

An application of Imperialist Competitive Algorithm to Simulation of Energy Demand Based on Economic Indicators: Evidence from Iran

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Abstract

This paper deals with simulation of energy demand based on economic indicators in Iran. Applying an Imperialist Competitive Algorithm (ICA) approach, the paper develops two forms of non-linear energy demand to simulate energy demand based on the past data. It also develops an Imperialist Competitive Algorithm Energy Demand Simulation (ICAEDS) model using the data on population, Gross Domestic Product (GDP) and export of goods and services. The parameter values of the model are optimized using the available data. The functional forms of the model proposed in this paper are of exponential and quadratic types. The quadratic form of the ICAEDS model provided a better-fit solution due to the data that exhibit wide fluctuations. The ICAEDS model projects the energy demand in Iran until 2017.

Keywords: Energy demand, Imperialist Competitive Algorithm, Simulation, Iran.

JEL Classification Codes: Q41, C15, C53, C61

1. Introduction

Energy plays a major role in achieving economic, social, and technological progress; It complements labor and capital in production (Ebohan, 1996; Templet, 1999). Energy use increases as more economic sectors develop and more channels of output flows are opened (Templet, 1999). Global energy demand will increase 60% more from 2002 to 2030—with a yearly average of 1.7% (Tiris, 2005). Development trajectories of energy can be characterized by sectoral changes in the economy (Lise and Van Montfort, 2007), and by population, import and export dynamics. Some authors (For

example, Uri, 1980; Kavrakoglu, 1983; Yu and Been, 1984; Ebohon, 1996; Cheng and Lai, 1997; Ceylan and Ozturk, 2004; Canyurt and Ozturk, 2006; Say and Yucel, 2006) consider income as the main determinant of energy consumption.

Iran is one of the major economic powers in the Middle East; With a GDP of 483014 billion Rials (approximately 48.3 billion dollars), it is among the first twenty largest economies of the world. In 1991, the final energy consumption of Iran amounted to 446/9 MBOE¹ with an increase to 1052/7 MBOE in 2007. During this period, the level of GDP increased from 251833 billion Rials (approximately 25 billion dollars) to 483014 billion Rials (approximately 48.3 billion dollars). Iran is an oil-rich country with manifest problems in management of its domestic energy consumption.

This paper attempts to forecast the future energy consumption of Iran using macroeconomic indicators. Then it assesses the accuracy of forecasts in simulation and predicts the path of energy demand in Iran. The data on energy consumption has been compiled from 2007 energy balance sheet, tabulated by the Ministry of Energy.

In the literature on energy, meta-heuristic methods that solve combinatorial optimization problems have been applied to estimate energy consumption. Ceylan and Ozturk (2004) use a Genetic Algorithm (GA) in estimating energy demand, and Canyurt and Ozturk (2006) propose variants of GA for estimating demand for oil. Canyurt et al. (2006) use GA approaches in estimating demand for transport energy use. Ozcelik and Hepbasli (2006) apply a meta-heuristic method to estimating petroleum energy production and consumption. Toksari (2007) develops an Ant Colony Optimization (ACO) energy demand model for Turkey. Unler (2009) used Particle Swarm Optimization (PSO) in estimating energy demand. To our knowledge, however, the Imperialist Competitive Algorithm (ICA) has not yet been applied in estimating energy demand.

The Imperialist Competitive Algorithm (ICA) is a new socio-politically motivated global search strategy that has recently been introduced for dealing with different optimization tasks (Atashpaz-Gargari and Lucas, 2007). This evolutionary optimization strategy has shown great performance in terms of both the convergence rate and achievement of better global optima (Atashpaz-Gargari and Lucas, 2007 ; Rajabioun et al. 2008(a) ; Biabangard-Oskouyi et al. 2008 ; Sepehri Rad and Lucas, 2007 ; Atashpaz-Gargari et al. 2008 ; Rajabioun et al. 2008(b)).

Nevertheless, its effectiveness, limitations and applicability in various domains still are under surveillance. Atashpaz-Gargari et al (2008), use an ICA approach in designing an optimal controller, which not only decentralizes but also optimally controls an industrial Multi- Input, Multi-Output (MIMO) distillation column process. Rajabioun et al use almost the same in a more complicated MIMO system that is a 3*3 model of Evaporator Plant. Biabangard-Oskouyi et al (2008), use ICA to reverse analysis of an Artificial Neural Network (ANN) in order to characterize the properties of materials from sharp indentation test. Rajabioun, Atashpaz-Gargari, and Lucas, C. (2008), use ICA in finding the Nash equilibrium point in games.

In order to find the optimal priorities for each user in recommender systems, Sepehri Rad and Lucas (2007), use ICA in "Prioritized User-Profile" approach to recommender systems, trying to implement more personalized recommendation by assigning different priority importance to each feature of the user-profile by different users. Atashpaz-Gargari et al(2008), use ICA to optimally shrink the Gershgorin bands in a MIMO plant and then design a simple PID controller for each of SISO plants in a diagonally dominant system.

In this paper, we propose to implement an ICA-based model for forecasting energy demand with Iran as a case. Energy demand based on economic indicators can take various functional forms. The models proposed here are of exponential and quadratic form. The economic indicators used during the model development are GDP, population and export of goods and services. The paper is organized

¹ MCOE: million barrels of oil equivalents.

as follows: Section 2 that comes after this introductory section sets out the ICA construct. The specific ICA that we use to estimate energy demand is detailed in Section 3. Section 4 develops energy demand models for the Iranian case drawing on the algorithm proposed in Section 3. In this section the proposed models are applied to project Iran's energy demand for the years 2008-2017 using two scenarios. And finally section 5 will summarize and bring the paper to its conclusions.

2. A Brief Account of Imperialist Competitive Algorithm

Evolutionary optimization methods, inspired by natural processes, have shown good performance in solving complex optimization problems. For example, genetic algorithms (inspired by biological evolution of human and other species), ant colony optimization (based on ants effort to find optimal path to the food source) and simulated annealing (based on real annealing process in which a substance is heated over its melting point and then cooled to reach to a crystalline lattice) are widely used to solve engineering optimization problems.

Evolutionary optimization algorithms are generally inspired by modeling the natural processes and other aspects of species evolution, especially human evolution. But Imperialist Competitive Algorithm (ICA) uses socio-political evolution of human as a source of inspiration for developing a strong optimization strategy. In particular, this algorithm considers imperialism as a level of human social evolution and by mathematically modeling this complicated political and historical process, it arrives at a tool for evolutionary optimization. Since its inception, this novel method has been widely adopted by researchers to solve different optimization tasks. It is used to design optimal layout of factories, adaptive antenna arrays, intelligent recommender systems and optimal controller for industrial and chemical processes.

Imperialism is the policy of extending the power and rule of a government beyond its own boundaries. A country may attempt to dominate others by direct rule or by less obvious means such as a control of markets for goods or raw materials. The latter is often called neo-colonialism (Atashpaz and Lucas 2007). ICA is a novel global search heuristic that uses imperialism and imperialistic competition process as a source of inspiration.

Like other evolutionary algorithms, the proposed algorithm starts with an initial population (countries in the world). Some of the best countries in the population are selected to be the imperialists and the rest form the colonies of these imperialists. All the colonies of initial population are divided among the imperialists based on their power. The power of an empire seen as the counterpart of the fitness value in Genetic Algorithm (GA) is inversely proportional to the costs it incurs.

After dividing all colonies among imperialists, the colonies start moving toward their relevant imperialist country. The total power of an empire depends on both the power of the imperialist country and the power of its colonies. We will model this fact by defining the total power of an empire by the power of imperialist country plus a percentage of mean power of its colonies.

Then the imperialistic competition begins among all the empires. Any empire that is not able to succeed in this competition and increase its power (or at least prevent decreasing its power) will be eliminated from the competition. The imperialistic competition will gradually result in an increase in the power of powerful empires and a decrease in the power of weaker ones. Weak empires will lose their power and ultimately they will collapse. The movement of colonies toward their relevant imperialists along with competition among empires and also the collapse mechanism will hopefully cause all the countries to converge to a state in which there exist just one empire in the world and all the other countries are colonies of that empire. In this ideal new world, colonies have the same position and power as the imperialist.

2.1. Generating Initial Empires

The goal of optimization is to find an optimal solution in terms of the variables of the problem. We form an array of variable values to be optimized. In GA terminology, this array is called “*chromosome*”, but here the term “*country*” is used for this array. In an N_{var} dimensional optimization problem, a country is an $N_{var} \times 1$ array, defined by:

$$country = [p_1, p_2, p_3, \dots, p_{N_{var}}] \quad (1)$$

The variable values in the country are represented as floating point numbers. The cost of a country is found by evaluating the cost function f at the variables $(p_1, p_2, p_3, \dots, p_{N_{var}})$. Then

$$cost_i = f(country_i) = f(p_1, p_2, p_3, \dots, p_{N_{var}}) \quad (2)$$

To start the optimization algorithm we generate the initial population of size $N_{country}$. We select N_{imp} of the most powerful countries to form the empires. The remaining N_{col} of the population will be the colonies each of which belongs to an empire. Then we have two types of countries; *imperialists* and *colonies*.

To form the initial empires, we divide the colonies among imperialists based on their power. That is the initial number of colonies of an empire should be directly proportionate to its power. To divide the colonies among imperialists proportionally, we define the normalized cost of an imperialist by

$$C_n = c_n - \max_i \{c_i\} \quad (3)$$

where c_n is the cost of n th imperialist and C_n is its normalized cost. Having the normalized cost of all imperialists, the normalized power of each imperialist is defined by

$$p_n = \left| \frac{C_n}{\sum_{i=1}^{N_{imp}} C_i} \right| \quad (4)$$

From another point of view, the normalized power of an imperialist is determined by the proportion of colonies under possession of that imperialist. Then the initial number of colonies of an empire will be

$$N.C_n = \text{round}\{p_n \cdot N_{col}\} \quad (5)$$

where $N.C_n$ is the initial number of colonies of n th empire and N_{col} is the number of all colonies. To divide the colonies among imperialists we choose randomly $N.C_n$ colonies and assign them to each imperialist. The colonies together with the imperialist will form the n th empire.

2.2. Moving the Colonies of an Empire toward the Imperialist

As mentioned earlier, imperialist countries start to improve their colonies. We have modeled this fact by moving all the colonies toward the imperialist. This movement is shown in stage 2 of figure 2 in which a colony moves toward an imperialist by x units. The new position of colony is shown in a darker color. The direction of the movement is shown by the arrow extending from a colony to an imperialist. In this figure x is a random variable with uniform (or any proper) distribution. Then for x we have

$$x \sim U(0, \beta \times d) \quad (6)$$

where β is a number greater than 1 and d is the distance between a colony and an imperialist. A $\beta > 1$ causes the colonies to get closer to the imperialist state from both sides.

To explore variations around an imperialist, we allow for deviations from to the direction of the movement in a random manner. Figure 2 shows the new direction. In this figure θ is a random number with uniform (or any proper) distribution so that:

$$\theta \sim U(-\gamma, \gamma) \quad (7)$$

where γ is a parameter that adjusts the deviation from the original direction. The values of β and γ are chosen arbitrarily. In most cases a value of about 2 for β and about $\pi/4$ (Rad) for γ have resulted in good convergence of countries to the global minimum.

While moving toward an imperialist, a colony may reach a position with lower cost than that of the imperialist. In such a case, the imperialist moves to the position of that colony and vice versa. Then an imperialist will follow the algorithm in the new position and colonies start moving toward that position.

2.3. The Total Power of an Empire

The total power of an empire is mainly affected by the power of imperialist country, but the power of the colonies of an empire has an effect, albeit negligible, on the total power of that empire. We have modeled this fact by defining the total cost by:

$$T.C._n = Cost(imperialist_n) + \xi \text{ mean}\{Cost(colonies \text{ of } empire_n)\} \quad (8)$$

where $T.C._n$ is the total cost of the n th empire and ξ is a positive number that is considered to be less than 1. A small value for ξ implies that the total power of an empire is determined by just the imperialist; A large value implies an increasing role for the colonies in determining the total power of an empire. We have used a value of 0.1 for ξ in most of our analysis.

2.4. Imperialistic Competition

All empires try to take possession of colonies of other empires and control them. This imperialistic competition gradually brings about a decrease in the power of weaker empires and an increase in the power of more powerful ones. We model this competition by just choosing a number (usually one) of the weakest colonies of the weakest empires and allow for the empires to compete for acquiring the chosen colonies (colony).

To start the competition, first, we calculate the probability of each empire succeeding to acquire colonies in lieu of its total power. The normalized total cost simply is obtained by

$$N.T.C._n = T.C._n - \max_i \{T.C._i\} \quad (9)$$

where $T.C._n$ and $N.T.C._n$ are respectively total cost and normalized total cost of n th empire. Having the normalized total cost, the possession probability of each empire is given by

$$p_{p_n} = \frac{N.T.C._n}{\sum_{i=1}^{N_{imp}} N.T.C._i} \quad (10)$$

To divide colonies among empires using the probability of acquisition as a guide, we form the vector \mathbf{P} as

$$\mathbf{P} = [p_{p_1}, p_{p_2}, p_{p_3}, \dots, p_{p_{N_{imp}}}] \quad (11)$$

Then we create a vector of size \mathbf{P} with elements as uniformly distributed random numbers.

$$\mathbf{R} = [r_1, r_2, r_3, \dots, r_{N_{imp}}] \quad (12)$$

Next we form vector \mathbf{D} by simply subtracting \mathbf{R} from \mathbf{P} as

$$\mathbf{D} = \mathbf{P} - \mathbf{R} = [D_1, D_2, D_3, \dots, D_{N_{imp}}] = [p_{p_1} - r_1, p_{p_2} - r_2, p_{p_3} - r_3, \dots, p_{p_{N_{imp}}} - r_{N_{imp}}] \quad (13)$$

Referring to vector \mathbf{D} , we will assign the colonies to the empire whose relevant index in \mathbf{D} is earns a maximum number.

At the end, powerless empires will disintegrate in the imperialistic competition and their colonies will be divided among other empires. The criteria used in modeling the disintegration mechanism vary. In most of our model executions, a disintegrated empire is one that loses all of its colonies.

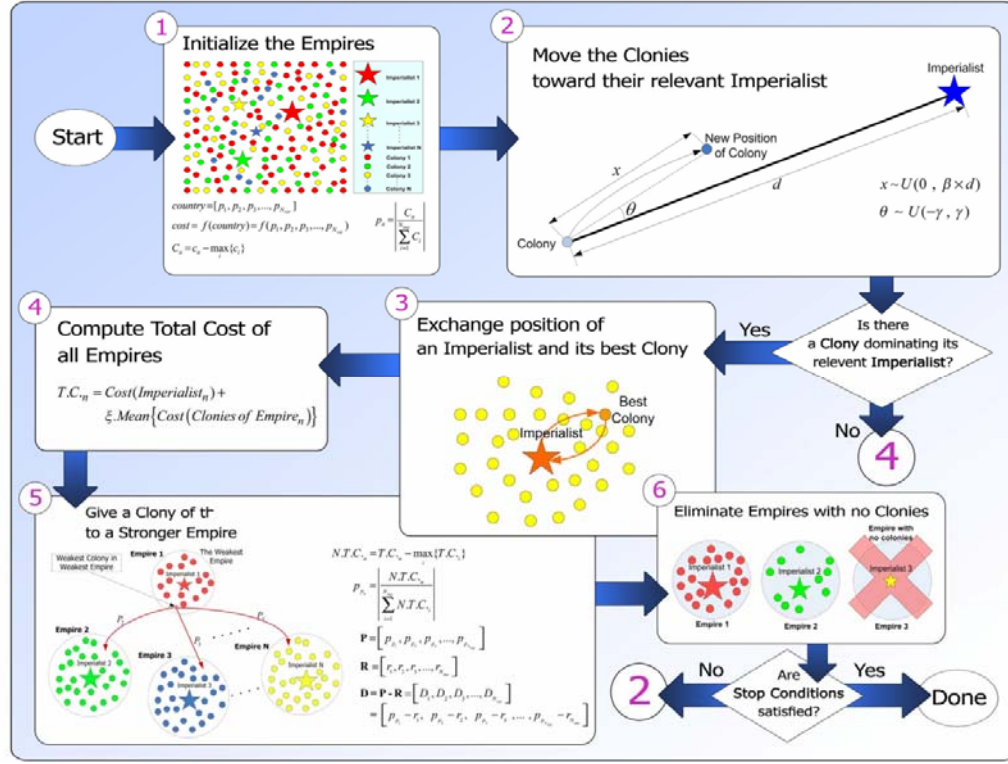
2.5. Convergence

After a while all the empires except the most powerful one will collapse and all the colonies will be under the control of this unique empire. In this ideal new world all the colonies will have the same positions and same costs and they will be controlled by an imperialist with the same position and cost as themselves. In this ideal world, there is no difference not only among colonies but also between colonies and imperialist. In such a condition, we put an end to the imperialistic competition and stop the algorithm. Later in this paper, we will apply the proposed algorithm to some of benchmark problems in the realm of optimization.

The main steps in the algorithm are summarized in the pseudo code shown in table 1, and a big picture of it is shown in Figure 1.

Table 1: The steps in the algorithm

- | |
|---|
| <ul style="list-style-type: none"> • Select some random points on the function and initialize the empires. • Move the colonies toward their relevant imperialist (Assimilating). • If there is a colony in an empire that has lower cost than that of imperialist, exchange the positions of the colony with the imperialist. • Compute the total cost of all empires (Related to the power of both imperialist and its colonies). • Choose the weakest colony (colonies) from the weakest empires and assign the colony (colonies) to the empire with the highest probability of acquisition potential (Imperialistic competition). |
|---|

Figure 1: The big picture of the proposed algorithm.

3. Simulating Energy Demand using ICA

The Imperialist Competitive Algorithm Energy Demand Simulation (ICAEDS) is developed by finding the global minimum of cost function. The objective of the ICAEDS model solution is to arrive at the minimum sum of squared error (SSE) between the observed and predicted values. This can be shown as

$$\text{Min } f(x) = \sum_{i=1}^n (E_i^{\text{observed}} - E_i^{\text{simulated}})^2 \quad (14)$$

where E_i^{observed} and $E_i^{\text{simulated}}$ represents actual and simulated energy demand during the period i and n is the number of observations; S_i is a weighting factor that usually is assigned a value of one.

We have simulated energy demand in Iran based on economic indicators and exponential and quadratic functional forms. The exponential functional form of ICAEDS can be formulated as

$$ICAEDS_{exp} = w_1 + w_2 X_1^{w_3} + w_4 X_2^{w_5} + w_6 X_3^{w_7} \quad (15)$$

and the quadratic functional form as

$$ICAEDS_{quad} = w_1 + w_2 X_1 + w_3 X_2 + w_4 X_3 + w_5 X_1 X_2 + w_6 X_1 X_3 + w_7 X_2 X_3 + w_8 X_1^2 + w_9 X_2^2 + w_{10} X_3^2 \quad (16)$$

where X_1 , X_2 and X_3 respectively represent Gross Domestic Product in billions of Rials (currently each US\$ is about 10000 Rials), population in million persons and export of goods and services in billions of Rials; w_i represents the weighting factors. The ICA optimizes the coefficient parameters.

4. An application of ICAEDS

4.1. Estimation of ICAEDS Parameters for the Current Data

The data are compiled from different sources. The data for final consumption of energy were compiled from Iran's energy balance sheets and the data on other variables were compiled from the data series published by the Central Bank of Iran. All variable are in constant 1997 prices. The observed general trend of transport energy demand, GDP, population and imports between 1991 and 2007 are depicted in Fig. 3. Two forms of the ICAEDS model with the parameters specified in table 2 are simulated.

Figure 2:

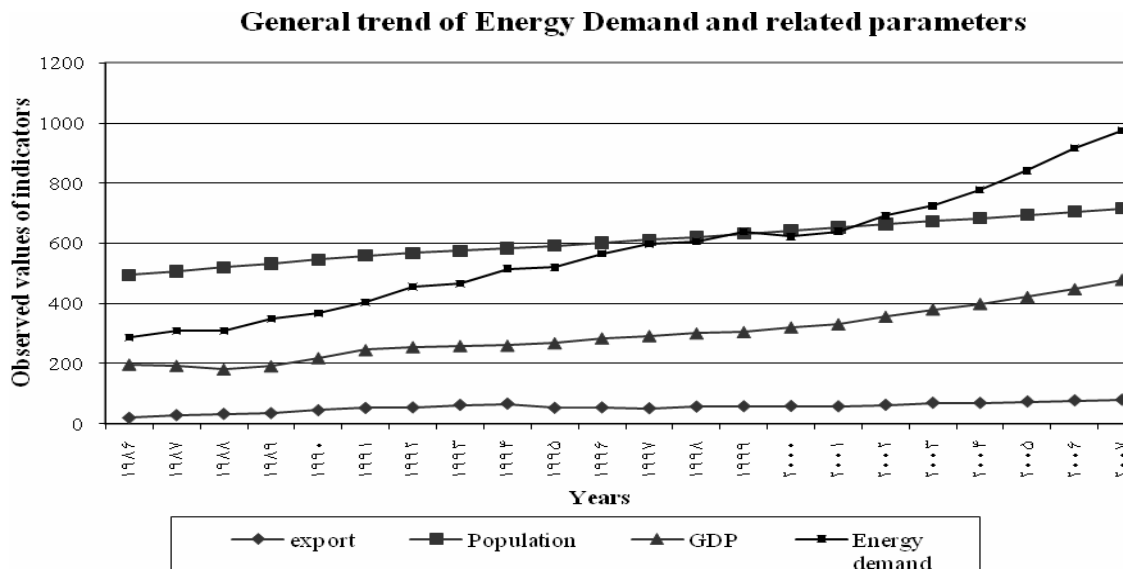


Table 2: Parameters of ICA

Item	Parameter
Number of countries	200
Number of empires	8
Number of iterations	500
Assimilation coefficient β	2
Assimilation angle γ	.05

Programming ICA for the purpose of simulation utilizes the MATLAB 7 software. The simulated exponential energy demand function using ICA is as follows:

$$ICAEDS_{exp} = -4.11 + 0.0262X_1^{1.6276} + 0.0058X_2^{1.64} + 0.1498X_3^{1.498} \quad (17)$$

$$SSE = 4987.57 \quad R^2 = 0.98$$

The simulated quadratic energy demand function using ICA is as follows:

$$\begin{aligned} ICAEDS_{quad} = & -1.81 - 1.2844X_1 + 0.3362X_2 + 1.76X_3 + 0.00169X_1X_2 \\ & + 0.000282X_1X_3 + 0.00013X_2X_3 + 0.00183X_1^2 \\ & + 0.00039X_2^2 + 0.000011X_3^2 \end{aligned} \quad (18)$$

$$SSE = 4367.2 \quad R^2 = 0.983$$

As the estimated models indicate, the simulated quadratic energy demand function has a lower SSE. During the ICAEDS modeling process, each form of the model is validated using the available data partly for use in estimating the weighting factors and partly for the testing purposes. First 17 years

of observed data from 1986 to 2002 are used for estimating the weighting factors and 5 years of data from 2003 to 2007 are used for testing. The testing procedure is carried out to obtain the minimum relative error between the observed and estimated values over the period of 2003–2007. These relative errors are reported in Table 3.

Table 3: Energy demand estimation of ICAEDS models between 2003 and 2007 years

Years	Observed energy demand (MBOE)	ICAEDS _{exp} (MBOE)	Relative Error (%)	ICAEDS _{quad} (MBOE)	Relative Error (%)
2003	724.6	747.68	3.18-	747.13	-3.11
2004	778.7	786.07	-0.94	785.90	-0.92
2005	842	843.56	-0.18	843.48	0.17-
2006	916.9	907.62	1.01	907.77	0.99
2007	975.2	980.33	-0.52	980.19	-0.51
			Average error=1.17		Average error=1.14

The table shows that ICAEDS models for energy demand estimation are very robust and successful. Although the largest deviation is -3.18% in quadratic functional form case, it still is quite an acceptable level. Furthermore the average relative error in this case is 1.14 compared to the average relative error for exponential form case of 1.17. Hence, we may conclude that the quadratic form of the ICAEDs model provided a better-fit solution compared the exponential form perhaps due to wide fluctuations that characterized the economic indicators.

4.2. Forecasting demand for energy using data from Iran

In order to forecast the future propensity of energy demand, we need to forecast the independent variables of the model first. To this end, we have simulated the variables of the model based on the time variable using exponential functional forms. The data used covers a time span from 1991 to 2007. The results are:

Annual GDP:

$$Y = 255.60733 + 0.38526X^{2.23878} \quad R^2 = 0.991 \quad (19)$$

Annual Population:

$$Y = 551.64879 + 6.54757X^{1.13746} \quad R^2 = 0.9998 \quad (20)$$

Annual export of goods and services:

$$Y = 50.10332 + 0.03202X^{2.41797} \quad R^2 = 0.9675 \quad (21)$$

where X stands for the explanatory variable in the time series and it takes a value of 1 for 1991, 2 for 1992 and so on.

In order to use this simulated model for forecasting the future values of the variables, steps must be taken to ensure that the residuals of the simulated model do not exhibit any non-stochastic characteristics and this can be done by testing for stationary. If residuals terms turn out to exhibit stationary characteristics, then one may conclude that due to the high R^2 demonstrated by the simulated functions, the path of changes of the estimated quantities approximately fit the actual path of the changes in quantities that in turn testify to the goodness of fit in estimating the parameters.

To test for stationary of the residuals of the simulated equations, this paper uses the Augmented Dickey fuller (ADF) Test used to identify unit roots. The number of lags in dependent variables required in the regression in order to remove autocorrelation among the disturbance terms are determined by Akaike (AIC) Schwarz-Bayesian(SBC) and Hannan-Quinn (HOC) rules. The ADF test

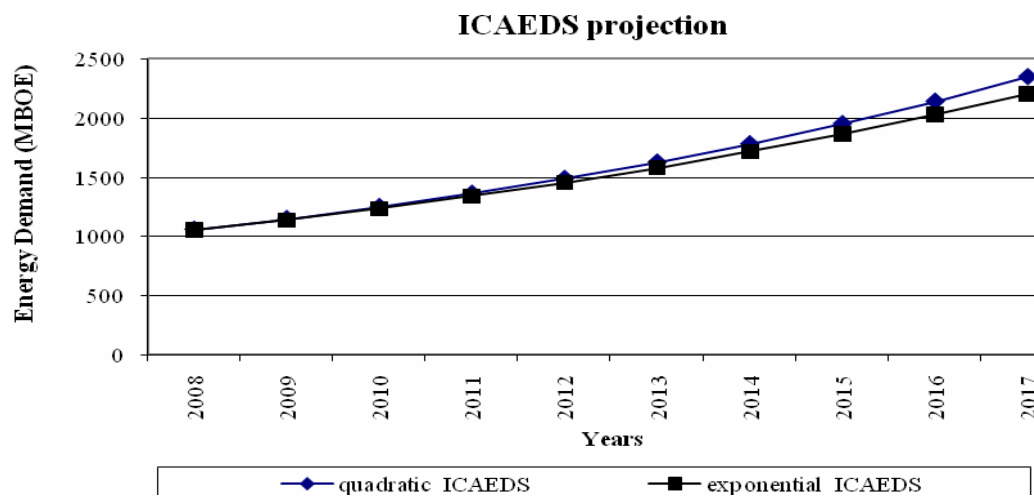
is performed for all residuals in the model using the Eviews Package and the results are reported in table 4.

Table 4: ADF test performed on residuals of the model (level)

	GDP	Population	Export of goods and services
Test statistic for the model with intercept and trend	-2.53	-2.73	-2.81
The critical value at 5 percent level	-3.759	-3.759	-3.733
The number of lags	1	1	0

Having made sure that residuals are not non-stationary, the simulated model is used to forecast the demand for energy from 2008 to 2017. This is shown in figure4.

Figure 4: Energy demand projections using ICAEDS



Hence (Fig 2), energy demand in Iran between now (2010) and 2017 will increase by about two times and this has grave policy implications.

5. Summery and Conclusions

Forecasting of energy demand can be investigated with fuzzy logic, neural networks or other meta-heuristic models such as TABU search, simulated annealing, etc. 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 analyses. In this paper we have applied the imperialist competitive model (ICA) to simulate energy demand in Iran using population, gross domestic product (GDP) and export of goods and services data. The models used took exponential and quadratic forms and the data covered the time span of 1986 to 2007. The quadratic form of the ICAEDS model provided slightly better fit solution to the observed data. Hence, this form can be selected for Iran's future energy projections. We used quadratic form to project energy demand in Iran from 2008 until 2017. For forecasting purposes the independent variables of the model are simulated and tested for its validity. The ICAEDS method proceeds to optimize the parameter values and use the current data to project energy demand. The proposed model is proved to be a successful energy demand forecasting tool. It can be used for other problems involving multiple regression models as well. The results of the present

study also are expected to give a new direction to scientist's engaged in energy demand forecasts to policy makers in making more informed policy decisions.

References

- [1] Atashpaz-Gargari, E., Lucas, C., 2007. "Imperialist Competitive Algorithm: An algorithm for optimization inspired by imperialistic competition". *IEEE Congress on Evolutionary Computation*, pp.4661–4667.
- [2] Atashpaz-Gargari, E., Hashemzadeh, F., Rajabioun, R. and Lucas, C., 2008. "Colonial Competitive Algorithm, a novel approach for PID controller design in MIMO distillation column process". *International Journal of Intelligent Computing and Cybernetics*, Vol. 1 No. 3, 2008, pp. 337–355.
- [3] Atashpaz-Gargari, E. et al 2008. "A Decentralized PID controller based on Optimal Shrinkage of Gershgorin Bands and PID tuning Using Colonial Competitive Algorithm". Forthcoming in *International Journal of Innovative Computing, Information and Control (IJICIC)*.
- [4] Biabangard-Oskouyi, A., Atashpaz-Gargari, E., Soltani, N., Lucas, C., 2008. "Application of Imperialist Competitive Algorithm for materials property characterization from sharp indentation test". *forthcoming in the International Journal of Engineering Simulation*.
- [5] Canyurt, O.E., Ozturk, H.K., 2006. "Three different applications of genetic algorithm (GA) search techniques on oil demand estimation". *Energy Conversion and Management* 47, 3138–3148.
- [6] Canyurt, O.G., Ozturk, H.K., Hepbasli, A., Utlü, Z., 2006. "Genetic algorithm (GA) approaches for the transport energy demand estimation: model development and application". *Energy Sources, Part A: Recovery, Utilization and Environmental Effects* 28 (15), 1405–1413.
- [7] Cheng, P.S., Lai, T.W., 1997. "An investigation of co-integration and causality between energy consumption and economic activity in Taiwan". *Energy Economics* 19 (4), 435–444.
- [8] Ceylan, H., Ozturk, H.K., 2004. "Estimating energy demand of Turkey based on economic indicators using genetic algorithm approach. *Energy Conversion and Management* 45 (15–16), 2525–2537.
- [9] Dincer, I., Dost, S., 1996. "Energy intensities for Canada". *Applied Energy* 53, 283–298.
- [10] Ebohon, O.J., 1996. "Energy, economic growth and causality in developing countries: a case study of Tanzania and Nigeria". *Energy Policy* 24 (5), 447–453.
- [11] Haldenbilen, S., Ceylan, S., 2005. "Genetic algorithm approach to estimate transport energy demand in Turkey". *Energy Policy* 33 (18), 89–98.
- [12] Hepbasli, A., Utlü, Z., Akdeniz, R.C., 2007. "Energetic and exegetic aspects of cotton stalk production in establishing energy policies". *Energy Policy* 35 (5), 3015–3024.
- [13] Kavrakoglu, I., 1983. "Modeling energy–economy interactions", *European Journal of Operational Research* 13 (1), 29–40.
- [14] Lise, W., Van Montfort, K., 2007. "Energy consumption and GDP in Turkey: is there a co-integration relationship?". *Energy Economics* 29 (6), 1166–1178.
- [15] Ozcelik, Y., Hepbasli, A., 2006. "Estimating petroleum energy production and consumption using a simulated annealing approach". *Energy Sources, Part B: Economics, Planning and Policy* 1 (3), 255–265.
- [16] Rajabioun, R. et al 2008. "Identification of a MIMO evaporator and its decentralized PID controller tuning using Colonial Competitive Algorithm". Accepted to be presented in *IFAC World Congress*.

- [17] Rajabioun, R., Atashpaz-Gargari, and Lucas, C. 2008. "Colonial Competitive Algorithm as a Tool for Nash Equilibrium Point Achievement". *Lecture notes in computer science*, Vol. 5073, pp. 680-695
- [18] Say, N.P., Yucel, M., 2006. "Energy consumption and CO2 emissions in Turkey: empirical analysis and future projection based on an economic growth". *Energy Policy* 34 (18), 3870–3876.
- [19] Sepehri Rad, H., Lucas, C. 2008. "Application of Imperialistic Competition Algorithm in Recommender Systems". 13th Int'l CSI Computer Conference (CSICC'08), Kish Island, Iran.
- [20] Templet, P.H., 1999. "Energy diversity and development in economic systems: an empirical analysis". *Energy Policy* 30, 223–233.
- [21] Tiris M., 2005. "Global trends for energy", Turkish Workshop on Sustainable Development: Meeting the Challenges, Julich.
- [22] Toksari, M.D., 2006. "Ant colony optimization for finding the global minimum". *Applied Mathematics and Computation* 176 (1), 308–316.
- [23] Toksari, M.D., 2007. "Ant colony optimization approach to estimate energy demand in Turkey". *Energy Policy* 35, 3984–3990.
- [24] Unler, A, 2008. "Improvement of energy demand forecasts using swarm intelligence: The case of Turkey with projections to 2025". *Energy Policy* 36, 1937–1944
- [25] Uri, N.D., 1980. "Energy, GDP and causality: a statistical look at the issues". *Energy Communications* 6 (1), 1–15.
- [26] Utlu, Z., Hepbasli, A., 2006a. "Assessment of the energy utilization efficiency in the Turkish transportation sector between 2000 and 2020 using energy and exergy analysis method". *Energy Policy* 34 (13). 1611-1618.
- [27] Utlu, Z., Hepbasli, A., 2006b. "Estimating the energy and exergy utilization efficiencies for the residential-commercial sector: an application". *Energy Policy* 34 (10), 1097–1105.
- [28] Yu, E.S.H., Been, K.H., 1984. "The relationship between energy and GDP: further Results". *Energy Economics* 6 (3), 186–190.