Original Research

Energy Demand Model of the Household Sector and Its Application in Developing Metropolitan Cities (Case Study: Tehran)

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Abstract

Excessive energy consumption is one of the serious problems of large cities in Iran. In order to avoid unreasonable growth in energy use as well as conservation of natural resources, more attention should be paid to energy consumption patterns in metropolitan cities. Accordingly, the current study aims at analyzing energy demand and its related pollutants in the household sector in Tehran Metropolitan. The study includes a discussion of past trends and future scenarios to reduce greenhouse gas emissions in this sector. Using LEAP software and according to Iran's long-term development policies, energy demand and its greenhouse gas emissions were evaluated based on a baseline scenario within a long-term horizon (from 2011 to 2036). Energy demand was analyzed in the form of seven alternative scenarios. The obtained results indicated that natural gas consumption will increase to 21,084 MCM by the year 2036. In addition, the electricity consumption rate will grow to 21,084 million kWh over the studied period, if the current trend of consumption continues. The findings also revealed that maximum energy savings (equal to 23%) can be achieved by implementing Note 19 of National Building Regulations until 2036. Consequently, with implementation of this law, around 21.7% of total greenhouse gas emissions can be reduced in Tehran.

Keywords: energy demand, LEAP, emission, scenario analysis, Tehran

Introduction

Some issues threaten the world with a severe crises in the future, including rapid population growth, increasing human dependence on energy sources, excessive consumption of natural resources, limited energy resources, and environmental pollution [1-3]. Considering that proper use of energy ensures continuity of life and sustainable development in each community, preservation of valuable sources of energy and proper management of its consumption are the main issues that have been placed on the agenda by all countries. Given the importance of the energy supply issue, all policymakers, politicians, and stakeholders in the energy sector are concerned with finding solutions to the mentioned problems [4-6]. Energy consumption optimization is one of the most important tools to face these challenges. It means choosing the correct pattern to establish and apply procedures and policies for production and consumption of energy [7, 8]. In addition to ensuring continued economic growth, energy optimization reduces

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degradation of energy resources as well as adverse effects resulting from the incorrect use of energy on the environment and society. However, energy optimization measures can be evaluated from different aspects. Less use of fossil fuels will result in decreased greenhouse gas emissions as the main cause of global warming [9]. In other words, in addition to conservation of valuable energy reserves, optimization indirectly controls global warming.

The energy consumption optimization issue has become a world-wide concern in recent decades, being the focus of discussions in a variety of research. In 2010 Ekonomou applied artificial neural networks (ANN) to predict the long-term energy consumption in Greece [10]. He evaluated the presented ANN model as an appropriate tool in modeling and predicting energy consumption rates within a long-term period. In 2009 Kannan and Strachan compared energy systems and sectoral modeling approaches to model the UK residential energy sector under long-term decarbonisation scenarios [11]. They concluded with a discussion on the assumptions and drivers of emission reductions in different models of the residential energy sector. Vassileva et al. [12] conducted very little investigation on the integration of household' consumption trends, with the parameters influencing them and the characteristics of the provided feedback. They finally concluded that the monthly income is amongst the most influential factors determining electricity consumption, although only in high and low income groups.

In 2010 Menyah and Wolde-Rufael examined the long-run and the causal relationship between economic growth, pollutant emissions, and energy consumption for South Africa within the period 1965-2006 in a multivariate framework that includes labor and capital as additional variables [13]. They found a short-run as well as a long-run relationship among the variables with a positive and a statistically significant relationship between pollutant emissions and economic growth using the bound test approach to cointegration.

In 2010 Acaravci and Ozturk examined the causal relationship between carbon dioxide emissions, energy consumption, and economic growth by using autoregressive distributed lag (ARDL) bounds testing approach of cointegration for 19 European countries [14]. They found a positive long-run elasticity estimate of emissions with respect to energy consumption at 1% significance level in Denmark, Germany, Greece, Italy, and Portugal.

In 2012 Hamit-Haggar investigated the long-run and the causal relationship between greenhouse gas emissions, energy consumption, and economic growth for Canadian industrial sectors over the period 1990-2007 [15]. They concluded that there seems to be a weak one-way causality flowing from energy consumption and economic growth to greenhouse gas emissions in the long-run.

In 2005 Ghanadan and Koomey applied LEAP Software to explore alternative energy pathways in California [16]. In addition, some studies have been done in the field of reduction of CO_2 emissions caused by the electricity sector in Japan [17].

In 2011 Dagher and Ruble assessed the possibility of using renewable energies in Lebanon to reduce greenhouse gas emissions caused by electricity generation and consumption [18]. Environmental emissions and greenhouse gases in the Islamic Republic of Iran were studied by Awami and Farahmadpour in 2008 [19]. Using the above-mentioned model, research has been done in the field of greenhouse gas reduction in the household sector of Iran. In this study, improving efficiency and reforming energy carrier prices as well as related scenarios have been analyzed by reducing energy consumption rates from 2000 to 2010 [20]. In 2010 Shabbir and Ahmad conducted a study to monitor urban transport air pollution and energy demand in Rawalpindi and Islamabad using the LEAP Model [21]. Presently, more than 150 countries in the world use this software to meet their objectives [22].

The household sector, which is mainly associated with energy consumption of building units, has the highest contribution of energy consumption in Iran. About 35% of total hydrocarbure energy consumption in Iran is devoted to this sector [23]. The highest proportion of the total energy consumed by the household sector is allocated to heating, cooling, and lighting appliances. Total energy consumption per capita of the sector is far different from the relevant international standards. Tehran as Iran's capital city contains approximately one-fifth of the total population of the country.

The main carriers of energy in the household sector in Tehran are natural gas and electricity. The consumption of other hydrocarbure carriers of the sector is extremely small [23]. It is noteworthy that the number of household electricity subscribers in 2010 in Tehran was 2,737,443 members, and the average consumption per capita was 2,613 kWh in the same year [24, 25]. The population covered by gas services in this year totaled 15 million people (more than 4.2 million households). Currently, the per capita consumption equals 2,080 m^3 per household per year [26]. Despite such a high per capita consumption, there have been few studies done on environmental impact assessments of energy consumption in Tehran. The current research focuses on estimating air pollution caused by energy consumption of the household sector in Tehran. Our paper also analyzes different scenarios to answer the following questions:

- What are the main pollutants released by fuel consumption in the household sector of Tehran?
- What is the future trend of fuel consumption in the household sector of Tehran?
- What is the future role of alternative fuels in reduction of fossil fuels consumed by the household sector of Tehran?
- What are the most effective policies for management of fossil fuels consumed by the household sector of Tehran?

Finally, some appropriate policies are recommended to modify the pattern of energy demand in this sector.

Materials and Methods

LEAP Model

In current research, LEAP Software was applied to model energy demand and its greenhouse gas emissions in the household sector of Tehran through a long-term baseline scenario (from 2011 to 2036). The software is a tool for integrated modeling of energy, economy, and environment based on predefined scenarios [27]. In LEAP Software, the scenarios are developed based on consumption structure as well as energy conversion and production under a wide range of population alternatives, economic development, technology, price, etc. [22, 28, 29]. Despite the extensive data requirements, the model has a very simple structure and is suitable for predicting the effects of energy efficiency

Sector	End use	Device	Final energy	Environmental Emissions
Household	Space heating	Central	Natural gas and gas oil	CO / CO_2 / CH_4 / other
		Heater	Natural gas and gas oil	
		Package	Natural Gas	
		Electric heater	Electricity	–
		Heat pump	Electricity	–
		District heating	Natural Gas	CO / CO_2 / CH_4 / other
	Consumed hot water	Central	Natural Gas	CO / CO_2 / CH_4 / other
		Tankless water heater	Natural Gas	
		Wall package	Natural Gas	
		Electric water heater	Electricity	–
		Solar water heater	Sun	–
	Cooking	Oven	Natural Gas	CO / CO_2 / CH_4 / other
		Oven	Liquid Petroleum Gas (LPG)	
		Electric stoves	Electricity	
		Electric samovar	Electricity	
		Electric rice cooker	Electricity	
		Slow cooker	Electricity	
		Tea maker	Electricity	
		Electric fryer	Electricity	-
		Microwave oven	Electricity	
		Sandwich maker	Electricity	
	Space cooling	Evaporative cooler	Electricity	
		Gas cooler	Electricity	
		Compressor central chiller	Electricity	
		Central absorption chiller	Natural Gas	CO / CO_2 / CH_4 / other
		Solar absorption chiller	Electricity and Sun	-
	Lighting	Incandescent	Electricity	-
		Fluorescent T5	Electricity	-
		Halogen	Electricity	-
		CFLs	Electricity	-
		Fluorescent T8	Electricity	-
		LED	Electricity	
		PV-LED	Electricity	-
	Annealing	Refrigerator	Electricity	-
		Fraser	Electricity	-
		Fridge freezers	Electricity	-
		Optimum	Electricity	-
	Appliances	Vacuum cleaner	Electricity	-
		Television	Electricity	-
		Computer	Electricity	-
		Meat grinder	Electricity	-
		Iron	Electricity	-
		Washing machine	Electricity	-
		Dishwasher	Electricity	-
		Ventilation fans	Electricity	-
		Mixer	Electricity	-
		Juicer	Electricity	-
		Treadmill	Electricity	-
		Sewing machine	Electricity	-
		Others	Electricity	–

[Energy intensity (GJ/household)]
[Emission factor (g/GJ)]

Fig. 1. Tree structure of energy demand model in Tehran.

policies. Generally, LEAP is made up of a hierarchical structure that has four levels: section, subsection, end-use, and device [30, 31].

In the branches, energy flows from the most distal consumption part (device and technology) toward higher levels. Actually, total energy demand is derived from calculating demand rate for each branch and sub-branch in tree structure. In spite of the simple structure and easy computational relationships, a large volume of data is needed to run the model, which is not always possible. Fig. 1 shows the tree structure of the model as well as its required information. In one of the energy demand modeling methods, energy demand of each activity is obtained by multiplying two factors: activity level and energy intensity. Effective energy consumption for each level of activity in demand network is calculated by this model. After summarizing the amount of energy consumption at different levels of activities, sectoral demand and total consumption can be calculated. In this model, the amount of the required effective energy in household sector is dependent on various factors such as household consumption structure and patterns, the number of residential units, efficiency of energy-consuming equipment, etc.

Calculations

For calculating demand rate in Tehran, in addition to activity levels, it is necessary to specify energy intensity in all end-use branches. For example, natural gas and electricity are used as energy carriers by each household in Tehran to meet its cooking requirement. Therefore, it is required to determine the annual consumption rate of the carriers in cooking sub-section.

Energy demand in this model is obtained from the following equation:

$$Energy\ Use = \sum_{i=1}^{n} Q_i \times I_i \quad (1)$$

...where:
Q_i – quantity of activity level i
I_i – intensity of energy use of activity level i

As mentioned earlier, the activity level of Q_i is dependent on different factors such as total population, a proportion of the population using activity level of i and so on. Accordingly, the activity level of (i) is calculated from the following equation.

$$Q_i = N_i \times P_i \times M_i \quad (2)$$

...where:
Q_i – quantity of activity level i
N_i – number of customers eligible for end-use i
P_i – penetration (total units/total customers) of end-use service i (can be>100%)
M_i – magnitude or extent of end-use service i

N_i parameters, including the number of residential households and the area of residential units (square meters), can have different definitions. Selection of definition type is associated with access to type of data available in the subsection. The calculation manner of energy consumption intensity for several end-use sections of the mentioned model is given in the following:

According to field studies conducted by the National Iranian Gas Company [32], space heating, hot water consumption, and cooking, respectively, allocate themselves 63%, 28%, and 9% of total final consumption in Tehran.

Therefore, the intensity of natural gas consumption for each type of end-use can be calculated by the following equation:

$$\alpha + \beta + \delta = 100 \quad (3)$$

...where:
α – percentage of space heating
β – percentage of hot water consumption
δ – percentage of cooking

$$E_{SPt} + E_{HWt} + E_{Cot} = E_{totalt} \, E_{totalt} / H_{totalt} \quad (4)$$

...where:
E_{SPt} – consumption intensity for space heating (m^3 per household)
E_{HWt} – consumption intensity for consumed hot water (m^3 per household)
E_{Cot} – consumption intensity for cooking (m^3 per household)

$$E_{SPt} = \alpha\, E_{Total\ t}/H_{Total\ t}$$
$$E_{HWt} = \beta\, E_{Total\ t}/H_{Total\ t} \quad (5)$$
$$E_{Cot} = \delta\, E_{Total\ t}/H_{Total\ t}$$

Due to the relatively low price of natural gas compared to electricity, households exclusively use gas for all heating and cooking purposes. According to state regulations, households do not have access to petroleum products; therefore natural gas is the main fuel in Tehran.

Intensity of Electricity Consumption for Cooling and Other Purposes

The following equation is used to calculate intensity of electricity consumption for cooling and other purposes:

$$I = \sum h_i.P_i.X_i \times 0.365 \quad (6)$$

...where:
I – intensity of electricity consumption (KW hours per year per household)
P_i – power consumption of i^{th} device (such as iron, refrigerator, gas cooler, etc.) (W)
h_i – daily consumption hours for i^{th} device
X_i – percentage of households consuming the i^{th} device (percentage of households consuming rice cooker or microwave). For example, electrical power consumption in cooking is as follows:

$$I_{coocking} \sum_{i=1}^{3} h_i \times P_i \times X_i \times 0.365 =$$
$$= 180 \times 0.07 + 180 \times 0.02 = 21.6 \ ({KWh}/{Hh} - yr) \quad (7)$$

Given the percentage of final consumers, the power consumption rates of electrical samovar, slow cooker, and rice cooker were calculated to determine the intensity of power consumption for cooking.

Scenario Making

In this research, energy demand and greenhouse gas emissions were evaluated by a baseline scenario over a long term (from 2011 to 2036). Energy demand was studied in the form of 7 alternative scenarios, as follows:

Basic Scenario

In this scenario, economic growth and other socioeconomic indicators are going to be exactly the same as the current trend. In this case, it is assumed that no policy will be authorized.

Energy Management Scenario

In this managerial scenario, the impacts of seven different policies such as energy efficiency, reducing consumption, and Note 19 of National Building Regulations, etc. were investigated on reduction of energy demand as well as greenhouse gas emissions.

Scenario 1: Using Energy-Efficient Light Bulbs

In this scenario, replacement of incandescent light bulbs with energy-efficient light bulbs was evaluated. Incandescent lamps produce light with high energy loss so that more than 90% of its consumed energy is converted to heat. It should be noted that the lifetime of energy-efficient light bulbs is 8-10 times longer than incandescent lamps.

Scenario 2: Implementation of Note 19 of National Building Regulations

In accordance with Article 33 of the Iranian Organization of Engineering (IOE), the Ministry of Housing and Urban Development (MHUD) is fully responsibility for supervising implementation of national building rules and regulations in designing and using all buildings. On the basis of this article, MHUD has published national regulations on 20 notes in which the 19th note is related to energy savings in buildings. Currently, implementation of Note 19 of National Building Regulations is obligatory for all public buildings. Since 2005 onwards, it has been mandatory for all private buildings situated in Tehran and subordinate cities, while for buildings located on other cities and provinces the regulation must be obligatory according to a predefined time schedule. Note 19 of National Building Regulations makes it obligatory to observe measures including replacement of double-glazed windows, installation of thermostatic valves, installation of Building Management System (BMS) in engine rooms, insulation of external walls in buildings and minimization of joints in buildings. In 2005 the overall implementation ratio of the regulation was only 14% in all districts of Tehran, most of which was related to the use of double-glazed windows and insulation of pipe installations. Thermal insulation in walls and ceilings has been observed in less than 10% of cases investigated in Tehran. The conducted surveys in Tehran from 2006 to 2007 indicated that Note 19 was implemented in less than 20% of buildings and it was too minimal in other provinces (FCOC, 2010). In this scenario, it was assumed that the time schedule is exactly the same as the previous one and the regulation was enforced in 2011. Besides, it was supposed that Note 19 of National Building Regulations will be observed in all new buildings until 2019.

Scenario 3: Expanding the Use of Solar Energy

Tehran has great potential for utilization of solar energy in terms of geographical location and solar radiation. Conducted research and surveys reveal that only solar energy can be used as renewable energy in Tehran.

Scenario 4: Generation of Decentralized Electric Power Systems

Regarding the applicability of Combined Heat and Power (CHP) technology in the world and its amount of energy savings, the forth scenario focused on generation of decentralized electric power systems. Accordingly, it was assumed that the utilization percentage of the technology in the household sector will be started from 2015, and it will reach 1% in 2020 and 5% in 2036.

Scenario 5: Migration from Tehran

Considering a proposal to transfer departments and large ministries out of Tehran, the plan was investigated as a separate scenario in the current study. Accordingly, it was supposed that only 7% out of the entire city population will migrate by the year 2036. It is worth noting that, based on the proposed long-term planning of the government, 10 to 15% of the residents should be transferred out of Tehran.

Scenario 6: Using Heat Pumps

Although heat pump technology has a special place in all energy scenarios around the world, it is in its early stages in Iran. In this research, it is predicted that its application rate reach 3-5% by 2036.

Scenario 7:
Appliance Improvement

In this study, two strategies were considered to improve the efficiency of equipment and appliances.

A – obligating appliance importers to import high-quality products with low energy consumption labels

B – obligating household appliance manufacturers gradually to improve energy labels from G to A (2012-20).

Scenario 8:
Energy Management Scenario

This scenario examines integration and simultaneous implementation of the seven scenarios presented in the previous sections. Considering the overlap between the scenarios, it represents the impact of implementing an integrated energy management program on energy consumption rate as well as potentials for energy efficiency improvement in Tehran.

Result and Discussion

The Results Obtained from the Baseline Scenario

As mentioned earlier, LEAP Model was run under the alternative scenarios to estimate the household energy demand in Tehran for the years between 2006 and 2036. Greenhouse gas emissions for the baseline and alternative scenarios were also estimated in this research. Fig. 2 demonstrates total consumption rate of energy carriers in the household sector of Tehran. The figure shows that if the current trend of energy consumption continues, natural gas and electricity consumption rates will be respectively equal to 85 and 95 million barrels of oil equivalent by 2036. In other words, there will be a steadily rise equal to 30% in electricity and natural gas consumption in the next 25 years.

The results of the reference scenario have revealed the need to adopt energy optimization policies now more than ever. Therewith, the potentials for energy savings in the

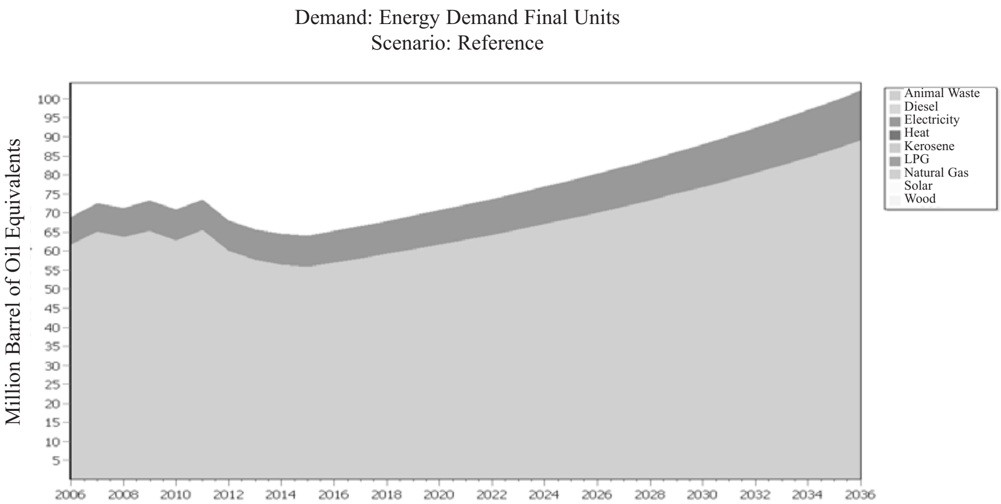

Fig. 2. Combining the consumption rate of energy carriers in the household sector of Tehran in the reference scenario.

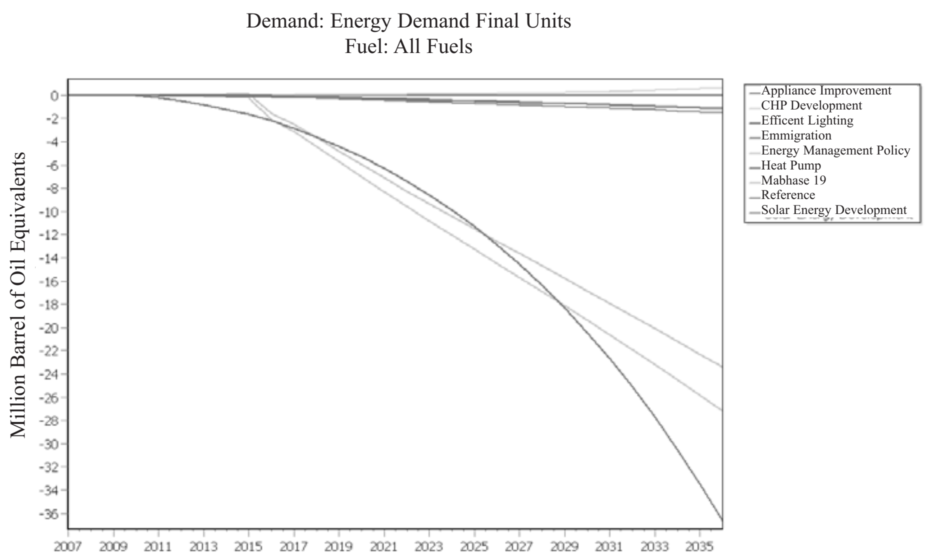

Fig. 3. Potentials for energy savings given the considered scenarios.

Table 1. The implementation impact of Note 19 of the National Building Regulations on electricity consumption and its comparison with the reference scenario (Billion kWh).

Scenarios	2011	2016	2021	2026	2031	2036
Note 19	13.1	13.4	14.3	15.5	17.1	19.1
Reference scenario	13.1	13.5	14.9	16.6	18.6	21.1
Total	26.2	26.8	29.2	32.1	35.7	40.2

household sector of Tehran were accurately studied to determine which section is more prone to implement energy optimization policies. The obtained findings are depicted in Fig. 3. According to the figure, Note 19 of National Building Regulations, migration and BMS, respectively, will be the most effective strategies to control excessive energy consumption by 2036. In the meantime, no significant energy savings will be observed by expanding the use of solar energy, heat pump, or CHP technologies. In the case of using BMS systems, a gradual rise in energy savings (approximately 8%) is expected to be achieved by the year 2036 while the impact of migration on the amount of savings (just short of 25%) will be more tangible. The cumulative effects of simultaneous implementation of all the scenarios under the title of "Energy management scenario" on energy savings is out of the question. There will be a marked improvement of almost 45% in energy savings if the energy management scenario is implemented properly. As shown in Fig. 3, by implementing Note 19 of National Building Regulations, maximum energy savings equivalent to 23% can be achieved by 2036. In other words, with law enforcement, 21.7% of greenhouse gas emissions will be mitigated in the city.

Table 1 presents the implementation impact of Note 19 of National Building Regulations on reducing electricity consumption by Tehran households. Since the base year onwards, the effectiveness of the regulation will be more noticeable. It should be mentioned that there are 300 sunny days in Tehran. This shows that the city is prone to expanded use of solar energy. Therewith, "expanding the use of solar energy" was investigated as a separate scenario.

Fig. 4 illustrates the increasing role of the use of solar energy in Tehran in a 30- year period from 2006 to 2036. As the figure suggests, the tendency for solar energy has gradually increased, and the consumption rate continues to grow until 2036. It is expected that the consumption rate will reach its peak (almost 0.5 million tones of oil equivalent) by 2036. Despite the growing trend of solar energy consumption, a significant gap will remain (approximately 10 million tons of oil equivalent) between solar and fossil fuel energy consumption rates.

Interpreting the Findings of the Scenarios

Table 2 gives the share of each scenario in energy consumption in Tehran. As Table 2 shows, energy management policy will be able to reduce energy consumption of the carriers equal to 51.5 million barrels of oil equivalent. Meanwhile, appliance improvement, heat pump, CHP development and efficient lighting will impose no impact on controlling the consumption rate.

Fig. 5 illustrates the role of different scenarios in reduction greenhouse gases until 2036. It is forecasted that energy management policy (the eighth scenario) will dramatically reduce greenhouse gas emissions from around 23 million metric tons of carbon dioxide equivalents (MMTCDE) to just less than 16 MMTCDE within the considered period. Migration of the residents (the fifth scenario) will be the second effective strategy toward controlling greenhouse gas emissions in Tehran so that a decline of approximately 5 MMTCDE will be achieved, if only 7% out of the whole

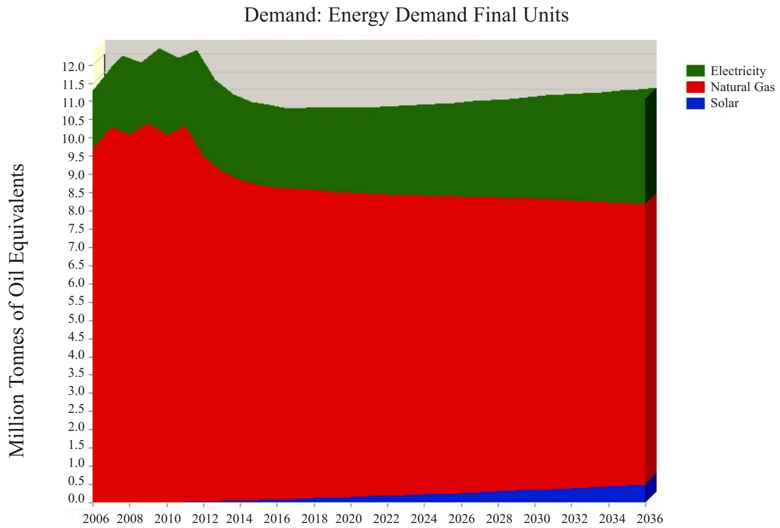

Fig. 4. Expanded use of solar energy in Tehran in 2036.

Table 2. The energy carrier consumption in the Tehran household sector (million barrels of oil equivalent).

Scenarios	2011	2016	2016	2016	2021	2026	2031	2036
Appliance Improvement	73.5	65.3	65.3	65.3	72.2	80.4	90.2	102.1
BMS	73.3	64	64	64	68.6	74.4	81.4	90.2
CHP Development	73.5	65.3	65.3	65.3	72.3	80.6	90.5	102.8
Efficient Lighting	73.5	65.1	65.1	65.1	71.9	79.8	89.3	100.9
Emigration	73.3	63.1	63.1	63.1	65.9	67.5	67.5	65.5
Energy Management Policy	73	60.5	60.5	60.5	58.4	56.3	53.7	50.6
Heat Pump	73.5	65.3	65.3	65.3	72.2	80.4	90.2	102.1
Note 19	73.5	63.7	63.7	63.7	65.1	67.8	72.3	78.7
Reference	**73.5**	**65.3**	**65.3**	**65.3**	**72.2**	**80.4**	**90.2**	**102.1**
Solar Energy	73.5	65.2	65.2	65.2	71.9	79.9	89.4	101
Total	734.1	642.9	642.9	642.9	690.9	747.5	814.6	895.9

city population migrate by the year 2036. Considering the basic scenario, greenhouse gas emissions will reach about 34 MMTCDE in 2036. In other words, the eighth and fifth scenarios will respectively reduce greenhouse gas emissions equal to 18 and 12 MMTCDE in 2036. As the figure suggests, using energy-efficient light bulbs and improving appliances will impose no dramatic impact on controlling greenhouse gas emissions; however, their deterrent role shouldn't be ignored. Expanded the use of solar energy and CHP development will both almost equally be involved in reducing greenhouse gas emissions (nearly equal to 2 MMTCDE).

Fig. 6 depicts electricity demand of the household sector in Tehran during the period between 2006 and 2036. Based on the reference scenario, if the current trend continues, the demand for electricity will rise to approximately 21 billion kilowatt hours (kWh) in Tehran in 2036. As the results show, implementation of energy management policy (the eighth scenario) will result in a significant decline equal to 10 billion kWh in electricity demand by the year 2036. In the meantime, migration will impose an undeniable impact on reducing the demand for electricity in 2036. Accordingly, a reduction equal to 17 billion kWh will be predicted to achieve in electricity demand by migration of only 20% of the entire city population. Solar energy development, BMS, energy-efficient light bulbs, appliance improvement and Note 19 have almost the same effect in reducing electricity demand (equal to 3 billion kWh). It should be mentioned that heat pump and CHP development will not be able to play an important role in reducing demand for electricity until 2036.

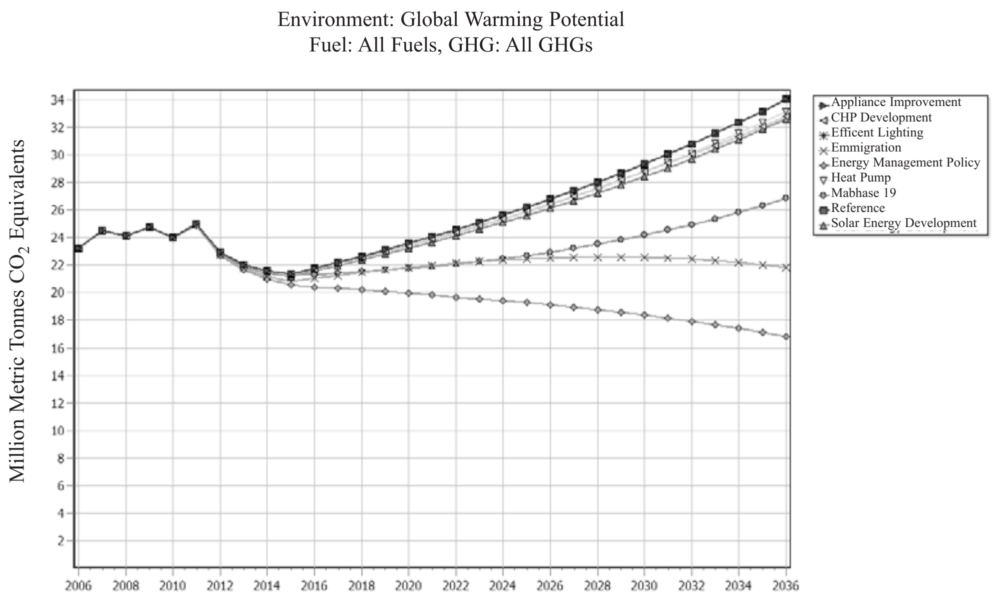

Fig. 5. The trend of greenhouse emissions regarding the considered scenarios.

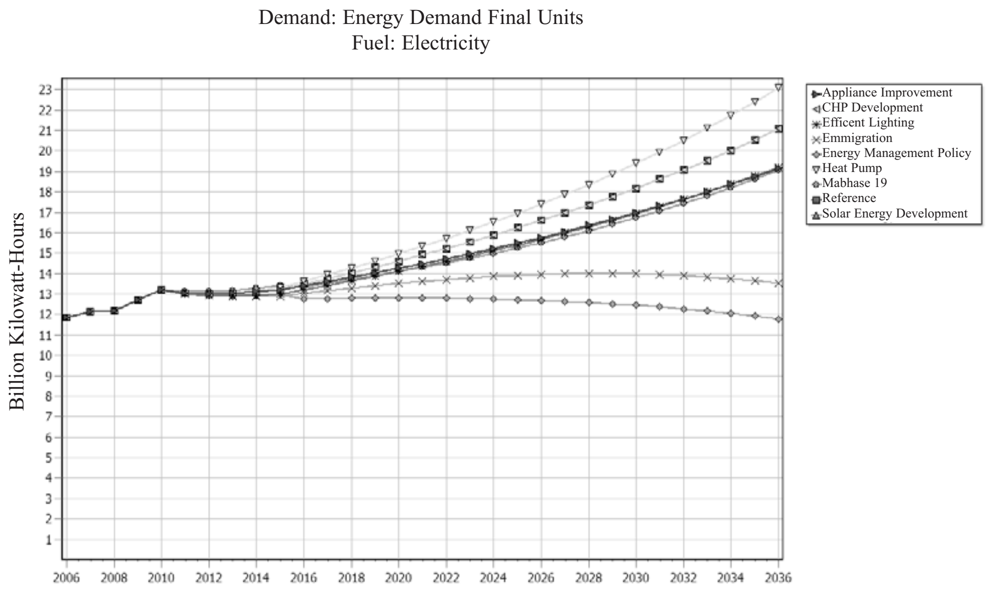

Fig. 6. Prospects for electricity demand in the Tehran household sector.

Fig. 7 demonstrates predictions for natural gas demand of the household sector in Tehran within the period of 2006-2036. As in previous cases, maximum reduction (equal to 8 billion cubic meters of natural gas (BCM)) in demand for natural gas will be achieved by implementing the energy management policy. Migration is the second priority managerial strategy, reducing about 5 BCM of natural gas demand in Tehran within the considered period. Implementation of Note 19 of National Building Regulations will cause a reduction of 4 BCM of natural gas demand in Tehran. As the fourth most effective strategy, BMS will decrease natural gas demand equal to 2 BCM by the year 2036. Development of CHP and solar energy, with a similar amount of influence, will decrease natural gas demand tantamount to 1 BCM. Appliance improvement and energy-efficient light bulbs won't be able to impose any noticeable impact on declining the demand for natural gas during the studied period.

Conclusions

Nowadays, energy consumption optimization is considered one of the pillars of principled management based on sustainability indices in metropolitan cities. Ever-increasing fuel demand, uncontrolled population growth, and limited resources have directed decision-makers toward taking appropriate decisions for management of fuel and energy consumption in megacities. Accordingly, the current study was conducted to estimate energy demand by household sector in Tehran within the period 2006-36. The research findings revealed that due to the growth of urban households in Tehran by the year 2036, the consumption rate of natural gas and electricity will respectively reach 13,742 MCM and 21,084 Billion kWh if the current energy consumption patterns are not modified. According to the defined scenarios, maximum energy savings will be obtained in the case of integrating a

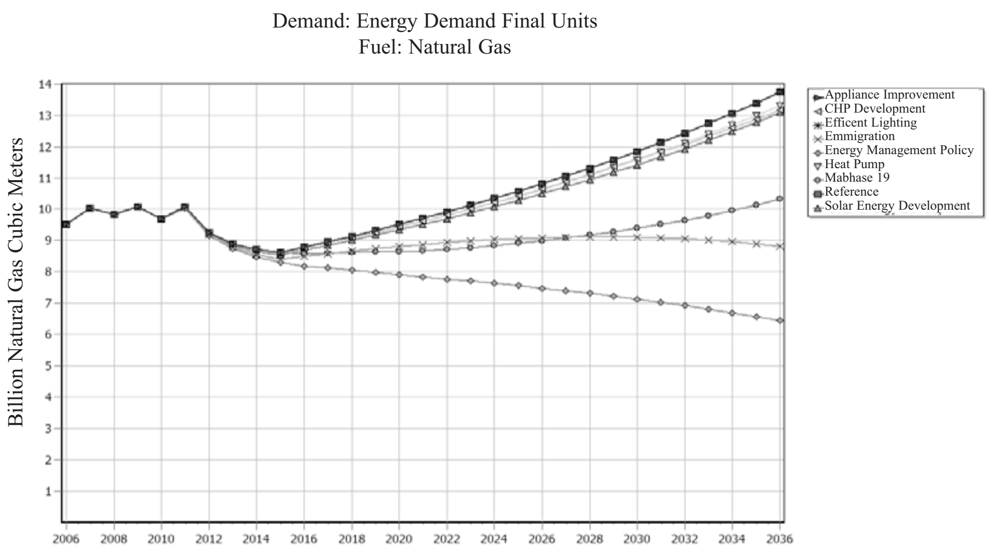

Fig. 7. Prospects for natural gas demand of the Tehran household sector.

variety of relevant managerial strategies such as solar energy development, population decentralization policies, and the use of energy-efficient light bulbs, etc. Among the proposed strategies, it is predicted that implementation of Note 19 will greatly help the savings in energy demand (equal to 20%) by the year 2036. Currently, construction does not meet the required standards; hence, buildings are one of the major sources for energy waste in Tehran.

Tehran, with an estimated population of 8,429,807, is one of the largest cities in the Middle East. The ever-growing population of the city will result in a dramatic rise in energy demand by 2036. Population control effects on energy demand rate is quite impressive so that a slight reduction in population of the city (around 20%) will lead to significant energy savings (about 5 BCM of natural gas and 17 billion kWh of electricity).

Although the policies including development of CHP, solar energy and heat pumps are not be able to noticeably control energy demand of Tehran in the short-term, however, they will be helpful in a long-term prospect.

Generally, the Iranian government should take immediate measures to reduce greenhouse emissions as well as energy consumption. Then the measures can be extended on a national level.

- The government should obligate comprehensive implementation of Note 19 of National Building Regulations in all buildings under construction in Tehran from 2011 onward. Note 19 includes a variety of measures, including external wall insulation in under construction buildings, double-glazed windows with thermal break, and utilization of energy-efficient lighting, as well as the use of equipment such as package, wall heater, and engine room with label B or A.
- Appliances with energy label A should be allowed to be imported. The government should also bear part of the price in the form of subsides.
- After a 5-year period, the government should encourage household producers through supportive and strategic legislations to produce energy-efficient florescents such as T-8 and CFLs. Besides, the government should ban the import of systems and light bulbs.
- The government should continue to expand the use of solar water heaters and provide required subsidies. In this respect, the necessary training for the maintenance of household solar heaters should be offered.
- The government should prepare a clear policy with a schedule and assess the savings accurately.

As a fossil-fuel-rich country, Iran has sought to maximize energy savings in recent years in order to efficiently use such precious materials in various industries and preserve it for later generations. Due to the effectiveness of Note 19 developing countries also can implement it in their own countries. It should be mentioned that cost-benefit analysis has also been conducted for the current study, which will be presented by a new article.

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