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Estimating the Turkish residential–commercial energy output based on genetic algorithm (GA) approaches

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Abstract

The present study develops three forms of equations to better analyze energy use and make future projections based on genetic algorithm (GA) notion, and examines the effect of the design parameters on the energy utilization values. The models developed in the quadratic form are applied to Turkey, which is selected as an application country. Turkey's future residential energy output demand is estimated based on GDP, population, import, export, house production, cement production and basic house appliances consumption figures. Among these models, the so-called GA-RWTVR model, which uses residential housing production, house appliances sales of washing machine, television, vacuum cleaner and refrigerator as design parameters/indicators, was found to provide the best fit solution to the observed data. It may be concluded that the models proposed can be used as an alternative solution and estimation techniques to available estimation techniques in predicting the future energy utilization values of countries.
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Keywords: Genetic algorithm; Energy use; Energy modeling; Energy policy; Future projections; Turkey

1. Introduction

Turkish energy consumption has risen dramatically over the past 20 years due to the combined demands of industrialization and urbanization. Turkey's primary energy consumption has increased from 32 million tons of oil equivalent (mtoe) in 1980 to 74 mtoe in 1998 (Hepbasli and Ozalp, 2003).

In 1999 and 2000, of Turkey's total input energy, 36.25% and 39% were used by the industrial sector, followed by the residential–commercial sector at 32.23% and 33%, the transportation sector at 23.15% and 20%, the agricultural sector at 5.08% and 4.8%, and the non-energy (out of energy) use at 3.26% and 3.2%, respectively. The share of the industrial sector in this breakdown is expected to continue to grow at approximately 9% per year and to reach 49% and 59% in 2010 and 2020, respectively. As Turkey's economy has expanded in recent years, the consumption of oil has increased. This growth in consumption is expected to continue up to the year 2020 at a rate of about 4.5% per year. The proportion of oil is expected to decrease somewhat as natural gas usage increases. It is projected that these figures will be 29% for oil, 35% for coal, and 11% for natural gas by 2020 (World Energy Council/Turkish National Committee, 2001; Mendilcioglu, 2000).

In a study performed by Utlu and Hepbasli (2003a), Turkey's total energy and exergy utilization efficiencies are calculated to be 43.24% and 24.04% in 1999, and 44.91% and 24.78% in 2000, respectively. The energy efficiency values are found to be 23.88%, 30.10%, 68.97% and 57.76% in 1999, and 23.71%, 30.11%, 68.81% and 57.05% in 2000 for transportation, utility, industrial, and commercial–residential sectors, respectively. Besides this, the exergy efficiency values are obtained to be 23.80%, 30.28%, 35.97% and 8.12% in 1999, and 23.65%, 30.47%, 35.51% and 8.02% in 2000 for the same order of sectors. This study has clearly shown the necessity of the planned studies towards increasing exergy efficiencies in the Turkish sectors considered (Utlu and Hepbasli, 2003a, b).

Residential energy consumption depends mainly on the available amounts of local resources, which are

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closely connected with the present rural economy and living standards (Xianohua and Zhenming, 1996). In the Turkish residential–commercial sector, energy consumption for heating is too high (more than 70% of the energy consumed) since buildings have almost no insulation (Ocak et al., 2004). Besides this, in the EU residential sector, about 57% of the total final energy consumption is used for space heating, 25% for domestic hot water and 11% for electricity (Chwieduk, 2003). Energy use per unit of building area in Turkey could be reduced by nearly half through the application to all buildings of the new Heat Insulation Standards on building envelopes (Dilmac and Kesen, 2003), issued in 2000. While existing buildings require 200–250 kWh/m^2, the new standards could bring requirements down to 100–150 kWh/m^2. At current rates of building stock turnover, the estimated energy efficiency gains could take several decades to materialize (Ocak et al., 2003; Dincer, 1997).

Energy modeling is a subject of widespread current interest among engineers and scientists concerned with problems of energy production and consumption. Modeling in some areas of application is now capable of making useful contributions to planning and policy formulation (Dincer and Dost, 1996). In this regard, energy planning is not possible without a reasonable knowledge of past and present energy consumption and likely future demands (WEC-TNC, 2000).

Estimating the energy demands in Turkey has been executed by the Minister of the Energy and Natural Resources (MENR). Every 5 years in Turkey, the State Planning Organization (SPO) prepares a *Development Plan* with the assistance of expert organizations for all sectors including the energy sector. The MENR prepares energy production and demand projections in accordance with the growth targets given by the SPO in Turkey. Energy demand projections based on various factors, including development, industrialization, urbanization, technology and conservation. The figures are revised each year in the light of the performance over the past year (Hepbasli and Ozalp, 2003; Hepbasli et al., 2002).

Genetic algorithms (GAs) are well known types of evolutionary computation methods today and have been adapted for a large number of applications in different areas. These include from image processing in medicine (Fitzpatrick et al., 1984) to optimization of bonding parameters in material science (Zhang et al., 2003a) and determination of heat transfer coefficients (Zhang et al., 2003b). Interest is also growing within the studies performed in the energy-related fields, such as nuclear energy (Pereiraa and Lapa, 2003), solar energy (Kalogirou, 2004), low energy design in buildings (Coley and Schukat, 2002), optimization of building thermal design (Wright et al., 2002) and cogeneration (Manolas et al., 1997). However, a few studies on modeling and estimating the energy demands using GA approaches have been performed to date (Canyurt et al., 2003).

In the previous studies (Fitzpatrick et al., 1984; Zhang et al., 2003, 2004; Pereiraa and Lapa, 2003; Kalogirou, 2004; Coley and Schukat, 2002; Wright et al., 2002; Manolas et al., 1997), GA was applied for the optimization of the systems and also for determining system characteristics. In the present study, GA is composed in order to predict the future energy trends of countries. For this purpose, three various models developed are applied to Turkey, which is selected as an application country. For the energy estimation, the past data of energy and indicators are used as design parameters in the GA. Import, export, gross domestic product (GDP), and population show the economic situation and they are the main indicators for the total energy consumption. Indicators of building production, cement production and house appliances such as television, washing machine, vacuum cleaner and refrigerator indicate the trend of residential energy consumption. The effect of house appliances, the house production and major economic indicators are selected by GA and used in estimating Turkey's future residential energy output values.

2. Analysis

GAs were first proposed by John Holland in 1975 (Holland, 1975) and further developed for engineering applications by Goldberg (1989). They manipulate concepts derived from biology and are philosophically based on the Darwin's theory of survival of the fittest (Dunn and Dobhansky, 1950). GAs encode a possible solution to a specific problem on simple chromosome string like data structure and apply specified operators to these structures so as to preserve important information, and to produce a new set of population with the purpose of generating strings which map to high function values. The basic operations of GA, a selection, a crossover of genetic information between reproducing parents and a mutation of genetic information affect the binary strings characteristic in natural evolution.

Genetic operations manipulated the bit string representations of possible solutions to the considered problem. Each string represents one design, and multiple strings constitute the entire set of designs. Multiple designs can be represented by head-to-tail stacking in any given order. By taking w_i as the coefficients of the GAEOEM, the stacking of weighting variables can be represented as follows:

Weighting variables	w_1	w_2	w_i	…
Binary sting representation	0 1 0…1 1	0 0 1…0 1	1 1 1…0 0	…

The three basic operations of GA are performed based on the fitness function evaluation. More fit members of the population can participate more than once, while less fit members may entirely be suppressed that leads to an increase in average fitness. The fitness value of the ith member in the population can participate in this operation based on its probability. The probability of the ith member in population is computed as follows:

$$P_i = \frac{f_i}{\sum_{k=1}^{m} f_k}. \quad (1)$$

The GA works according to rules as defined by the laws of evolutionary genetics is based on fitness evaluation. The model seeks the *''fittest''* model to the observed values. In the GAEOEM, the model parameters of GDP, population, import, export, house production, cement production, basic house appliances consumption figures produce the estimation of the TRCEO values, which is the best match measured demand and reference values. The fitness function, $F(x)$, takes the following form:

$$\text{Min } F(x) = \sum_{j}^{m} s_j (E_{actual} - E_{predicted})^2, \quad (2)$$

where E_{actual} and $E_{predicted}$ are the observed and predicted energy values, respectively, m is the number of observations and s_j is the weighting factor.

The genetic processes continue to search new designs with enhanced fitness until a specified number of function evaluations.

Iterative search after many generations of evolution leads the population to an optimal design. A set of design in the population is altered in structure and constitution based on the fitness, and searches after many generations of evolution towards to an optimal design. The fitness indicates the *goodness* of design, and therefore, the objective function is a logical choice for the fitness measure. The GAEOEM searches the most fitted members by minimizing the error. The algorithm randomly selects a set of models by minimizing error and evolves them to create the best model. The quadratic forms of the GAEOEM can be written as follows:

$$\begin{aligned} E = {} & w_1 + w_2 X_1 + w_3 X_2 + w_4 X_3 + w_5 X_4 + w_6 X_5 \\ & + w_7 X_6 + w_8 X_1 X_2 + w_9 X_1 X_3 + w_{10} X_1 X_4 \\ & + w_{11} X_1 X_5 + w_{12} X_1 X_6 + w_{13} X_2 X_3 + w_{14} X_2 X_4 \\ & + w_{15} X_2 X_5 + w_{16} X_2 X_6 + w_{17} X_3 X_4 + w_{18} X_3 X_5 \\ & + w_{19} X_3 X_6 + w_{20} X_4 X_5 + w_{21} X_4 X_6 + w_{22} X_1^2 \\ & + w_{23} X_2^2 + w_{24} X_3^2 + w_{25} X_4^2 + w_{26} X_5^2 + w_{27} X_6^2, \end{aligned} \quad (3)$$

where X_i represents the population, GDP, population, export, import, residential housing production, cement production, house appliances sales of refrigerator, washing machine, television and vacuum cleaner, while w_i is the corresponding design variables.

Observation of X_i values shows that the growth of population (P), GDP (G), export (E), import (I), residential housing production (R), cement production (C), house appliances sales of refrigerator (R), washing machine (W), television (T) and vacuum cleaner (V) have been increasing according the social development in Turkey.

The scenarios are made in order to perform better predictions of the TRCEO. In the first two scenarios, two sets of design parameters/indicators have been used in the GA; then important parameters were selected and used in the third scenarios.

Scenario 1 (GA-PGEIRC): It is assumed that the values for population (X_1), GDP (X_2), export (X_3), import (X_4), residential housing production (X_5) and cement production (X_6) of Turkey increase with time.

Scenario 2 (GA-RWTVR): Residential housing production (X_1), house appliances sales of washing machine (X_2), television (X_3), vacuum cleaner (X_4) and refrigerator (X_5) have been used as a design parameter/indicator. These parameters give valuable important information related to the social and economic development changes in Turkey. It is assumed that there is a linear increase in these design parameters for the future energy output prediction.

Scenario 3 (GA-PGIRWT): The important design parameters of population (X_1), GDP (X_2), import (X_3), residential housing production (X_4), washing machine (X_5) and television (X_6) were selected as a residential–commercial energy output indicator. There is a strong relation among the residential-commercial energy and indicators.

3. Results and discussion

The three various models developed are applied to Turkey's residential–commercial sector. The data related to the design parameters are collected from different sources. The GDP and total final energy consumption data are also gathered from the World Energy Council–Turkish National Committee (WEC–TNC, 1999) and the MENR (MENR, the Ministry of Energy and Natural Resources, 2003). Turkey's general population, GDP, import, export, residential housing production, cement production, house appliances sales of refrigerator, washing machine, television and vacuum cleaner figures are obtained from the State Statistics Institute (SIS, 2003). Besides this, the future estimation of the TRCEO is taken from both the MENR (2003) and Utlu (2003), which will be stated only the MENR projections throughout this study, since the values up to 2020 are based on the estimations of the MENR. Besides this, all the data used are calculated by Utlu (2003), with the proposed figures between 2020 and 2023.

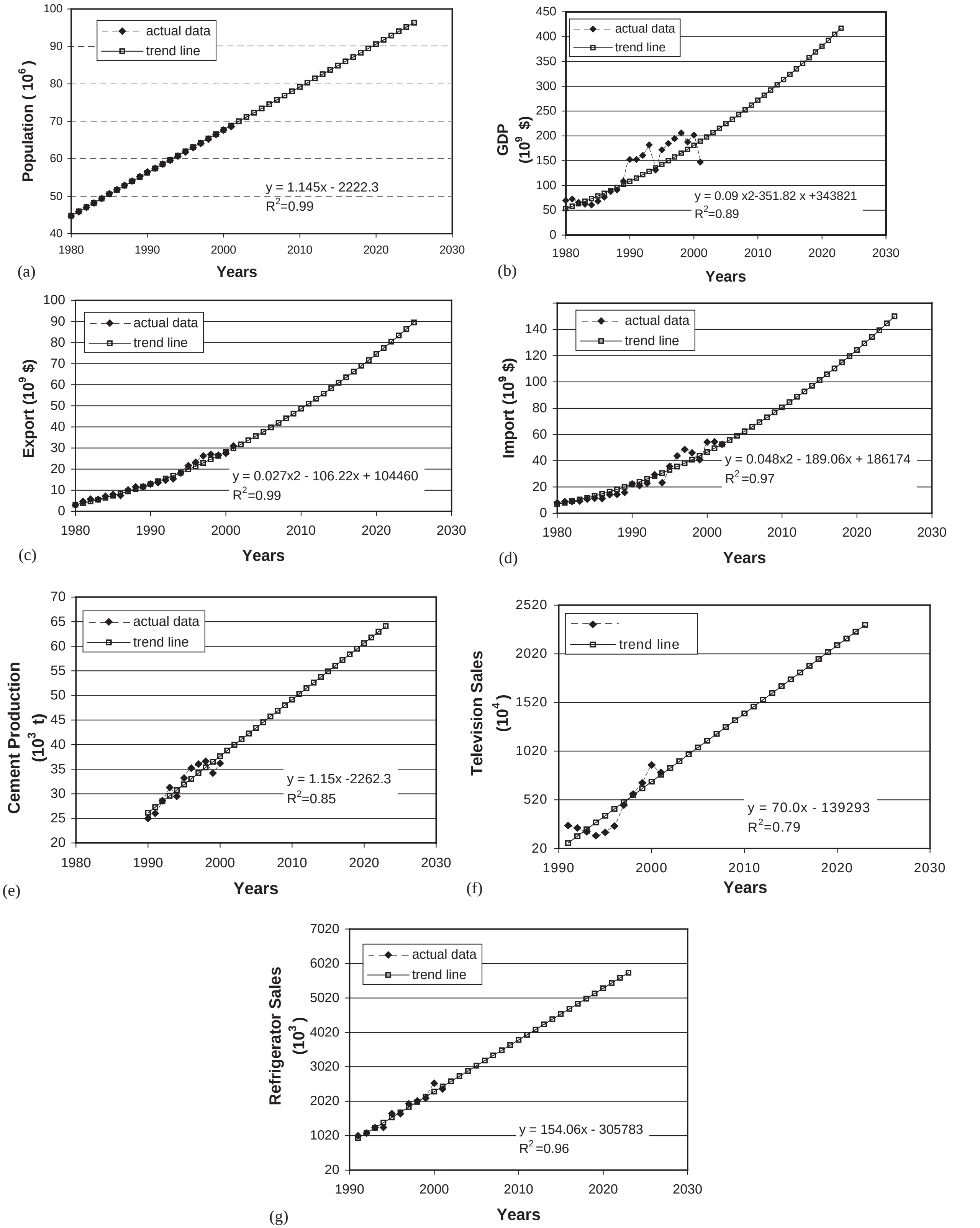


Fig. 1. (a) Population trend; (b) GDP and its corresponding fitted polynomial trends; (c) export trend; (d) import trend; (e) cement production trend; (f) television sales trend and (g) refrigerator sales trend.

By providing the upper and lower bounds of parameters, the GAEOEM is performed using the following user-specified parameters.

Population size (n): 100
Generation number (k): 450
Probability of crossover (p_c): 0.8
Probability of mutation (p_m): 0.02

The convergence of the objective function was examined in the GAEOEM. The obtained model converges in an acceptable number of generations. The convergence of the algorithms can be obtained from Canyurt (2002).

The forms of the GAEOEM models were obtained according to the energy output indicators of population, GDP, export, import, residential housing production,

Table 1
Comparison of the GA based models with MENR (MENR, 2003; Utlu, 2003)

Years	Residential–commercial energy output (observed) MENR (MENR, 2003; Utlu, 2003) (PJ)	GAEOEM GA-PGEIRC (PJ)	Relative error (%)	GAEOEM GA-RWTVR (PJ)	Relative error (%)	GAEOEM GA-PGIRWT (PJ)	Relative error (%)
1995	435.49	433.30	0.50	435.49	0.00	439.29	−0.87
1996	427.52	415.34	2.85	427.52	0.00	424.29	0.76
1997	435.64	442.44	−1.56	435.64	0.00	436.44	−0.18
1998	436.22	438.61	−0.55	436.22	0.00	437.20	−0.23
1999	432.37	429.78	0.60	432.37	0.00	433.06	−0.16
2000	464.44	464.80	−0.08	464.44	0.00	462.39	0.44
2001	455.73	455.29	0.10	455.73	0.00	456.33	−0.13
2002	496.70	517.74	−4.24	496.70	0.00	508.60	−2.40

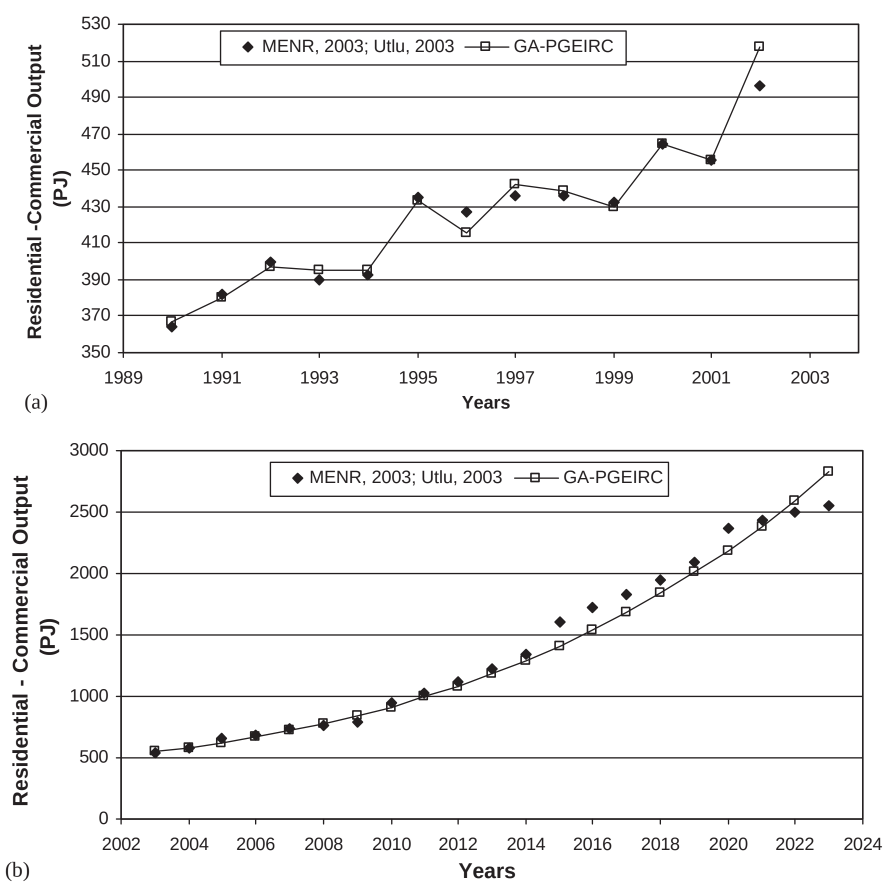


Fig. 2. (a) Actual and fitted data obtained from GA-PGEIRC Scenario 1 of the residential–commercial energy output values of Turkey. (b). Comparison of GA-PGEIRC Scenario 1 and MENR for future residential–commercial energy output value projections of Turkey.

house appliances sales of washing machine, television, vacuum cleaner, refrigerator and cement production of Turkey. Future energy output estimation has been obtained for different scenarios and future trends of the energy output indicators. The trend of some indicators is shown in Figs. 1a–g.

After the application of the GAEOEM, the following parameter values are obtained, which result in the minimum Sum of Square Errors (SSE) between the experimental data and estimated results. The forms of the GAEOEM developed for three different kinds of approaches are given by the following equations:

$$E_{output}^{GA1-PGERC} = w_1 + w_2X_1 + w_3X_2 + w_4X_3 + w_5X_4 + w_6X_5 + w_7X_6 + w_9X_1X_3 + w_{10}X_1X_4 + w_{11}X_1X_5 + w_{12}X_1X_6 + w_{18}X_3X_5 + w_{26}X_5^2, \quad (4)$$

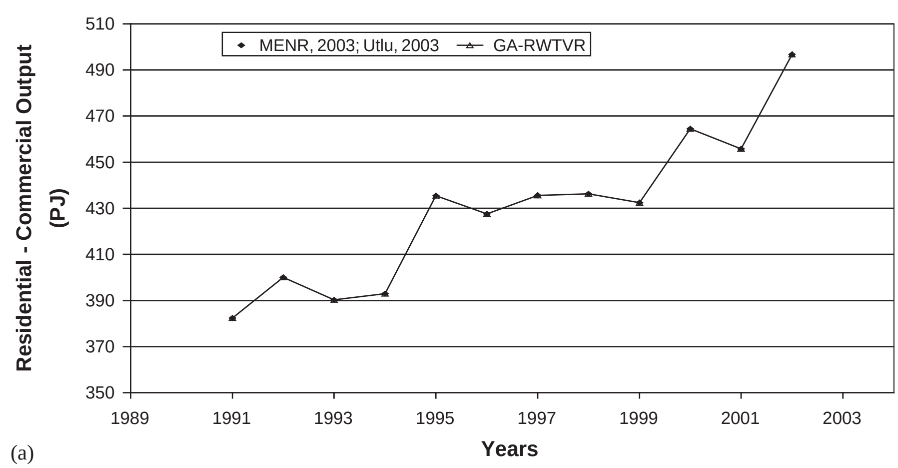
where $w_1 = -4535.680$, $w_2 = 21.911$, $w_3 = 1.461$, $w_4 = -49.806$, $w_5 = -105.973$, $w_6 = 25.332$, $w_7 = 188.886$, $w_9 = 0.559$, $w_{10} = 1.998$, $w_{11} = 0.012$, $w_{12} = -3.010$, $w_{18} = 0.036$ and $w_{26} = -0.055$; remaining w_i parameter values are found zero from the GA results.

$$E_{output}^{GA2\text{-}RWTVR} = w_1 + w_2X_1 + w_3X_2 + w_4X_3 + w_5X_4 + w_6X_5 + w_8X_1X_2 + w_{11}X_1X_5 + w_{13}X_2X_3 + w_{14}X_2X_4 + w_{15}X_2X_5 + w_{18}X_3X_5 + w_{20}X_4X_5, \quad (5)$$

where $w_1 = -832.401$, $w_2 = 1.380$, $w_3 = 3.354$, $w_4 = -2.770$, $w_5 = -0.882$, $w_6 = 0.157$, $w_8 = -0.009$, $w_{11} = 0.006$, $w_{13} = 0.003$, $w_{14} = 0.001$, $w_{15} = -0.002$, $w_{18} = 0.0002$ and $w_{20} = 0.0002$; remaining w_i parameter values are found zero from the GA results:

$$E_{output}^{GA3\text{-}PGIRWT} = w_1 + w_2X_1 + w_3X_2 + w_4X_3 + w_5X_4 + w_6X_5 + w_7X_6 + w_8X_1X_2 + w_9X_1X_3 + w_{10}X_1X_4 + w_{11}X_1X_5 + w_{14}X_2X_4 + w_{17}X_3X_4 + w_{20}X_4X_5, \quad (6)$$

where $w_1 = -4477.070$, $w_2 = 120.547$, $w_3 = 21.156$, $w_4 = -215.757$, $w_5 = 14.522$, $w_6 = -3.053$, $w_7 = 6.641$,



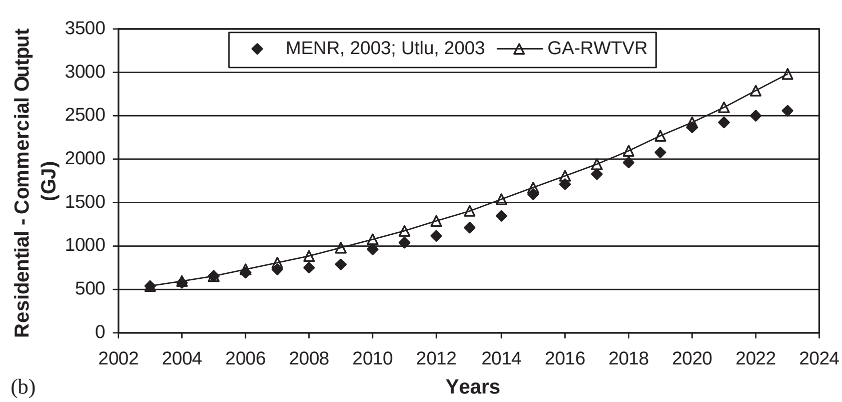


Fig. 3. (a) Actual and fitted data obtained from GA-RWTVR Scenario 2 of the Turkish residential–commercial energy output values. (b) Comparison of GA-RWTVR Scenario 2 and the MENR for the future residential–commercial energy output value projections of Turkey.

$w_8 = -0.364$, $w_9 = 4.017$, $w_{10} = -0.401$, $w_{11} = -0.112$, $w_{14} = 0.018$, $w_{17} = -0.162$ and $w_{20} = 0.011$; remaining w_i parameter values are found zero from the GA results.

During the GAEOEM modeling process, the three various forms of the model developed are validated using the available data partly for use in estimating the weighting factors and partly for the testing purposes. The testing procedure is performed to obtain the minimum relative error between the observed and estimated values in the period of 1995–2002. Table 1 indicates the application of the three forms of the GAEOEM model results and the corresponding relative estimation errors. As can be seen from this table, the average relative errors on GA-RWTVR are lowest compared to the others, followed by GA-PGIRWT and GA-PGEIRC.

The three forms of the GAEOEM are applied for estimating the TRCEO values and the results are compared with the MENR projections (Goldberg, 1989; WEC–TNC, 1999), as shown in Figs. 2–5. GA scenarios are also capable of locating the economic crisis at 1994 and 1999. It may be concluded that all the three scenarios considered seem to be capable of predicting the TRCEO values as an alternative to the MENR.

In order to estimate the future projection, equations have been obtained using the past known values. Residential–commercial energy output (RCEO) variation between 1990 and 2002 is shown in Fig. 2a for the MENR results and present estimation of Scenario 1 (GA-PGEIRC). Present estimation of Scenario 2 (GA-RWTVR) is compared with the MENR results, as shown in Fig. 3a, while Fig. 4a is obtained for Scenario 3 (GA-PGIRWT). As illustrated in these figures, good agreements have been achieved. The future trends of the RCEO are compared with the MENR results, as indicated in Figs. 2b–4b. It is clear from these figures that the MENR results are in a good accordance with present estimation.

The comparison of the MENR with GA-PGEIRC Scenario 1, GA-RWTVR Scenario 2 and GA-PGIRWT Scenario 3 for the RCEO values of Turkey between 1990 and 2002 is illustrated in Fig. 5a. The comparison of the MENR results with GA-PGEIRC Scenario 1, GA-RWTVR Scenario 2 and GA-PGIRWT Scenario 3 for the future residential–commercial energy output projections of Turkey up to 2023 is also shown in Fig. 5b. It can be seen from Figs. 5a and b that GA estimation in good accordance with the results of the MENR.

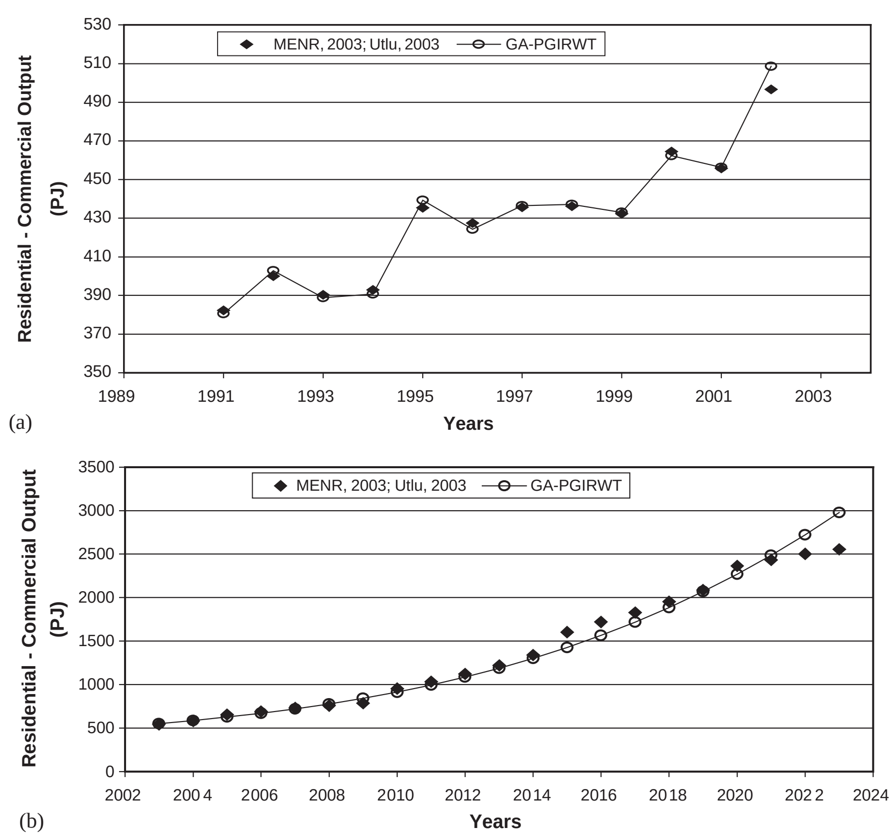
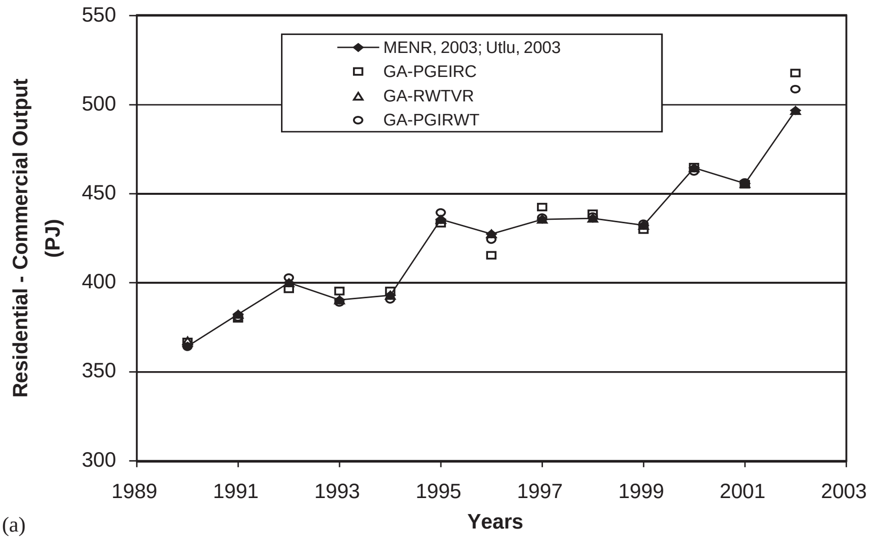
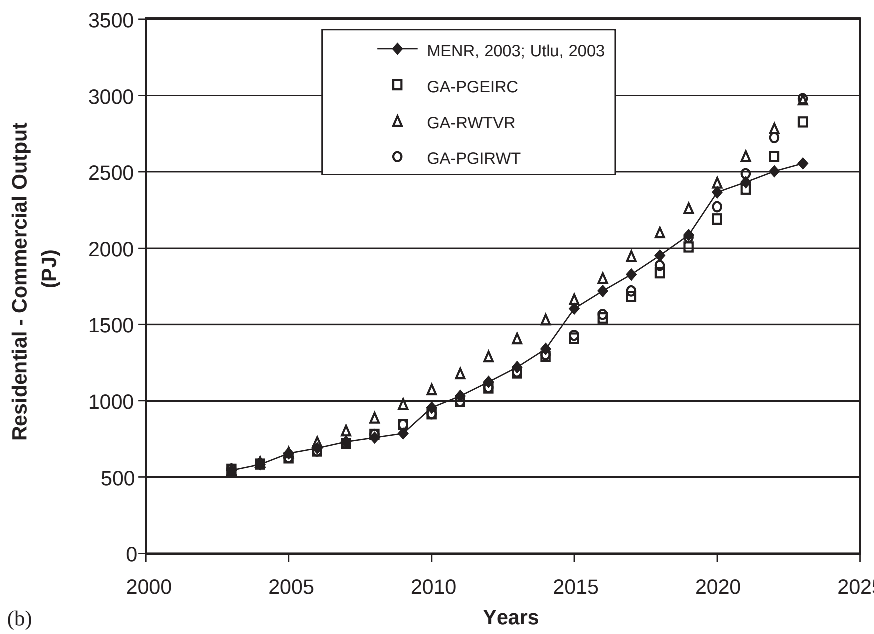


Fig. 4. (a) Actual and fitted data obtained from GA-PGIRWT Scenario 3 of the Turkish residential–commercial energy output values. (b) Comparison of GA-PGIRWT Scenario 3 and the MENR for future residential–commercial energy output value projections of Turkey.



(a)



(b)

Fig. 5. (a) Comparison of the MENR, GA-PGEIRC Scenario 1, GA-RWTVR Scenario 2 and GA-PGIRWT Scenario 3 for the Turkish residential–commercial energy output values between 1990 and 2002. (b) Comparison of the MENR, GA-PGEIRC Scenario 1, GA-RWTVR Scenario 2 and GA-PGIRWT Scenario 3 for the future residential–commercial energy output value projections of Turkey.

4. Conclusions

The main conclusions that can be drawn from the present study are summarized as follows:

(a) The three forms of the GAEOEM in the quadratic form were developed using the data of the Turkish residential–commercial sector over an 8-year period from 1995 to 2002. The results obtained from the model were compared with the observed data for testing purposes and the MENR projections for future estimation. The developed models based on the GA approach proved to be a successful energy estimation tool. In this regard, GAs may be successfully applied to a wide range of fields for modeling and prediction in energy engineering systems.

(b) Among the three models developed, the GA-RWTVR model provided the best-fit solution to the observed data.

(c) The use of GA is easy and does not need many parameters for future projections, therefore it is preferable.

(d) It is expected that this study will give a new direction to engineers, scientists, and policy makers in implementing energy planning studies and in dictating the energy strategies as a potential tool.

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