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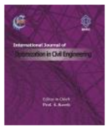

PREDICTION OF ELECTRICITY CONSUMPTION USING THREE META-HEURISTIC ALGORITHMS

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ABSTRACT

Energy production and consumption play an important role in the domestic and international strategic decisions globally. Monitoring the electric energy consumption is essential for the short- and long-term of sustainable development planned in different countries. One of the advanced methods and/or algorithms applied in this prediction is the meta-heuristic algorithm. The meta-heuristic algorithms can minimize the errors and standard deviations in the data processing. Statistically, there are numerous methods applicable in the uncertainty analysis and in realizing the errors in the datasets, if any. In this article, the Mean Absolute Percentage Error (MAPE) is used in the error's minimization within the relevant algorithms, and the used dataset is actually relating to the past fifty years, say from 1972 to 2021. For this purpose, the three algorithms such as the Imputation–Regularized Optimization (IRO), Colliding Bodies Optimization (CBO), and Enhanced Colliding Bodies Optimization (ECBO) have been used. Each one of the algorithms has been implemented for the two linear and exponential models. Among this combination of the six models, the linear model of the ECBO meta-heuristic algorithm has yielded the least error. The magnitude of this error is about 3.7%. The predicted energy consumption with the winning model planned for the year 2030 is about 459 terawatt-hours. The important socio-economical parameters are used in predicting the energy consumption, where these parameters include the electricity price, Gross Domestic Product (GDP), previous year's consumption, and also the population. Application of the meta-heuristic algorithms could help the electricity generation industries to calculate the energy consumption of the approaching years with the least error. Researchers should use various algorithms to minimize this error and make the more realistic prediction.

Keywords: electricity consumption prediction, meta-heuristic algorithms, MAPE, CBO, ECBO, IRO.

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1. INTRODUCTION

Energy is one of the significant factors in industrial production in any country. The influence of various types of energies in human's life, such as electricity, is increasing on a daily basis. One of the substantial challenges of the most countries in the world is the energy production and consumption. Any country with more access to the energy sources can act and plan more efficiently regarding the economic developments. Forecasting of the energy consumption in the approaching years is one of the most important parameters in the planning. This planning can be conducted either traditionally or scientifically, or better to say, methodologically. Since the majority of the predictions are made by analyzing the old data, the traditional method could yield the erroneous results, thus it is recommended to use the modern and/or scientific methodologies. Application of the Artificial Neural Networks (ANN) and Meta-heuristic Algorithms, and also the other applicable methods in predicting the electricity consumption have been mentioned in many of the research works. The Neural Networks are of the suitable tools for predictions, by examining the trend of the existing data, and predicting the continuation of this trend. The Neural Networks as combined or developed by meta-heuristic algorithms are also used in forecasting of the energy consumption. But the meta-heuristic algorithms are not directly used in the predictions. The main ability and/or facilitation of these algorithms is the optimization. The algorithms could minimize or maximize the objective function of a problem. In the forecasting of the electricity consumption, the algorithms are used to minimize the error percentages of the processed data and they would be of help in selecting of the most appropriate model. The main goal of the authors of this article is to help further investigate the potential of meta-heuristic algorithms in reducing prediction error. There are many parameters to be influential in the establishment of the electricity consumption prediction model. The most important parameters of such are the population, GDP, electricity price and previous year's electricity consumption. There are several criteria and methods for checking the data error in the relevant statistics. The most important of these indicators are the MAPE, MSE, RMSE and MAE. These indicators are abbreviated as the Mean Absolute Percentage Error, Mean Squared Error, Root Mean Square Error and Mean Absolute Error, respectively. In this article, some algorithms and models have been reviewed to check the possibility of the minimization of the error, as in fact, it has been one of the important purpose of the researchers to achieve a more realistic prediction. Either just one, or a combination of the above methods could have been used in various researches, in which, some of them are mentioned below. Obviously, further research will lead to the creation of new and novel methods for predicting electricity consumption.

Lei et al. [1] used the deep fusion model to forecast the household electricity consumption in Australia. Johannesen et al. [2] used regression techniques to predict the electrical energy demand for urban areas. Amin et al. [3] predicted the energy demand and analyzed the household electricity consumption in multiple time scales. He et al. [4] presented an electricity consumption prediction model based on a kind of regression neural network. Muralitharan et al. [5] presented a model to analyze the electrical energy consumption in India, in which, in this model, the Artificial Neural Networks (ANN) trained using Genetic Algorithms (GA) and Particle Swarm Optimization (PSO) are used. Kaboli et

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al. [6] estimated the electrical energy demand for five countries in the ASEAN region. Therefore, the information about the population, GDP, export and import to and from Malaysia, Thailand, Singapore, Indonesia, and Philippines were used to model the electric energy consumption. Pérez-García and Moral-Carcedo [7] predicted the electrical energy demand in Spain using the decomposition modeling. In this study, the variables such as population and domestic production rate were investigated as the parameters that are affecting the electric energy consumption. Azadeh et al. [8] used several meta-heuristic algorithms to estimate the demand for the electrical energy consumption for 16 countries in the world until the year 2030. Li and Tang [9] used a gray forecasting model to forecast the electricity consumption in China, where they used a genetic algorithm to reduce the forecasting differentiation. A lot of research works have been done on optimization by algorithms, but in fact, the task of the researcher is to find the best algorithm for this problem. Researches show that CBO, ECBO, and IRO algorithms have been considered and used in many types of investigations and analysis. In this article, we have used these three algorithms to check the percentage reduction of the error. In the following, we address the researches that have been conducted using these three algorithms. One of the most recent articles about combining the two algorithms for optimization is related to the research of Shaygan et al. (2020) with the combination of the two algorithms as CBO and MBF, from which the acceptable results have been obtained [10-12]. In 2019 and 2020, Shayegan et al. also published two different articles discussing the mouthbrooding fish algorithm for cost optimization of reinforced concrete one-way ribbed slabs and solid slabs [13,14]. Moreover, the results of the CBO algorithm were compared with the two other algorithms in optimizing the reservoir of a dam [15]. The use of the CBO meta-heuristic algorithm is discussed by Kaveh et al. [16]. After 2014, the use of CBO became more popular in several areas of research, some of which are mentioned below.

Kaveh et al. [17] applied the CBO for the optimization of truss structures with discrete sizing variables. Kaveh et al. [18] had a comparative study of CBO and ECBO for the optimal design of skeletal structures, as compared the capability of the CBO and ECBO through two trusses and two frames structure. Kaveh et al. [19] discussed the two-dimensional colliding bodies algorithm for the optimal design of truss structures and explained the two-dimensional CBO and its utility for the optimization of truss structures. Moreover, Kaveh et al. [20] modified the CBO algorithm for the optimized cost design of the concrete bridges. Additionally, Kaveh et al. [21] explained the difference between CBO, ECBO, and NECBO and the capabilities of NECBO in the optimization. Also, one of the recent famous meta-heuristics is the Improved Ray Optimization (IRO) algorithm presented by Kaveh et al. [22]. They have developed the Ray Optimization (RO) algorithm as a novel population-based meta-heuristic conceptualized based on Snell's light refraction law when the light travels from a lighter medium to a darker medium. Other metaheuristic are modified and applied to structural design [23-26]. We have used the meta-heuristic algorithms developed by Kazemi et al. [27]. The research method, formulas, and relationships are presented in this article, in which, the genetic algorithm (GA), particle swarm optimization (PSO) algorithm, and imperialism competition algorithm (ICA) are used to determine the equations for predicting the electrical energy demand. In our article, we replace and analyze the three new algorithms of CBO, ECBO, and IRO. In the rest of this article, the three algorithms CBO, ECBO, and IRO are briefly explained, then the research method is explained, and afterwards, the most efficient algorithm among these three algorithms is selected to predict the electricity consumption. The next step is to forecast the electricity consumption until the year 2030.

2. META-HEURISTIC ALGORITHMS

The meta-heuristic algorithms have helped to solve many engineering problems. These optimization programs are used to obtain the minimum or maximum value of the objective functions under some specific constraints. The philosophy of the meta-heuristic algorithms is often inspired by the natural phenomena or physical laws. The method and style of the animal behavior such as social life, defense against enemies, food preparation, having children, or other activities have been the basis of many meta-heuristic algorithms. There are different types of optimization algorithms, which increase in number almost every day. These algorithms are divided into two single-objective and multi-objective functions. In most cases, in order to simplify and solve the problem, a single objective function is considered and the problem is solved by defining the penalty function. A single-objective optimization problem has simple relations that are mentioned in many scientific papers such as paper, so it is avoided to repeat it here. Considering that in this article, the three algorithms CBO, ECBO, and IRO are used for optimization, where their summary and general definition are explained.

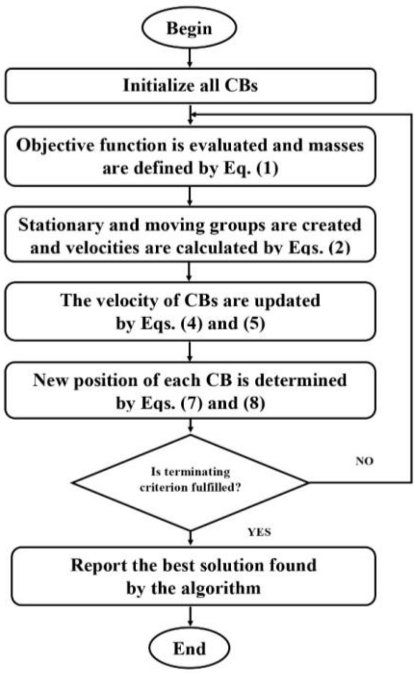

Figure 1. Flowchart of the CBO algorithm [16]

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2.1 Colliding bodies optimization (CBO)

The CBO (Colliding Bodies optimization) algorithm is one of the best meta-heuristic algorithms that was developed by Kaveh et al. [16] and it was also presented in Kaveh et al. [28]. This algorithm has been inspired by the collision of objects that move relative to each other with the least energy level after the collision. The CBO algorithm has a simple concept and, unlike most of the meta-heuristic algorithms, it does not depend on any internal parameters. In principle, the important advantage of this algorithm is that there is no need to adjust the internal parameters and use of simple formulation and complete understanding of it. Given the favorable results of the CBO algorithm, the willingness of researchers to use this algorithm will increase in the coming years. This algorithm has a high speed in program running time and is very agile. In this algorithm, one object collides with another, and objects move or change in such a way that energy is minimized, each object that hits (Xi) has a specific mass. To select a pair of objects to collide, the beating objects are classified in descending order based on the mass assigned to them and then they are classified into two categories, the "Stationary" group, and the "Moving" group. The moving objects hit stationary objects to improve their position and move stationary objects to a better position. The formulas and relationships related to this algorithm are detailed in the reference [16], so it is omitted to repeat it. The flowchart of the CBO algorithm is shown in Fig. 1.

2.2 Enhanced colliding bodies optimization (ECBO)

Many researchers have developed existing algorithms to improve their performance. The ECBO algorithm is one of these types of algorithms. In order to improve the CBO to get more reliable solutions and faster, the Enhanced Colliding Bodies Optimization (ECBO) was developed which uses the memory to save several historically best Colliding Bodies (CBs) and also utilizes a mechanism to escape from local optima [28]. The flowchart of ECBO is shown in Fig. 2.

The levels of this technique are given as follows, and each of these levels has its steps:

Level 1: Initialization
Level 2: Search
Level 3: Terminal condition check

The formulas and relationships of this algorithm are given in the reference [28] and therefore will not be repeated here.

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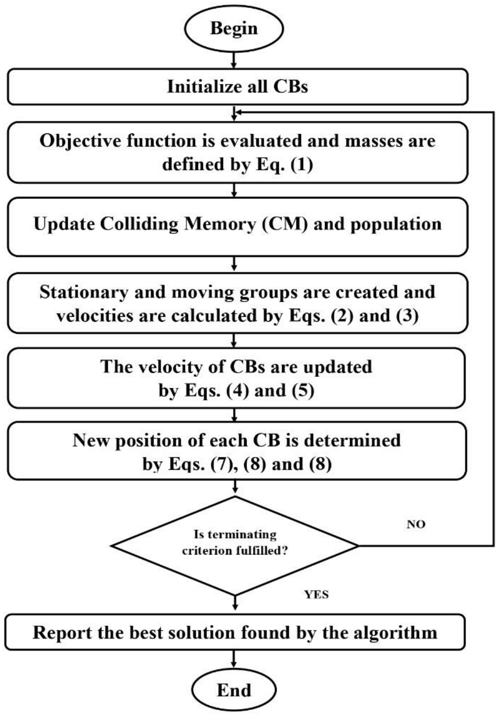

Figure 2. Flowchart of the ECBO algorithm [28]

2.3 Improved ray optimization (IRO)

Kaveh and Khayatazad (2012), have invented the Ray Optimization (RO) algorithm [22] as a novel population-based meta-heuristic conceptualized based on Snell’s light refraction law when light travels from a lighter medium to a darker medium. Based on Snell's light refraction law, when light travels from one medium to another, it refracts. The refraction depends on the angle between the incident ray and the normal vector of the interface surface of two mediums and the refraction index ratio of the two mediums. Its direction changes in a way that gets closer to the normal vector when it passes from a lighter medium to a denser one. This physical behavior is the basis of the RO. The agents of RO are considered as beginning points of rays of light updated in the search space or traveled from one medium to another one based on Snell's light refraction law. Each ray of light is a vector so that its beginning point is the previous position of the agent in the search space, its direction and length are the searching step size in the current iteration, and its endpoint is the current position of the agent achieved by adding the step size to the beginning point. Considering an effective vector as the normal vector of the interface surface between two mediums and an effective value for the refraction index ratio of two mediums, the refraction vector can be achieved based on Snell's law as the new searching step size. Consequently, the new position of the agents is updated to explore the search space and converge to the global or near-global optimum. The current position of the agents as one of the starting or ending points of this vector is inevitable to use Snell's law. However, the other one should be selected in a way that creates a good balance between exploration and exploitation. The RO is considered effectively the normal vector so that it starts from a point determined based on the individual and collective knowledge of agents and ends in the current position of agents. The RO starts from randomly the generated initial candidate solutions and random initial search step sizes. These are the rays of light that travel from one medium to another in the cyclic body of the algorithm. The RO aims to improve the quality of the solutions by refracting the rays toward the promising points obtained based on the best-known solution by each agent and all of them. Kaveh et al. [26] developed an Improved Ray Optimization (IRO) algorithm employing a new approach to generating new solution vectors which have no limitation on the number of variables, so in the process of the algorithm, there is no need to divide the variables into groups like RO. The procedure which returns the violated agents into feasible search space is also modified. These improvements enhance the accuracy and convergence rate of RO. Here, the IRO is used because of its efficiency and simplicity over the RO algorithm. The IRO algorithm also has several levels and steps that are mentioned in the reference [29], so they are not presented here. The flowchart of the IRO algorithm is provided in Fig. 3.

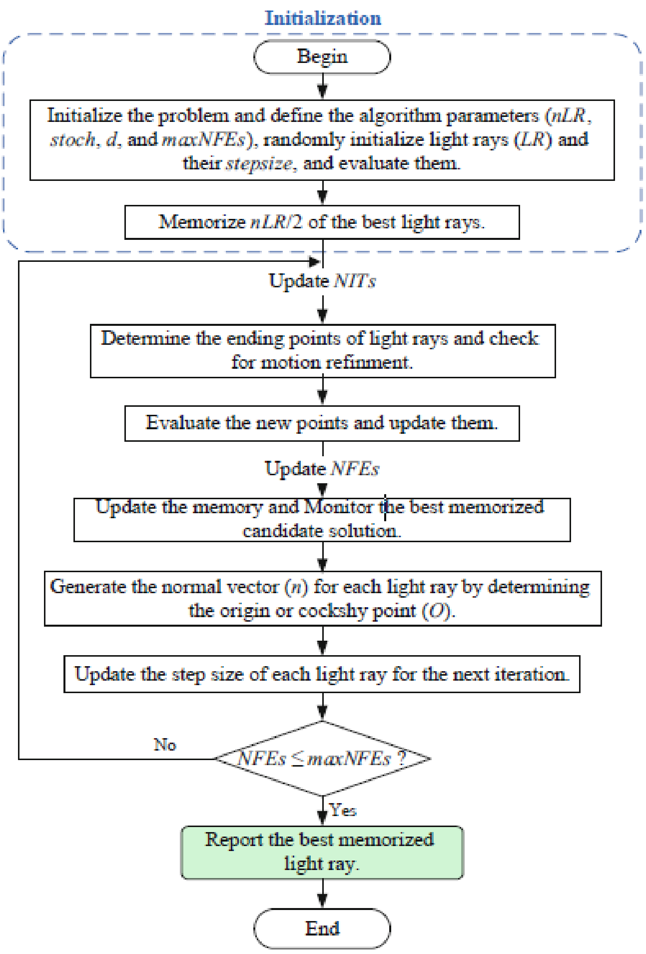

Figure 3. Flowchart of the IRO algorithm [22]

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3. RESEARCH METHODS

This research is applied in the descriptive analytical research group. Fifty years of statistics have been used to ensure a suitable answer. All required statistics have been collected from 1972 to 2021. These statistics are taken from official organizations and companies. The "Organization of Statistics" and the "Ministry of Energy in Iran" are the most important statistical sources of this research. The data is divided into two parts, one part for training and the other part for test. About 80% of the data is used for training and the remaining 20% for testing. Then the parameters are adjusted and the error index is minimized as much as possible for training and test data. If the accuracy of the model is not acceptable, the algorithm is redone again and the parameters of the model are adjusted. This step continues until an acceptable accuracy is reached. Fig. 4 shows the conceptual model of the research. As shown in the Fig. 4, the output variable (electricity consumption) is a function of the input variables (population, GDP, real electricity price, and previous year's consumption). The model is defined for all three algorithms as linear and non-linear (exponential).

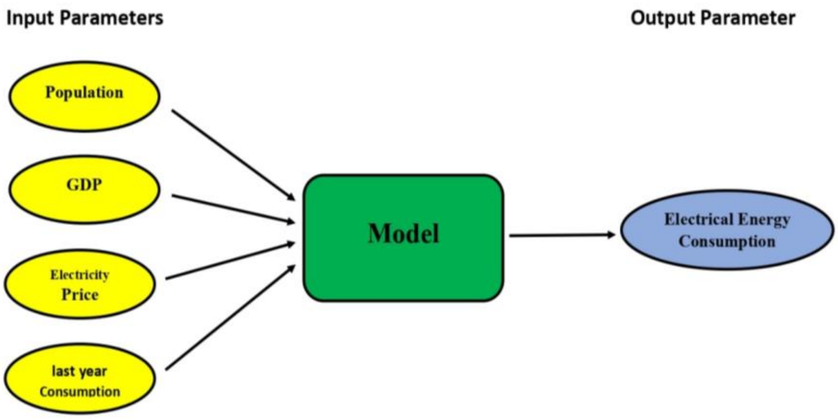

Figure 4. The conceptual model of the research

For the linear and exponential models, the equations (1) and (2) are used. Here Elec(t), Pop, GDP, Price, Elec(t-1) are respectively, electricity consumption in the current year, population, GDP, electricity price, and previous year's consumption:

$$Elec(t) = w1 * Pop + w2 * GDP + w3 * Price + w4 * Elec(t-1) + w5 \quad (1)$$

$$Elec(t) = w1 * Pop^{w2} + w3 * GDP^{w4} + w5 * Price^{w6} + w7 * Elec(t-1)^{w8} + w9 \quad (2)$$

The most suitable model with the lowest percentage of error is obtained with the help of the index introduced in equation (3). In fact, the Mean Absolute Percentage Error (MAPE) is obtained from this relationship:

$$MAPE = \frac{1}{n}\sum_{n}^{1} \left| \frac{x(i)-y(i)}{x(i)} \right| * 100 \quad (3)$$

n = Number of data

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x(i) = Real amount
y(i) = Predicted value

In order to predict the future demand, the input variables must be known. For this purpose, the input variables are predicted according to the average annual growth rate of the last 10 years. The MATLAB program has been used to design this model by meta-heuristic algorithms.

4. NUMERICAL EXAMPLE

This model was implemented based on Iran's past 50-years statistics. According to the previous experience, it has been shown that the electricity consumption in Iran has increased annually. But the rate of this consumption should be obtained using the new methods. Each one of the three algorithms was run for 20 different states of each model. In each run, the error value was recorded after reaching the stop criterion (specified number of repetitions). Finally, the best model was selected based on the highest convergence. Table 1 shows the optimal coefficients obtained for the introduced models by the all three algorithms. The lower and upper limits of each variable have been obtained by trial and error between -1000 and +1000.

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Table 1: Optimal coefficients for several models

Model	IRO $_{Linear}$	IRO $_{exponential}$	CBO $_{Linear}$	CBO $_{exponential}$	ECBO $_{Linear}$	ECBO $_{exponential}$
W1	-0/5890	291/0306	0/0552	1/4057	-0/0189	1/4059
W2	-1/1842	593/1733	0/3618	2/6347	0/2581	2/6341
W3	-3/7399	284/9734	0/0653	46/2879	-0/3076	-75/9074
W4	2/3222	601/7962	0/8815	4/3367	1/0398	83/5798
W5	0/0892	503/1980	0/0018	9/1923	0/0084	-56/7807
W6		578/1695		19/4720		2/1923
W7		492/7380		-82/5279		67/4402
W8		616/0369		14/2075		8/7035
W9		0/0306		0/0183		0/0183

Also, in the continuation of the calculations, Table 2 shows the absolute percentage of the average error for the construction (including training and test data). As shown in the Table 2, the best model is the linear ECBO one.

Table 2: The MAPE in different models

Model	MAPE – Train	MAPE - Test
IRO $_{Linear}$	0.2003	1.2258
IRO $_{exponential}$	0.6649	0.9417
CBO $_{Linear}$	0.0220	0.1117
CBO $_{exponential}$	0.0939	2.614
ECBO $_{Linear}$	0.0305	0.0379
ECBO $_{exponential}$	0.0934	3.3856

The convergence curve of the six models used in this research is shown in Fig. 5. Each of the three algorithms has two linear and exponential curves.

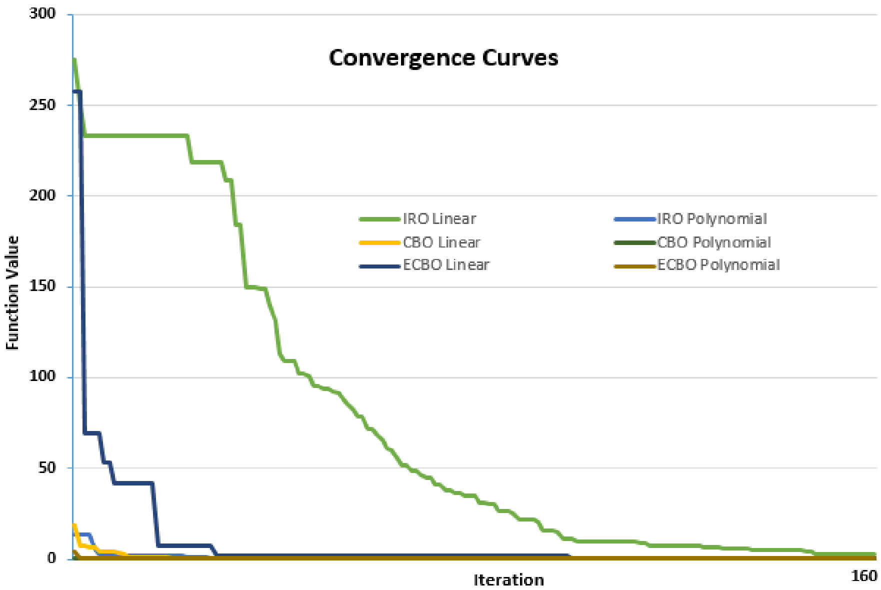

Figure 5. Convergence curve of the six models

The Fig. 6 shows the levels of the errors in each one of the models, the linear ECBO model has the least error. This error is obtained as 3.7%.

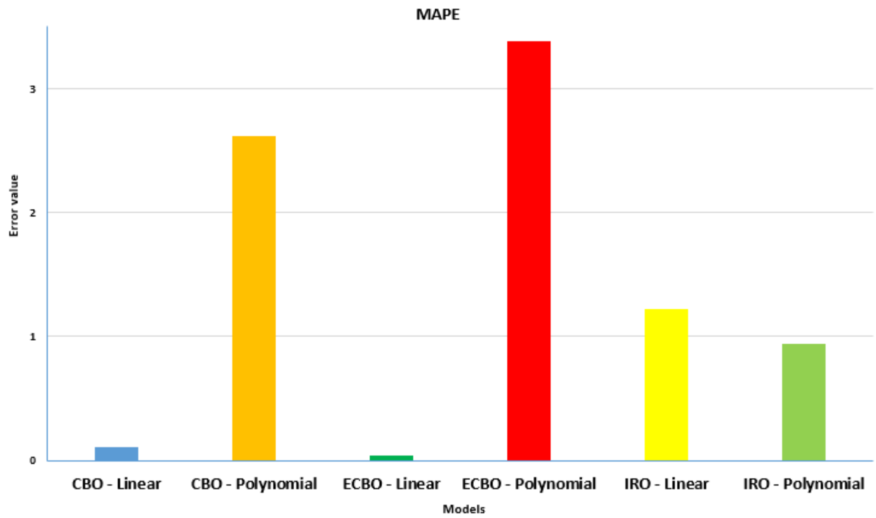

Figure 6. The MAPE in six models

Although according to the used references, the investigations are done on MAPE, but in order to complete the study, some of the most important methods of minimizing the statistical error have also been calculated. These values are listed in Table 3. In other

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components of error minimization, such as MSE, RMSE and MAE, as well as MAPE, the best results are for the linear ECBO algorithm.

Table 3: Error minimization methods in different models

Model	MSE	RMSE	MAPE	MAE
CBO $_{Linear}$	9.E+08	30,182	0.1117	28,366
CBO $_{Polynomial}$	3.E+12	1,634,407	2.6148	782,218
ECBO $_{Linear}$	1.E+08	11,773	0.0379	9,728
ECBO $_{Polynomial}$	2.E+12	1,511,502	3.3855	957,311
IRO $_{Linear}$	1.E+11	374,158	1.2258	323,094
IRO $_{Polynomial}$	6.E+10	236,974	0.9417	233,995

In order to compare the value of the MAPE in different algorithms, the table of this parameter obtained from the reference article studies [27] is given in Table 4.

Table 4: MAPE in Reference article [27]

Model	MAPE
GA $_{Linear}$	0.0455
GA $_{exponential}$	0.0518
PSO $_{Linear}$	0.0362
PSO $_{exponential}$	0.0285
ICA $_{Linear}$	0.0318
ICA $_{exponential}$	0.0379

But because the data of the reference article is for the years 1968 to 2015 and the data of our research is for the years 1972 to 2021, the results of the two articles cannot be compared.

The last step is to calculate the consumption forecasting for the approaching years. Considering that the United Nations envisions 2030 as the year when human society reaches the goals of sustainable development, the forecast continues until this year. After using the superior model, the forecasting data for the approaching years until the year 2030 are shown in Table 5. In order to predict the electricity consumption, some parameters such as population, GDP, electricity price and previous year's consumption have been used. These parameters have been predicted using the trend of the past ten years and the prices have been returned to fixed financial prices according to the reference article. A change in these parameters will cause a change in the forecast of electricity consumption. According to the discussion with several experts in the power generation industry, the process of forecasting electricity consumption in this article is reasonable and defensible. The main purpose of this article is to investigate the potential and capacity of algorithms in predicting electricity consumption. The specialists in the science of statistics and data prediction can help a lot in the development of these type of evaluations. Sensitivity analysis is the experimental process by which we determine the relative importance of the various factors of a system. For every new meta-heuristic, we need to know how sensitive an approach is to its control parameters and which control parameters are robust/or sensitive, but in our paper, the superior model is obtained by linear ECBO algorithm, and the ECBO algorithm does not have internal parameters like the CBO algorithm. Therefore, sensitivity analysis was not performed in this article.

Table 5: Consumption Prediction

Year	Population (Million People)	GDP (Billion Rials)	Price (Rials per kilowatt hour)	Prediction (Terawatt hour)
2022	85.31	36,188,986	982	337
2023	86.22	39,586,890	1038	358
2024	87.13	42,984,794	1094	378
2025	88.04	46,382,699	1150	395
2026	88.95	49,780,603	1207	412
2027	89.85	53,178,507	1263	426
2028	90.76	56,576,412	1319	439
2029	91.67	59,974,316	1375	449
2030	92.58	63,372,220	1432	459

The graph of electricity consumption from 1972 to 2021 is shown in green and the forecast until 2030 is shown in red in Fig. 7.

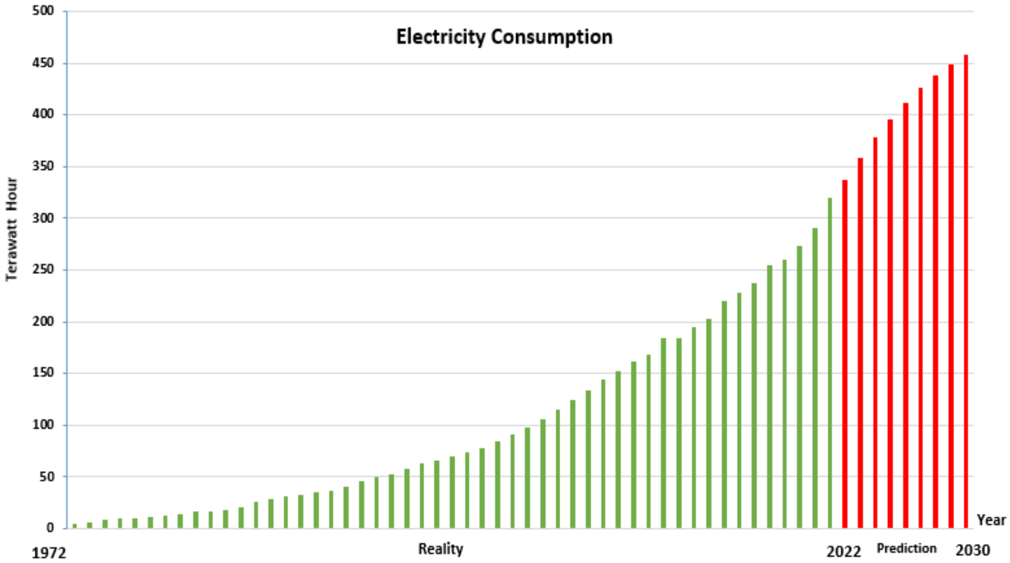

Figure 7. The Electricity Consumption

5. CONCLUSIONS

The growth and development of countries depend on the proper energy management. Electricity is one of the most important types of energy sources, especially in the 21st century. It is possible to predict the electricity production by calculating the production of

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existing power plants and futuristic developmental projects. But, predicting electricity consumption is a very complicated case. There are traditional and novel methods for predicting the electricity consumption. The modern methods such as neural networks and meta-heuristic algorithms have minimized prediction errors. Three meta-heuristic algorithms IRO, CBO, and ECBO were investigated and six models were prepared in this article. These models included two linear and exponential modes in the three algorithms. Among the six models, the linear model of the ECBO algorithm had the least error, therefore, calculations were made based on that. The value of the Mean Absolute Percentage Error (MAPE) in the winning model was 3.7%. The increasing trend of electricity consumption until 2030 was calculated. The amount of electricity consumption in 2030 will be about to 459 terawatt-hours. In order to predict the electricity consumption, four socio-economical parameters have been used. These four parameters are population, electricity price, GDP, and the previous year's consumption rate. By using the meta-heuristic algorithms and minimizing the prediction error, it is possible to plan for the country's electricity grid and the necessary developments. Researchers can reduce this amount of error by using other meta-heuristic algorithms and comparing the results of the algorithms. The authors of this article suggest to the power generation industry and managers to use the novel forecasting methods such as neural networks and meta-heuristic algorithms.

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