Comparing Energy Demand Estimation Using Artificial Algae Algorithm: The Case of Turkey

Ayşe Beşkirli, Mehmet Beşkirli, Hüseyin Haklı, and Harun Uğuz

***Abstract*—Energy demand estimation is an important issue in terms of the economy and resources of a country. In this study, an Artificial Algae Algorithm (AAA) was used to estimate Turkey's long-term energy demand. The AAA is a fast, powerful and effective evolutionary optimization technique used to solve continuous optimization problems. Two different equations (linear and exponential) were used for the energy demand estimation by considering the relationship between the increase in economic indicators and the increase in energy consumption in Turkey. Turkey's long-term energy demand was estimated from 2006 to 2025 with the AAA method by using gross national product (GNP) and information about imports, exports and population. The AAA method was compared to other methods in published literature to show its success when applied to the energy demand problem. It was found that the results obtained by the proposed method were more robust and successful than those of the other methods.**

***Index Terms*—Artificial algae algorithm, optimization, energy demand, estimation, Turkey.**

I. Introduction

Energy plays a crucial role in the economic and social development of a country from past to present, because social, economic and industrial developments cause an increase in the amount of energy needed by a country. Therefore, the analysis of energy issues and the development of energy policies are a most important priority [1], [2]. Turkey, which is a Eurasian country extending from the Anatolian peninsula in southwest Asia to the Balkan region of southeast Europe [3], is a developing country. The estimation of energy demand is very important for developed and developing countries. The energy policy in Turkey has changed considerably from the 1973 and 1979 oil crises until today [4]. Turkey has planned for a strong economy, which will have to be supported with a steadily increasing energy supply in the long-term – in spite of unstable growth and permanent inflation during some periods [5]. Therefore, estimating energy demand accurately has become increasingly important. The more accurate the estimations are, the more successful the planning work will be. Although energy estimation studies have been conducted in other countries for a long time, the studies on this topic in Turkey have accelerated towards the end of the 1990s. At the end of the 1970s, the State Planning Organization (SPO), the Turkish Statistical Institute (TSK) and the Ministry of Energy and Natural Resources (MENR) started to use mathematical models to forecast energy demand [6], [7]. While Turkey evaluates estimates for energy demand from a general perspective, these studies have always predicted that the estimated energy demand was greater than the actual energy demand [8]. The fact that the estimated energy demand was larger caused the country to generate more energy than necessary because Turkey produces about 30% of the energy it needs, while the remaining demand is satisfied by imports [9]. Therefore, numerous models have been developed by many researchers to find the relationship between energy consumption and income by using various means, which include mathematical formulas directly or indirectly related to energy development models [10], [11]. Studies were carried out with different techniques to estimate the primary energy demand that Turkey needs. These studies were performed based on statistical techniques [12]-17], artificial intelligence techniques [18]-[20] and heuristic techniques [3, [5], [8], [21]-[24].

Today, many problems related to engineering applications have been adequately addressed by using heuristic methods. In particular, population-based heuristic algorithms can produce very fast results with multi-point procedures. In this study, the AAA method, based on swarm intelligence, was proposed to accurately estimate the demand for energy. For the estimation of energy demand, both linear and exponential energy estimation models were preferred. Their input parameters were GNP, population, and import and export data. The success of the AAA method was found to be satisfactory when comparing it to other studies in published literature. The amount of Turkey's primary energy supply demand was estimated by using the obtained coefficient values and the proposed scenarios. It was observed that the estimations were very close to the amount of actual energy demand observed.

In the subsequent sections of the paper, the Artificial Algae Algorithm (AAA) is explained in Section II. The results of the experimental study are given in Section III, while the conclusion is shown in Section IV.

II. Original Artificial Algae Algorithm

The AAA was one of the recently suggested meta-heuristic algorithm for solving continuous optimization problems. Algae are eukaryote livings in a wide variety of species. They have different nuclear membranes and chlorophylls. While microalgae are the name used for the algae having single nucleus, the algae which has multi nucleus are called as macroalgae. AAA is proposed as a bio-based novel meta-heuristic method by inspiring the characteristics and

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living behavior of the microalgae by Uymaz in 2015 [25]. An algae colony originates in a group of algae cell which are living together. AAA consist of three stages, and these stages are called as helical motion, evolutionary and adaptation process. Helical motion process is modelled by inspiring behaviors of helical motion of algae in liquid and being close to the light. Evolutionary process is modelled by inspiring the mitosis reproduction behavior of the algae. Adaptation process is modelled by inspiring environmental adaptation behavior of the algae.

AAA is presented briefly in this section, and detailed information about the algorithm could be found in [26].

Algae colony consist of an array which represents the algae population. This array is given as follows (Eq.1 and Eq.2);

$$\text{Population of algal colony} = \begin{bmatrix} x_1^1 & \cdots & x_1^D \\ \vdots & \ddots & \vdots \\ x_N^1 & \cdots & x_N^D \end{bmatrix} \quad (1)$$

$$x_i = \left[x_i^1,\ x_i^2, \dots x_i^D\right] \quad i = 1, 2, \dots, N \quad (2)$$

where x_i^j denotes an algae cell of the ith algae colony of jth dimension. The number of algae cell within an algae colony equal to the dimension of the problem. Each x_i presents a proper solution within the solution space. Each algae cell in the algae colony is thought to be act collectively towards to a proper place in the solution space. The optimal solution is obtained when an algae colony achieves an ideal solution.

TABLE I: ENERGY DEMAND (MTOE), GNP, POPULATION, IMPORT AND EXPORT DATA OF TURKEY BETWEEN 1979 AND 2011

Year	Energy Demand (MTOE)	GNP ($\$10^9$)	Population (10^6)	Import ($\$10^9$)	Export ($\$10^9$)
1979	30.71	82	45.53	5.07	2.26
1980	31.97	68	44.44	7.91	2.91
1981	32.05	72	45.54	8.93	4.70
1982	34.39	64	46.69	8.84	5.75
1983	35.70	60	47.86	9.24	5.73
1984	37.43	59	49.07	10.76	7.13
1985	39.40	67	50.31	11.34	7.95
1986	42.47	75	51.43	11.10	7.46
1987	46.88	86	52.56	14.16	10.19
1988	47.91	90	53.72	14.34	11.66
1989	50.71	108	54.89	15.79	11.62
1990	52.98	151	56.10	22.30	12.96
1991	54.27	150	57.19	21.05	13.59
1992	56.68	158	58.25	22.87	14.72
1993	60.26	179	59.32	29.43	15.35
1994	59.12	132	60.42	23.27	18.11
1995	63.68	170	61.53	35.71	21.64
1996	69.86	184	62.67	43.63	23.22
1997	73.78	192	63.82	48.56	26.26
1998	74.71	207	65.00	45.92	26.97
1999	76.77	187	66.43	40.67	26.59
2000	80.50	200	67.42	54.50	27.78
2001	75.40	146	68.37	41.40	31.33
2002	78.33	181	69.30	51.55	36.06
2003	83.84	239	70.23	69.34	47.25
2004	87.82	299	71.15	97.54	63.17
2005	91.58	361	72.97	116.77	73.48

III. IMPLEMENTATION OF THE SUGGESTED METHOD FOR THE ENERGY DEMAND ESTIMATION PROBLEM

The energy demand estimation was constructed from GNP, population, import and export data. It is believed that these four factors have a significant impact on determining the energy demand of a country; the data for these criteria were used to develop energy demand models with the AAA [3, 22]. Table 1 shows GNP, population, export and import data, as well as the energy demand values for Turkey between 1979 and 2005. These data was obtained from Turkish Statistical Institute (TSK), Ministry of Energy and Natural Resources (MENR), Energy Reports and previous works [10].

Table I indicates that Turkey is in the process of continuous development, and its economic values have increased over the years. It can also be concluded from the table that there is a correlation between the increase in economic values and the increase in energy consumption. Energy demand estimations were modeled in two different ways: linear and exponential. The linear and exponential forms are given in Equations 3 and 4, respectively [21]:

$$E_{linear} = w_1 + w_2X_1 + w_3X_2 + w_4X_3 + w_5X_4 \quad (3)$$

$$E_{exponential} = w_1 + w_2X_1^{w_3} + w_4X_2 + w_5X_3^{w_6} + w_7X_4^{w_8} \quad (4)$$

The purpose of the energy demand estimation is to find the most suitable values for data. The X_1, X_2, X_3 and X_4 given in Equation 3 and 4 indicate GNP, population, import and export values, respectively. Coefficient values (w_i) that can estimate the most suitable energy demand in given years are calculated according to these values. The objective function used in the study is shown in Equation 5.

$$\min f(v) = \sum_{i=1}^{r} \left(E_i^{observed} - E_i^{predicted}\right)^2 \quad (5)$$

where $E_i^{observed}$ and $E_i^{predicted}$ indicate observed and predicted values, respectively, and r indicates the number of observations.

A. Comparison of the AAA and Other Models in Published Literature

The AAA method was compared with other models in published literature to observe whether it was successful in solving the energy demand problem. Different heuristic methods were applied to the energy demand estimation problem, such as ACO (Ant Colony Optimization) by Toksarı [3], ABCVSS (Artificial Bee Colony with Variable Search Strategies) by Uguz [24], PSO (Particle Swarm Optimization) by Unler [22] and BA (Bat Algorithm) by Haklı [27].

The AAA was independently run 10 times for both models. The best results were considered. Coefficient values obtained for the linear model were as follows:

$$E_{linear} = 0.0039X_1 + 1.9121X_2 + 0.3732X_3 - 0.4831X_4 - 55.8926 = 41.7120 \quad (6)$$

In the exponential version of the proposed model, the coefficients obtained are given below:

$$E_{exponential} = -100X_1^{-1.2166} + 1.4520X_2 + 39.2724X_3^{0.13} + 71.5140X_4^{-3.147} - 85.9253 = 47.3887 \quad (7)$$

According to Equations 6 and 7, relative error values obtained for the linear and exponential models are 41.7120 and 47.3887, respectively. In this study, because the value obtained from the linear model is better than that of the exponential method, the energy demand estimation was performed by considering the linear model. For the linear form, relative error values for AAA, ABCVSS, BA, ACO and PSO algorithms are shown in Table II. It can be observed from the table that the coefficients and relative errors of the AAA and ABCVSS methods were very close to each other, while the other three methods produced higher relative error values.

TABLE II: RELATIVE ERROR VALUES FOR THE LINEAR FORM

Coefficients	AAA	ABCVSS	BA	ACO	PSO
***w*1**	−55.8991	−55.9091	−57.7676	−51.3046	−55.9022
***w*2**	0.0038	0.0038	0.00002	0.0124	0.0021
***w*3**	1.9123	1.9126	1.9549	1.8102	1.9126
***w*4**	0.3735	0.3734	0.4023	0.3524	0.3431
***w*5**	−0.4835	−0.4833	−0.5316	−0.4439	−0.4240
R. Error	41.7120	41.7029	42.4890	45.7239	42.6139

Ten sets of data between 1996 and 2005 were used to observe the validity of the energy demand estimation performed according to the coefficients obtained by the AAA. The results are shown in Table III. The highest relative error (3.37%) was obtained in 1999. The reason for this is that GNP, export and import values decreased in 1999 [8].

TABLE III: ENERGY DEMAND ESTIMATION OF THE PROPOSED MODELS BETWEEN 1996 AND 2005

Year	Observed Energy Demand (MTOE)	Estimated Energy Demand (MTOE)	Amount of Errors	Relative Errors (%)
		Linear (AAAL)	Linear (AAAL)	Linear (AAAL)
1996	69.86	69.71	−0.15	−0.21
1997	73.78	72.31	−1.46	−1.99
1998	74.71	73.30	−1.41	−1.89
1999	76.77	74.18	−2.59	−3.37
2000	80.50	80.71	0.21	0.27
2001	75.40	75.71	0.31	0.42
2002	78.33	79.13	0.80	1.02
2003	83.84	82.37	−1.47	−1.76
2004	87.82	87.19	−0.63	−0.72
2005	91.58	93.10	1.52	1.66

Table IV shows the mean relative error values of the algorithms used in published literature and for the linear form of the AAA between 1996 and 2005.

TABLE IV: MEAN RELATIVE ERRORS FOR AAA AND VARIANT MODELS BETWEEN 1996 AND 2005

Algorithms Linear Form	Mean Absolute Relative Error	Reference
PSO	1.43	Ünler [22]
ACO	1.41	Toksarı [3]
BA	1.35	Haklı [27]
ABCVSS	1.33	Uğuz [24]
AAA	1.33	Proposed Method

When examining the mean relative errors in Table IV, the AAA and ABCVSS methods obtained the lowest relative error (1.33). Thus, it can be said that the AAA approach is robust and successful for the energy demand estimation. Three different scenarios were used to estimate the energy demand for Turkey between 2006 and 2025 by considering current data. These scenarios were obtained from the study conducted by Toksarı in 2007. Table V shows the energy demand values between 2006 and 2025 for the linear model by using the coefficients obtained from the AAA and the given scenarios. Moreover, Table V indicates the energy demand values observed between 2006 and 2014.

TABLE V: FUTURE PROJECTIONS OF TOTAL ENERGY DEMAND IN MTOE ACCORDING TO SCENARIOS

Year	Observed Energy Demand (MTOE)	Linear		
		Scenario-1	Scenario-2	Scenario-3
2006	99.59	94.68	104.41	94.13
2007	107.63	96.33	105.64	95.20
2008	106.34	98.06	106.93	96.32
2009	106.14	99.88	108.28	97.50
2010	109.27	101.80	109.68	98.73
2011	114.48	103.81	111.14	100.02
2012	120.09	105.92	112.66	101.37
2013	120.29	108.14	114.25	102.78
2014	123.94	110.47	115.91	104.27
2015	N/A	112.92	117.64	105.82
2016	N/A	115.49	119.45	107.45
2017	N/A	118.19	121.34	109.16
2018	N/A	121.02	123.31	110.96
2019	N/A	124.00	125.37	112.84
2020	N/A	127.13	127.52	114.81
2021	N/A	130.41	129.77	116.88
2022	N/A	133.86	132.12	119.06
2023	N/A	137.48	134.58	121.34
2024	N/A	141.28	137.15	123.74
2025	N/A	145.27	139.84	126.25

When Table V is examined, it is seen that scenario 2 produced estimations very close to the observed energy demand value. However, scenario 1 presented estimations with a higher accuracy over the years. Scenario 3 produced energy demand values considerably less than observed values. In the linear model, it can be said that scenario 2 is more suitable than the other scenarios.

IV. CONCLUSION

In this study, the primary energy demand for Turkey between 2006 and 2025 was estimated by using the AAA method. To achieve this, 27 years' of data, including GNP, population, import and export values between 1979 and 2005, were used. Coefficients for the linear and exponential forms were used for this method and the study tried to find the optimal values of these coefficients that can optimize the estimation by the AAA method. The Observed Energy Demand values between 2006 and 2014 were used to test the validity of this model. Furthermore, when evaluating the mean absolute relative errors of the methods – because the

AAA method obtained the lowest error for the linear form – it can be said that the proposed method is a successful tool for energy demand estimation.

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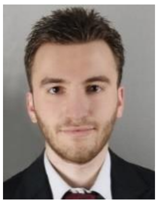

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