under three oil price cases, namely, High, Base and Low cases. The three price cases are shown in Fig. 3. More details on the households, and development and industrial projects parameters, which are used in the simulation, are discussed in [10]. Fig. 4 and Fig. 5 show the expected electric load and water demand, respectively up to 2030. The conventional method forecasting results of MEW are superimposed on the three cases for comparison purposes.

It is expected that MEW case would have higher values due to the extrapolation method. However, the proposed demand model reflects the realistic demand which is bound by the GDP. The later is highly dependent on the oil revenues as a result of oil prices. In the Base case, the expected maximum electric load and water demand are 22 GW and 680 MIGD, respectively. Even the high case scenario, the forecasted load and water demands are considerably off with the MEW forecast results.

6 Conclusion

This paper presented an electricity and water demand model that is Kuwait specific. The model forecasts the electricity and water demands up to 2030. The analysis showed that the demands highly depend on the GDP. This conclusion is based on the correlations that were calculated between GDP and electric load and water consumption. This dependency is expected to continue as long as the economic diversification is at its current level. High economic diversification activity (e.g., above 25%

non-oil related revenues) is expected to reduce the non-Kuwaiti population and be more dependent on national workforce, and hence, the demands are found to decrease accordingly.

Other means to reduce the per capita consumption is by adopting energy conservation and demand side management programs. There is no indication in the near future in the country for adopting such programs, such as, tariff increase, laws enforcement on the use of energy saving materials, equipments, and devices. Therefore, the current consumption behavior is expected to continue and the electric load and water consumption is expected to be as mentioned in the Base case (assuming the oil price in the Base case).

References:

[1] O. Alsayegh, O. Almatar, F. Fairouz, and A. Almulla, A/C Systems Effect on the Long Term Power Demand, *Proceedings of the Institution of Mechanical Engineering Part A: Journal of Energy and Power*, Vol. 221, No. 1, 2007, pp. 67-75.

[2] L. Schipper, A. Ketoff, and A. Kahane, Explaining Residential Energy Use By International Bottom-Up Comparisons, *Annual Review of Energy*, Vol. 10, 1985, pp. 341-405.

[3] M. Wood, Kuwait's Energy Economy – Alternative Paths, *Engineering Congress on Alternative Energy Applications*, Kuwait, November 2-6, 2009.

[4] PACI, *Population and Buildings Year Book*, Public Authority for Civil Information, Kuwait, 2010.

[5] MEW, *Electricity and Water Statistical Year Book*, Ministry of Electricity and Water, Kuwait, 2010.

[6] G. Maheshwari, A. Almulla, Y. Al-Hadban, J. Rasquina and R. Suri, *Comparative Energy Needs of Air and Water-Cooled Air Conditioning Unit*, Final Report No. KISR 5107, Kuwait Institute for Scientific Research, Kuwait, 1997.

[7] M. Hajeeh, N. Burney, A. Al-Othman, S. Al-Fulaij and M. Bu-Hamad, *Development and Automation of Macro Economic models*, Final Report, KISR 8419, Kuwait Institute for Scientific Research, Kuwait, 2006.

[8] M. Al-Enezi, N. Burney, W. Awagh, S. Hamada, S. Al-Fulaij; and S. Al-Shamali. 2004. A Plan for Energy Conservation and Management of Electricity Demand for the State of Kuwait, Vol. I, *Electricity Demand in Kuwait: An Assessment of Demand Management Policies*, Final Report KISR 7338, Kuwait Institute for Scientific Research, Kuwait, 2004.

[9] N. Burney, G. Maheshwari, M. Al-Abdulhadi, M. Ramadan, D. Al-Nakib, B. Khalaf, M. Al-Ramadan, F. Al-Matrouk, A. Al-Othman and M. Al-Jazaf, *Assessment of the Electricity and Water Sector in Kuwait. Final Report*, KISR 4295, Kuwait Institute for Scientific Research, Kuwait, 1993.

[10] M. Marzouk, *Forecasting demand for energy in Kuwait*, Technical Report TE 39, Kuwait Institute for Scientific Research, Kuwait, 1979.

[11] O. Alsayegh, M. Absi Halabi, M. Wood, S. Aljandal, F. Alghimlas, A. Ramadan, S. Alhajraf and A. Alqattan, *Development of a Strategy for the Exploitation of the Renewable Energy in the State of Kuwait*, Final Report EA038C, Kuwait Institute for Scientific Research, Kuwait, 2012.

[12] KPC, Kuwait Petroleum Corporation Strategy. *KPC News* Vol. 91, No. 7, August, 2009.

[13] IEA, *Medium-Term Oil and Gas Markets*. International Energy Agency, Paris, France, 2011.

Table 1. Correlation coefficients between socio-economic parameters and electricity and water demands.

	GDP	Kuwaiti pop.	Total pop.
Peak load	0.91	0.98	0.95
Peak water demand	0.81	0.95	0.91
Oil income	0.99	-	-
Non Kuwaiti pop	0.93	-	-

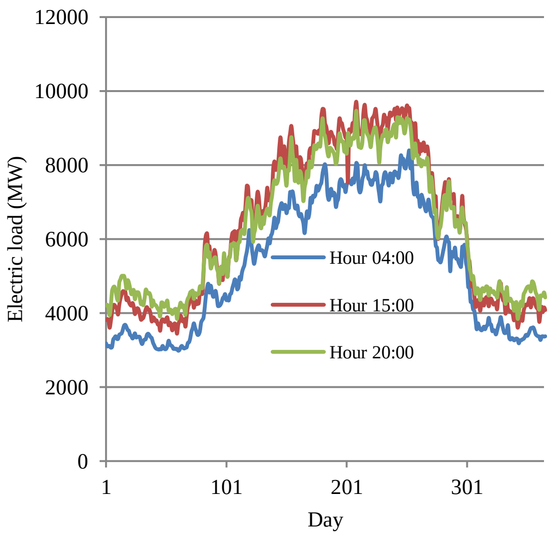

Fig. 1. Typical load profile in Kuwait (2008 load example).

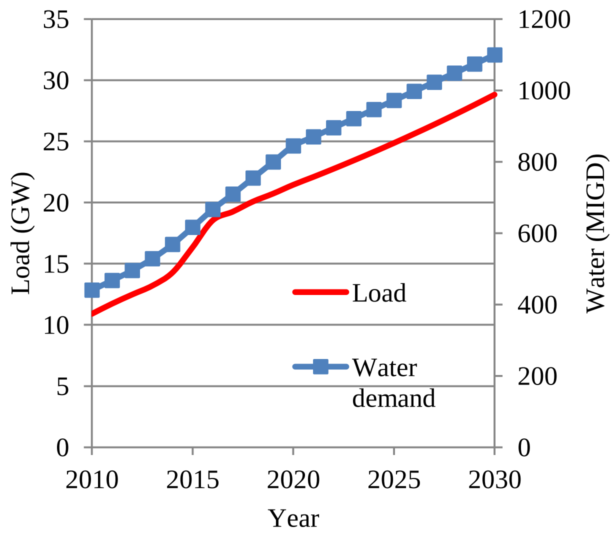

Fig. 2. Electricity and water forecast by MEW.

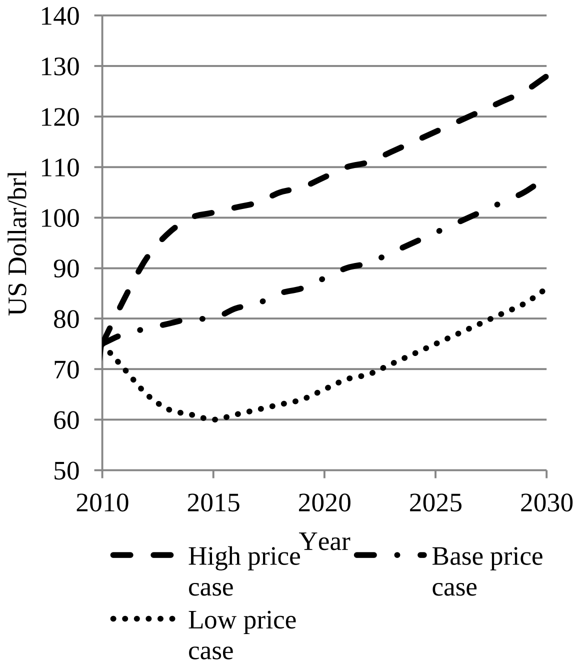

Fig. 3. Oil price scenarios.

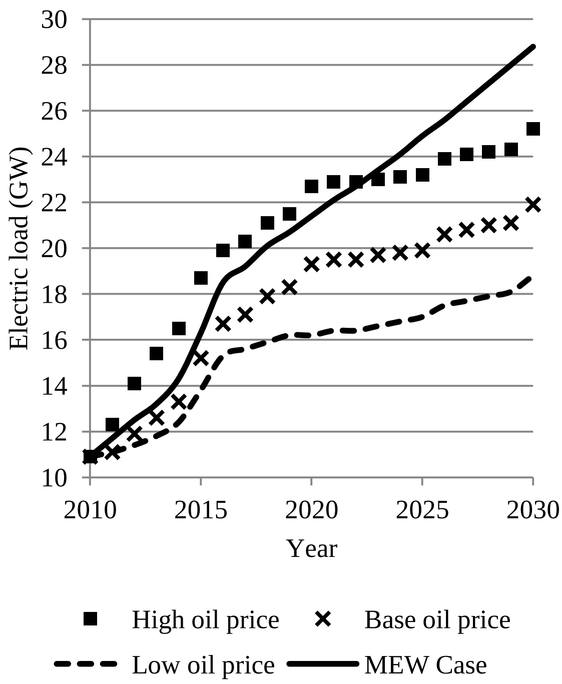

Fig. 4. Electric load scenarios.

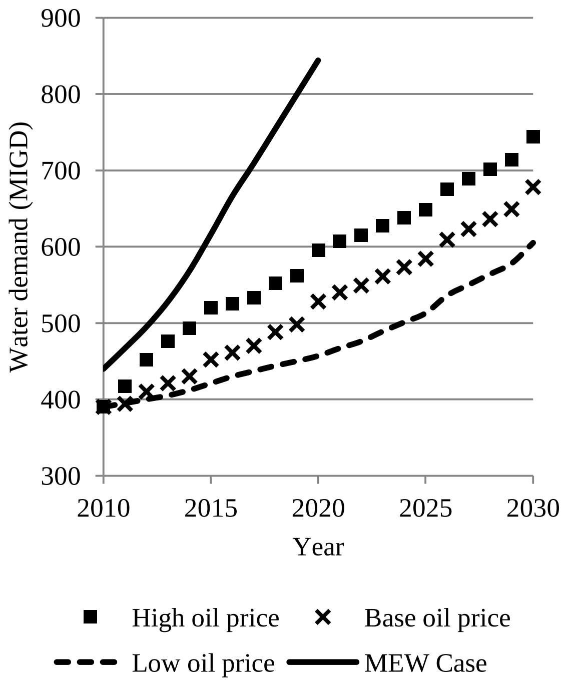

Fig. 5. Water demand scenarios.