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Improvement of energy demand forecasts using swarm intelligence: The case of Turkey with projections to 2025

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Abstract

The energy supply and demand should be closely monitored and revised the forecasts to take account of the progress of liberalization, energy efficiency improvements, structural changes in industry and other major factors. Medium and long-term forecasting of energy demand, which is based on realistic indicators, is a prerequisite to become an industrialized country and to have high living standards. Energy planning is not possible without a reasonable knowledge of past and present energy consumption and likely future demands. Energy demand management activities should bring the demand and supply closer to a perceived optimum. Turkey's energy demand has grown rapidly almost every year and is expected to continue growing. However, the energy demand forecasts prepared by the Turkey Ministry of Energy and Natural Resources overestimate the demand. Recently many studies are performed by researchers to forecast the energy demand of Turkey. Particle swarm optimization (PSO) technique has never been used for such a study. In this study a model is proposed, using PSO-based energy demand forecasting (PSOEDF), to forecast the energy demand of Turkey more efficiently. Although there are other indicators as well, gross domestic product (GDP), population, import and export are used as basic energy indicators of energy demand. In order to show the accuracy of the algorithm, a comparison is made with the ant colony optimization (ACO) energy demand estimation model which is developed for the same problem.

Keywords: Energy demand; Swarm intelligence; Turkey

1. Introduction

Energy transitions are the driving force for economical and technological development. Understanding long-term energy transitions and development trajectories is a great challenge in moving towards sustainable development in a globalizing world, especially for developing countries, like Turkey. Energy transitions are defined as; investments in possibly cleaner technologies to replace and expand the depreciating capital stock to meet growing energy demand. When considered a longer time horizon, significant changes in energy technologies and consumption could be observed.

Energy is generally expected to play a major role in achieving economic, social, and technological progress and to complement labor and capital in production (Ebohan, 1996; Templet, 1999). Energy use increases as more economic sectors develop and more channels of flow are opened (Templet, 1999). Global energy demand will increase 60% more from 2002 to 2030—with yearly average 1.7% (if no action is taken) (Tiris, 2005).

Development trajectories of energy can be characterized by sectoral changes in the economy (Lise and Van Montfort, 2007), population, import and export of the country. As already noted in the literature (Akarca and Long, 1980), there is a general agreement that a relationship exists between energy consumption and gross domestic product. Ebohan (1996) examined the causal directions between energy consumption and economic growth (proxied by GDP and GNP) for Nigeria and Tanzania.

As one of the basic indicators for energy demand, not only GDP is important but the structure of GDP as well.

Turkey has dynamic economic development and rapid population growth. As the Turkish economy grows, so does demand for energy. In practical terms, it means we are using energy more widely through increasingly efficient

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homes, cars, appliances and businesses. Therefore to develop and adopt efficient energy practices and technologies, is extremely important and prudent. The government should be advised to secure primary energy supplies and conversion capacity to enable the country to industrialize. The rapid growth from a low base suggests that Turkey still has to catch up with the industrialized nations in terms of economic development and industrialization.

With the beginning of planned development period in 1963, the combined demands of industrialization and urbanization in Turkey nearly tripled energy consumption in the 1960s and 1970s. The summary of primary energy production and consumption rates and GDP, with 5-year planning periods is given in Table 1. The growth rate of primary energy consumption is greater then the growth rate of primary energy production. The gap between production and consumption of primary energy gets larger for Turkey and consequently the development gap between Turkey and the industrialized nations is not closed yet. It is obvious that, the economic growth in the future will be matched by strong growth in energy demand.

Turkey is highly dependent to imports to satisfy its energy needs. Due to lack of fossil resources, Turkey's dependency level is around 70%, which may rise over 80% by 2030. By 2010, Turkey's oil demand will increase by 96%. Currently Turkey satisfies 40% of its energy needs by oil. 90% of its oil supplies are imported from the Middle East (Saudi Arabia, Iran, Iraq and Syria) and the Russian Federation. When it is compared to the European Union, Turkey depends on import more and the volatilities in the Middle East may affect Turkey more, therefore Turkey has to diversify its energy sources. In 2001, natural gas was constituting 19% of its energy needs. It will rise to 32% by 2010 while oil will be 33%. This makes Turkey highly dependent, since Turkey imports almost all of its gas supplies. Turkey's electricity demand has been growing very rapidly. It has increased from 56.8 TWh in 1990, to 118.5 TWh in 2000, with an annual average growth rate of 8.1%. The growth in electricity generation in recent years was below growth in electricity demand. Therefore, Turkey has become a certain importer of electricity since 1997. The electricity demand of Turkey is expected to increase 555.7 TWh in 2020. The installed electricity capacity has reached from 16.3 GW in 1990, to 26.1 GW in 1999, and is projected to increase to 104.9 GW in 2020.

Table 1
Growth rates for primary energy production, primary energy consumption and GDP (%)

Planning periods	GDP	Production	Consumption
1. Planning period (1963–1967)	6.6	6.9	5.5
2. Planning period (1968–1972)	6.3	1.9	7.4
3. Planning period (1973–1977)	5.2	1.9	7.3
4. Planning period (1973–1977)	1.7	2.7	3.8
5. Planning period (1979–1983)	4.7	4	6.5
6. Planning period (1985–1989)	3.5	0.9	4.4
7. Planning period (1996–2000)	3.5	1.3	4.5
8. Planning period (2001–2005)	6.7	1.2	6.1

Medium and long-term forecasting of energy demand based on realistic indicators is a prerequisite to become an industrialized country and thus to have high living standards. Overestimating the energy demand may cause redundancy in resources, while underestimating may cause series energy crises. In this study, a model which is using particle swarm optimization (PSO) (PSO-based energy demand forecasting (PSOEDF)) is proposed to forecast the energy demand of Turkey more efficiently. In the following section, a brief description of the problem and literature survey about the solution is given. In the Section 3, the concept of swarm intelligence and the basic PSO algorithm is given. Energy demand forecasting model, that is developed for Turkey case, is explained in the Section 4. Results of energy demand forecasting obtained by PSOEDF and future projections are presented in Section 5. Finally, the study is concluded in Section 6 with suggestions on future researches.

2. Literature review

The studies on energy demand forecasting of Turkey began at 1960s. The state planning organization (SPO) initiated the use of simple regression techniques for energy forecasting. Similar studies later have been continued by the Ministry of Energy and Natural Resources of Turkey (MENR). These early forecasts consistently predicted higher values than the consumptions, that actually occurred. Starting from 1984, several econometric modeling techniques have been employed for energy demand forecast. The model for analysis of energy demand (MAED) is the most commonly used technique by MENR. However, the energy demand forecasts determined by MAED still overestimates demand. Deviations from realization in the MAED applications between the year 1986 and 2000 can be seen in Fig. 1. There may be several reasons of this projection failure. Utgikar and Scott (2006) conducted a research to identify and analyze the causes of failures in energy forecasting studies.

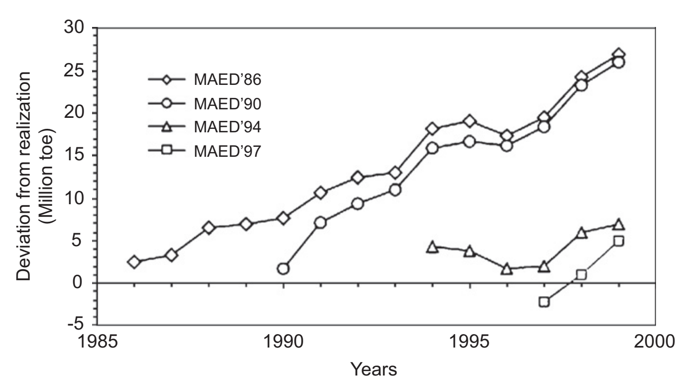

Fig. 1. Deviations from realization in the MAED applications between the years 1986 and 2000 (Ediger and Tatlidil, 2002).

Several studies are presented to propose some models for energy demand policy management. Gilland (1988) developed an energy demand projection of the world for the years 2000 and 2020. Gungor and Arikan (2000) developed a method to compare natural gas, imported coal, and nuclear power plants in terms of long-term production economy. Demirbas (2001) made a study about future developments and energy investments in Turkey. Isik (2004) presented a study that shows supply and demand situation in Turkey and examines its background. Ediger and Camdali (2007) made historical investigation from 1988 to 2004 to analyze energy and exergy efficiencies of Turkey. According to Kilic and Kaya (2007), 3500 MW of energy generation capacity systems per year, and private and public financial sources must be evaluated in order to meet the energy demand of Turkey.

Many studies are made for strongly estimating the energy demand of Turkey. Since the main purpose of these efforts is to develop a model that closes the gap between the energy demand predictions and observed energy demands, the problem is typically an optimization problem which tries to minimize the gap. A summary of techniques, used so far for energy demand forecasting is given in Table 2.

Dahl and Mcdonald (1998) developed a model to make forecasts based on country specific elasticities and made an analysis for 28 countries over the world. Ediger and Tatlidil (2002) proposed an approach that uses the analysis of cyclic patterns in historical curves to forecast the primary energy demand in Turkey. Ceylan and Ozturk (2004) developed a genetic algorithm (GA) energy demand (GAEDM) model to estimate energy demand based on economic indicators in Turkey. Yumurtaci and Asmaz (2004) proposed an approach to calculate future energy demand of Turkey, for the period of 1980 and 2050, based on the population and energy consumption increase rates per capita. Ozturk et al. (2005) developed two different nonlinear estimation models using GAs to forecast Turkey's electricity demand in future. Hobbs et al. (1998) used artificial neural networks (ANNs) for short-term energy forecasting. Sozen et al. (2005) also used ANN to forecast Turkey's net energy consumption (NEC). Ceylan et al. (2005) made an analysis for future estimation of the energy and exergy production and consumption of Turkey. Haldenbilen and Ceylan (2005) developed three forms of the energy demand equations in order to improve transport energy demand estimation efficiency for future projections based on GA notion. Toksari (2007) developed an ant colony energy demand estimation model for Turkey. Ediger and Akar (2007) used the autoregressive integrated moving average (ARIMA) and seasonal ARIMA (SARIMA) methods to estimate the future primary energy demand of Turkey from 2005 to 2020. Akay and Atak (2007) proposed an approach using gray prediction with rolling mechanism (GPRM) to predict the Turkey's total and industrial electricity consumption. Sozen and Arcakliogl u (2007) developed the energy sources estimation equations in order to estimate the future projections and make correct investments in Turkey using ANN approach.

Table 2
Studies for energy demand forecasting

Method used	Reference
Genetic algorithms (GA)	Ceylan and Ozturk (2004), Ozturk et al. (2005), Ceylan et al. (2005), Haldenbilen and Ceylan (2005)
Artificial neural networks (ANN)	Hobbs et al. (1998), Sozen et al. (2005), Sozen and Arcaklioğlu (2007)
Ant colony optimization (ACO)	Toksari (2007)
Autoregressive integrated moving average(ARIMA), seasonal autoregressive integrated moving average (SARIMA)	Ediger and Akar (2007)
Grey prediction with rolling mechanism (GPRM)	Akay and Atak (2007)
Linear regression (LR)	Yumurtaci and Asmaz (2004)

3. Swarm intelligence

Swarm intelligence is an attempt to design algorithms or distributed problem solving devices inspired by the collective behavior of social insects and other animal societies (Bonabeau et al., 1999). Ant colony optimization (ACO) and PSO are the most popular optimization frameworks based on the original notion of swarm intelligence. They are based on the repeated sampling of solutions to the problem at hand that means each agent provides a solution.

PSO is a population-based stochastic optimization technique developed in 1995 by Kennedy and Eberhart, which is inspired by social behavior of bird flocking and fish schooling. PSO shares many similarities with evolutionary computation techniques such as GAs. However, unlike GA, PSO has no evolution operators such as crossover and mutation. To apply PSO successfully, one of the key issues is to find how to map the solution of the problem into the PSO particle, which directly affects its feasibility and performance (Abraham et al., 2006).

PSO can be easily implemented and it is computationally inexpensive, since its memory and CPU speed requirements are low (Eberhart et al., 1996). Parsopoulos and Vrahatis (2002) conducted a survey to show the effectiveness of PSO algorithm for different types of problems.

The purpose of PSO is to optimize continuous nonlinear functions. In PSO, each agent is a particle-like data structure containing: the coordinates of the current location in the optimization landscape, the best solution point visited so far, the subset of other agents seen as neighbors. The system is initialized with a population of random solutions (particles) and searches iteratively through the *d*-dimensional problem space for optima by updating generations. Each particle keeps track of its coordinates (x_i) in the problem space which are associated with the best solution (fitness (f)) it has achieved so far (*pbest*). Another best value that is tracked by the particle swarm optimizer is the best value, obtained so far by any particle in the neighbors of that particle. This location is called *lbest*, when a particle takes all the population as its topological neighbors, the best value is a global best and is called *gbest*. The studies show that the PSO has more chance to "fly" into the better solution areas more quickly, so it can discover reasonable quality solution faster than other evolutionary algorithms.

The PSO concept consists of, at each time step, changing the velocity (v) of (accelerating) each particle toward its *pbest* and *lbest* locations according to Eq. (1). The new position of the particle is determined by the sum of previous position and the new velocity which is given in Eq. (2):

$$v_{ij}(t+1) = \omega v_{ij}(t) + c_1 r_1 (pbest_{ij}(t) - x_{ij}(t)) + c_2 r_2 (gbest_j(t) - x_{ij}(t)) \quad (1)$$

$$x_{ij}(t+1) = x_{ij}(t) + v_{ij}(t+1) \quad (2)$$

$$v_{ij} = \mathrm{sign}(v_{ij})\min(|v_{ij}|, v_{\max}) \quad (3)$$

Acceleration is weighted by a random term, with separate random numbers (r_1,r_2) between [0,1] being generated for acceleration toward *pbest* and *lbest* locations. The role of inertia weight ω at Eq. (1) is considered critical for the convergence of the algorithm. It is employed to control the impact of the previous velocities on the current one.

The paragraph below, provides an algorithm model for the general PSO method.

1. Initialize the size of particle swarm (n), and other parameters
2. Initialize the positions and velocities for all the particles randomly
3. While (the end criterion is not met) do
   (a) $t = t+1$;
   (b) Calculate the fitness value for each particle;
   (c) $gbest(t) = \arg\min_{t=1}^{n}(f(gbest(t-1)), f(x_1(t)), f(x_2(t)), \ldots, f(x_n(t)))$;
   (d) For $i = 1$–n
   (1) $pbest_i(t) = \arg\min_{t=1}^{n}(f(pbest_i(t-1)), f(x_i(t)))$
   (2) For $j = 1$ to dimension
   Update the jth dimension value of x_i and v_i according to Eqs. (1)–(3);
   (3) Next j;
   (e) Next i;
4. End while.

4. Energy demand forecast with PSO (PSOEDF)

In the preceding sections it was stated that four indicators were used to make an estimate of future energy demand. When the data in Table 3 is analyzed, it is observed that the population of Turkey has grown 0.63 times, the GDP has grown 3.43 times, while the import has

Table 3
Energy demand, GDP, population, import and export data of Turkey between 1979 and 2005 (TSI and MENR)

Years	Energy demand (MTOE)	GDP ($\$10^9$)	Population (10^6)	Import ($\$10^9$)	Export ($\$10^9$)	Growth rate (%) ($\$10^9$)
1979	30.71	82.00	43.53	5.07	2.26	-
1980	31.97	68.00	44.44	7.91	2.91	4.10
1981	32.05	72.00	45.54	8.93	4.70	0.25
1982	34.39	64.00	46.69	8.84	5.75	7.30
1983	35.70	60.00	47.86	9.24	5.73	3.81
1984	37.43	59.00	49.07	10.76	7.13	4.85
1985	39.40	67.00	50.31	11.34	7.95	5.26
1986	42.47	75.00	51.43	11.10	7.46	7.79
1987	46.88	86.00	52.56	14.16	10.19	10.38
1988	47.91	90.00	53.72	14.34	11.66	2.20
1989	50.71	108.00	54.89	15.79	11.62	5.84
1990	52.98	151.00	56.10	22.30	12.96	4.48
1991	54.27	150.00	57.19	21.05	13.59	2.43
1992	56.68	158.00	58.25	22.87	14.72	4.44
1993	60.26	179.00	59.32	29.43	15.35	6.32
1994	59.12	132.00	60.42	23.27	18.11	-1.89
1995	63.68	170.00	61.53	35.71	21.64	7.71
1996	69.86	184.00	62.67	43.63	23.22	9.70
1997	73.78	192.00	63.82	48.56	26.26	5.61
1998	74.71	207.00	65.00	45.92	26.97	1.26
1999	76.77	187.00	66.43	40.67	26.59	2.76
2000	80.50	200.00	67.42	54.50	27.78	4.86
2001	75.40	146.00	68.37	41.40	31.33	-6.34
2002	78.33	181.00	69.30	51.55	36.06	3.89
2003	83.84	239.00	70.23	69.34	47.25	7.03
2004	87.82	299.00	71.15	97.54	63.17	4.75
2005	91.58	361.00	72.97	116.77	73.48	4.28

grown 22 and the export has grown 31.5 times between the years 1979 and 2005. On the other hand, total energy consumption between the same years has grown 1.98 times. It can be easily seen that there is a tremendous increase in export, which means more industrialization. But rapid economic growth in Turkey has had less impact on energy consumption than might have been expected.

The level of future energy demand has important implications on future energy supplies for Turkey, with respect to availability of resources, cost and reliability of energy services, and environmental implications for meeting energy demand. Powerful tools are needed to make strong estimations of energy demand.

In energy demand forecasting the aim is to find the fittest model to the data. The fitness function of the model is given by

$$\mathrm{Min}\, f(v) = \sum_{i=1}^{m} s_i (E_i^{observed} - E_i^{predicted})^2 \tag{4}$$

where $E^{observed}$ and $E^{predicted}$ are the actual and predicted energy demand, respectively, m is the number of observations, and s_i is the weighting factor.

The PSOEDF searches the most fitted members by minimizing the error. Forecasting of energy demand based on economic indicators was modeled by using both linear and quadratic regression models. Linear form (Y_{linear}) can be expressed as

$$Y_{linear} = w_1 + w_2 + X_1 + w_3 X_2 + w_4 + X_3 + w_5 X_4 \tag{5}$$

and quadratic form ($Y_{quadractic}$) can be expressed as

$$\begin{aligned} Y_{quadratic} = {} & w_1 + w_2 X_1 + w_3 X_2 + w_4 X_3 + w_5 X_4 + w_6 X_1 X_2 \\ & + w_7 X_1 X_2 + w_8 X_1 X_4 + w_9 X_2 X_3 + w_{10} X_2 X_4 \\ & + w_{11} X_3 X_4 + w_{12} X_1^2 + w_{13} X_2^2 \\ & + w_{14} X_3^2 + w_{15} X_4^2 \end{aligned} \tag{6}$$

We give the algorithm of our PSOEDF method below:

1. Set t, n, c_1, c_2 and ω values
2. Find initial parameters (I) of $Y_{linear}/Y_{quadratic}$ according to standard linear and quadratic regression model.
3. Randomly determine positions for all particles in the neighborhood of I.
4. While (the end criterion is not met) do

(a) $t = t+1$;

(b) Calculate the fitness value for each particle according to

$f(v) = \Sigma_{i=1}^{k} s_i (E_i^{observed} - E_i^{predicted})^2$;

(c) For $i = 1$–n

$pbest_i = \min\{f(v)_{it}\}$

(d) Next i;

$gbest_t = \min_{i=1}^{n}\{pbest_i\}$

5. End while.

5. Experimental studies

A set of experiments that shows goodness of PSOEDF is presented in this section. The algorithm (PSOEDF) is coded with Matlab 7.0 software and run on a Pentium IV, 3.2 GHz, 1 GB RAM computer. Turkey's energy demand models are developed by using the PSO-based algorithm and observed data between 1970 and 2005 (Table 3). The data are collected from Turkish Statistical Institute and the MENR.

Statistical experiments based on a general factorial design are performed in order to find the best parameter set of the PSOEDF models. Three important factors, particle size (n), inertia weight (ω) and maximum iteration number (t) are considered. Each factor combination is tested 10 times with the test problem. It is found that the performance of the PSOEDF models does not deteriorate due to the variations in the t parameter but deteriorates due the variations on both n and ω. Only the CPU time increases with the increase of t. As a result of the statistical analysis, the parameter values are set as $n = 20$, $t = 1000$ and $\omega = 0.995$.

In order to make a fair comparison between ACO and PSO same data and scenarios are used with Toksari (2007).

In the linear form of the PSOEDF (PSO-LR), coefficients obtained are given below:

$Y_{linear} = -55.9022 + 0.0021 X_1 + 1.9126 X_2 + 0.3431 X_3$- $0.4240 X_4$

$f(v)_{linear}$: 42.6139, $r_{linear}{}^2 = 99.55\%$

In the quadratic form of the PSOEDF (PSO-QR), coefficients obtained are given below:

$$\begin{aligned} Y_{quadratic} = {} & -96.4408 - 0.4820 X_1 + 4.7370 X_2 + 1.0937 X_3 \\ & - 2.935 X_4 + 0.0188 X_1 X_2 + 0.0230 X_1 X_3 \\ & - 0.0255 X_1 X_4 - 0.0625 X_2 X_3 + 0.1014 X_2 X_4 \\ & + 0.0915 X_3 X_4 - 0.0027 X_1^2 - 0.0466 X_2^2 \\ & - 0.0387 X_3^2 - 0.0651 X_4^2 \end{aligned}$$

$f(v)_{quadratic}$: 17.664, $r_{linear}{}^2 = 99.81$

Forecasting of energy demand with PSOEDF models between 1996 and 2005 years is shown in Table 4. The largest deviation is 3.31% for PSO-LR and the largest deviation is −2.22% for PSO-QR. Then, it is observed that PSO-QR provided better fit solution due to the fluctuations of the economic indicators.

In order to show the accuracy of PSOEDF models, three scenarios are used for forecasting Turkey's energy demand in the years 2006–2025 and they are compared with Toksari's ACOEDE models. Since it is proven that ACOEDE already gives better results than MENR projection, it is not mentioned in this study either.

Scenario 1: It is assumed that the average growth rate of GDP is 6%, population growth rate is 0.17%, import growth rate is 4.5%, and export growth rate is 2% during the period of 2006–2025. Table 5 and Fig. 2 show that the forecasted values for two forms of ACOEDE and PSOEDF for the Scenario 1. The PSO-LR and PSO-QR gives lower forecasts of the energy demand than the ACOEDE.

Scenario 2: It is assumed that the average growth rate of GDP is 5%, population growth rate is 0.15%, %, import

Table 4
Forecasting of energy demand with PSOEDF models between 1996 and 2005 years

Years	Observed energy demand (MTOE)	Estimated energy demand		Amount of errors		Relative errors	
		PSO-QR	PSO-LR	PSO-QR	PSO-LR	PSO-QR	PSO-LR
1996	69.86	69.77	69.46	−0.09	0.40	0.13	0.57
1997	73.78	72.93	72.09	−0.85	1.69	1.16	2.29
1998	74.71	74.63	73.17	−0.08	1.54	0.11	2.06
1999	76.77	75.24	74.23	−1.52	2.54	2.03	3.31
2000	80.50	80.79	80.39	0.29	0.11	−0.35	0.14
2001	75.40	74.47	76.08	−0.93	−0.68	1.25	−0.90
2002	78.33	80.11	79.42	1.78	−1.09	−2.22	−1.39
2003	83.84	83.61	82.68	−0.23	1.16	0.27	1.38
2004	87.82	87.38	87.49	−0.44	0.33	0.50	0.38
2005	91.58	91.85	93.33	0.27	−1.75	−0.30	−1.91

Table 5
Future projections of total energy demand in MTOE according to Scenario 1

Years	Linear		Quadratic	
	ACOEDE	PSOLR	ACOEDE	PSOQR
2006	95.50	93.52	99.05	95.94
2007	97.27	95.18	102.63	99.46
2008	99.15	96.94	106.56	103.33
2009	101.11	98.79	110.80	107.50
2010	103.18	100.76	115.43	112.06
2011	105.35	102.81	120.35	116.92
2012	107.64	105.00	125.67	122.17
2013	110.03	107.29	131.32	127.75
2014	112.56	109.72	137.30	133.66
2015	115.21	112.27	143.59	139.87
2016	118.01	114.98	150.18	146.39
2017	120.95	117.83	156.99	153.13
2018	124.02	120.83	163.92	159.97
2019	127.26	124.00	170.91	166.88
2020	130.67	127.36	177.88	173.78
2021	134.24	130.88	184.56	180.37
2022	138.01	134.61	190.86	186.59
2023	141.96	138.54	196.48	192.13
2024	146.12	142.70	201.15	196.71
2025	150.50	147.08	204.47	199.94

Table 6
Future projections of total energy demand in MTOE according to Scenario 2

Years	Linear		Quadratic	
	ACOEDE	PSOLR	ACOEDE	PSOQR
2006	104.40	102.09	148.96	146.67
2007	105.77	103.21	156.02	153.62
2008	107.20	104.37	163.40	160.87
2009	108.69	105.59	171.11	168.46
2010	110.24	106.85	179.18	176.40
2011	111.86	108.17	187.57	184.65
2012	113.56	109.54	196.35	193.28
2013	115.32	110.97	205.47	202.25
2014	117.19	112.48	215.05	211.66
2015	119.12	114.04	224.97	221.42
2016	121.14	115.67	235.27	231.55
2017	123.24	117.36	245.95	242.04
2018	125.45	119.13	257.08	252.97
2019	127.75	120.97	268.58	264.26
2020	130.15	122.90	280.52	275.98
2021	132.69	124.94	292.89	288.13
2022	135.32	127.04	305.63	300.63
2023	138.07	129.24	318.78	313.53
2024	140.96	131.54	332.33	326.82
2025	143.98	133.94	346.26	340.47

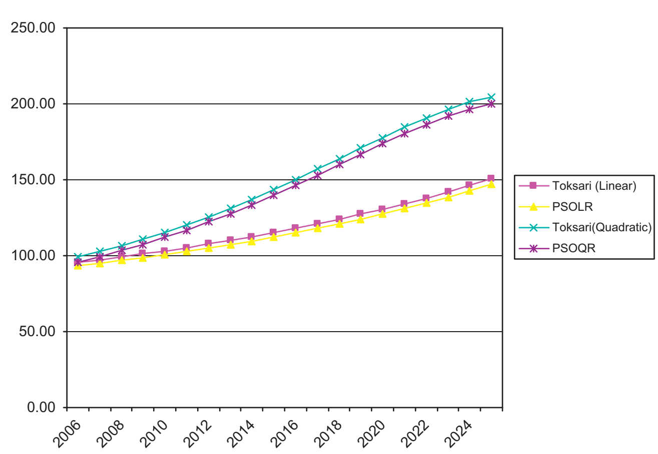

Fig. 2. Future projections of total energy demand in MTOE according to Scenario 1.

growth rate is 5%, and proportion of import covered by export is 45% during the period of 2006–2025. Table 6 and Fig. 3 presents that the forecasted values for two forms of PSOEDF and ACOEDE for the Scenario 2, the PSO-LR gives the lowest forecasts of the energy demand.

Scenario 3: It is assumed that the average growth rate of GDP is 4%, population growth rate is 0.18%, import growth rate is 4.5%, and export growth rate 3.5% during the period of 2006–2025. As can be seen from Table 7 and Fig. 4, two forms of PSOEDF give nearly the same forecasts and they are better than the ACOEDE projections. The lowest and highest values for the energy demand of Turkey can be obtained from PSOEDF models.

It is observed from the experiments that Scenarios 1 and 3 have their forecasts close. However, for Scenario 2, PSO-LR gives lower forecasts of the energy demand than

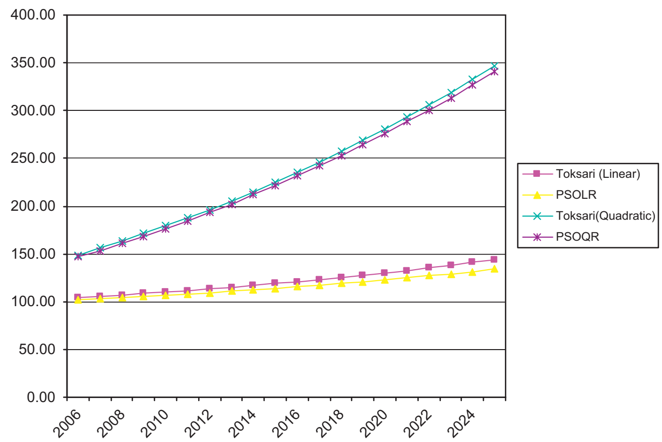

Fig. 3. Future projections of total energy demand in MTOE according to Scenario 2.

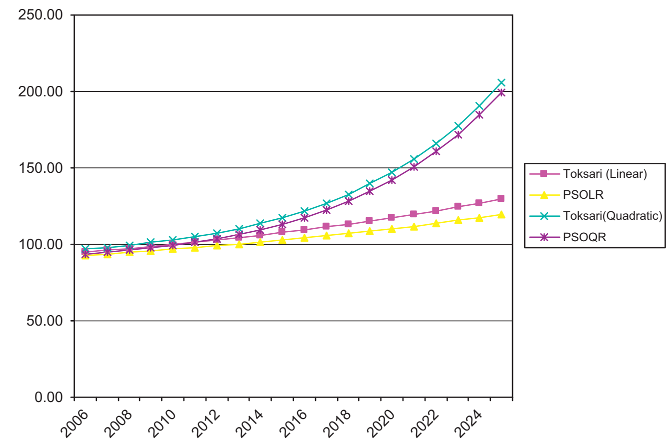

Fig. 4. Future projections of total energy demand in MTOE according to Scenario 3.

Table 7
Future projections of total energy demand in MTOE according to Scenario 3

Years	Linear		Quadratic	
	ACOEDE	PSOLR	ACOEDE	PSOQR
2006	94.94	92.83	96.88	93.72
2007	96.11	93.75	98.12	94.86
2008	97.34	94.71	99.50	96.12
2009	98.62	95.71	101.11	97.62
2010	99.97	96.76	102.97	99.35
2011	101.39	97.86	105.11	101.37
2012	102.86	99.00	107.58	103.70
2013	104.40	100.19	110.43	106.41
2014	106.01	101.43	113.69	109.54
2015	107.71	102.75	117.55	113.25
2016	109.48	104.11	121.93	117.48
2017	111.35	105.55	127.05	122.44
2018	113.28	107.03	132.85	128.08
2019	115.31	108.59	139.54	134.60
2020	117.46	110.24	147.27	142.16
2021	119.69	111.94	156.05	150.76
2022	122.04	113.74	166.14	160.67
2023	124.49	115.60	177.58	171.92
2024	127.07	117.58	190.66	184.80
2025	129.79	119.65	205.54	199.47

the PSO-QR. Both PSO-LR and PSO-QR should be used to forecast the energy demand of Turkey more efficiently.

6. Conclusion

The relation between the economic development of a country and its energy demand is considered a key issue and it involves many economic, social and technological analysis. In this study, forecasting of Turkey's energy demand based on GDP, population, import and export is studied. Since the model is nonlinear in form, PSO heuristic is used to achieve a near optimal objective function value.

Two forms of the PSOEDF developed using 27 data (1979–2005). Three scenarios are proposed to forecast Turkey's energy demand in the years 2006–2025 using the two forms of the PSOEDF. They are compared with the ACOEDE projection. Forecasting of energy demand of Turkey using the PSOEDF forms is underestimated when the results are compared to the ACOEDE results for all observations.

The range of scenarios developed here and their associated energy demands is quite small, but we hope they will provide a useful set of inputs into future energy system modeling.

Forecasting of energy demand can also be investigated with, fuzzy logic, neural networks or other metaheuristic such as tabu search, simulated annealing, etc. The results of the different methods could be compared with the PSO method to see the relative performance of the PSOEDF.

Although the proposed model is proved to be a successful energy demand forecasting tool, also it can be used for other problems that uses multiple regression models. The results of the present study are also expected to give a new direction to scientists and policy makers in implementing energy planning studies and in dictating the energy strategies as potential tool.

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