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Estimates of hydroelectric generation using neural networks with the artificial bee colony algorithm for Turkey

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ABSTRACT

The primary objective of this study was to apply the ANN (artificial neural network) model with the ABC (artificial bee colony) algorithm to estimate annual hydraulic energy production of Turkey. GEED (gross electricity energy demand), population, AYT (average yearly temperature), and energy consumption were selected as independent variables in the model. The first part of the study compared ANN-ABC model performance with results of classical ANN models trained with the BP (back propagation) algorithm. Mean square and relative error were applied to evaluate model accuracy. The test set errors emphasized positive differences between the ANN-ABC and classical ANN models. After determining optimal configurations, three different scenarios were developed to predict future hydropower generation values for Turkey. Results showed the ANN-ABC method predicted hydroelectric generation better than the classical ANN trained with the BP algorithm. Furthermore, results indicated future hydroelectric generation in Turkey will range from 69.1 to 76.5 TWh in 2021, and the total annual electricity demand represented by hydropower supply rates will range from 14.8% to 18.0%. However, according to Vision 2023 agenda goals, the country plans to produce 30% of its electricity demand from renewable energy sources by 2023, and use 20% less energy than in 2010. This percentage renewable energy provision cannot be accomplished unless changes in energy policy and investments are not addressed and implemented. In order to achieve this goal, the Turkish government must reconsider and raise its own investments in hydropower, wind, solar, and geothermal energy, particularly hydropower.

1. Introduction

Sustainable energy sources are essential to economic and social development, and improved quality of life in Turkey, as in other countries [1]. Consequently, the identification and analysis of energy resources, and the development of energy policy options are of prime importance worldwide [2,3].

Energy and electricity demands in Turkey are showing rapid increases, and the country is heavily dependent on expensive imported fossil fuel resources, which place a substantial burden on the economy. Furthermore, environmental concerns over air pollution continue to grow [4]. The energy demands in Turkey were 114 million tons of oil equivalent (toe) in 2011. Over 90% of the oil, natural gas, and hard coal demands were supplied by foreign resources, which included 80% of the total energy demands in 2008 [5]. Therefore, development of renewable energy resources appears to be the most efficient and effective solutions for clean and sustainable energy. Furthermore, reports indicate a close association between renewable energy and sustainable development [6].

Turkey presently has considerable renewable energy sources, including hydropower, biomass, geothermal, solar, and wind, which are viable and sustainable natural resources [7]. These renewable energy sources provided 58.2 TWh of electricity in 2011 [8], or 25.4% of the total power generation in Turkey. Hydropower represented 89.7% (52.3 TWh) of this total, and wind power and geothermal energy 9.3% (5.4 TWh). The remaining 1.0% was derived from waste material (0.5 TWh) [9]. Renewable energy supply in Turkey is dominated by hydropower. It is the second largest contributor in meeting Turkey's electric energy needs after thermal, e.g. natural gas, lignite, coal, and fuel oil, among others, which are derived from fossil fuels [10]. Therefore, the role of hydropower in electricity generation is substantially greater than any other renewable and sustainable energy source in many developing countries, including Turkey [11]. Furthermore, among all renewable

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energy resources, hydropower is the most abundant, inexpensive, clean, exhibits reduced environmental effects, and is a national source [12]. Hence, the contribution of hydropower in meeting electric energy needs is extremely important for the country. For these reasons, forecasting future hydropower production is critical, and will provide input to improve national energy policy strategies and individual energy investments. Many prior forecasting studies applied various forms of econometric methods. These techniques require assumptions, and cannot solve complex nonlinear patterns. Due to the limitations of statistical methodologies, recent studies have used intelligent solution approaches, including ANN (artificial neural networks), fuzzy regression, genetic algorithms, the ABC (artificial bee colony) algorithm, and ant colonies considering the contingency [13].

The primary objective of this study was to present a novel model for hydropower generation prediction in Turkey using the ANN with ABC algorithms. This study focused on modeling and forecasting hydropower generation in Turkey derived from basic energy, demographics, socio-economic, and environmental indicators to analyze hydropower prediction using the ANN-ABC technique. A sensitivity analysis was performed on indicators that influence hydropower generation to achieve more accurate prediction results. Sensitivity analysis results indicated population, GEED (gross electricity energy demand), energy consumption, and AYT (average yearly temperature) were optimal input parameters for the prediction model. Following best configuration determination, three different scenarios were employed to estimate future hydroelectric energy generation values in Turkey. Modeling and prediction of future hydro production under different scenarios will play a vital role in energy policy and strategy development for policy makers and related organizations.

2. Literature review

Various artificial intelligence techniques have been successfully applied over the last decade to model energy demand and consumption in different parts of the world, including ANN [14–21], fuzzy inference system [22–24], particle swarm optimization, and genetic algorithms [25,26].

Recently, similar to other parts of the world, soft computing techniques has been implemented for energy modeling on a widespread scale in Turkey. A number of studies were conducted to forecast Turkey's energy generation, consumption, and demand using different soft computing techniques.

ANN is one of the most commonly applied techniques. Sozen and Arcaklioglu [27] developed energy source equations to estimate future projections, and subsequently make reliable investments in Turkey using the ANN approach. Sozen [28] obtained numerical equations to estimate Turkey's energy dependency derived from basic energy indicators, and sectoral energy consumption using the ANN technique. Kankal et al. [29] used modeling and forecasting approaches to analyze energy consumption in Turkey by integrating demographic and socio-economic indicators employing regression analyses and the ANN technique. Results of these analyses indicated the ANN model predicted energy consumption better than regression models. Similarly, Sozen et al. [30,31] and Sozen and Arcaklioglu [32] used ANN for the same purpose. Cinar and Kayakutlu [33] proposed a feed forward back propagation ANN model to estimate annual hydroelectric generation values for Turkey. In addition, Hamzacebi [34], Kavaklioglu et al. [35], and Bilgili et al. [36] applied the ANN technique to predict electricity consumption in Turkey.

Another common approach used in energy modeling are GAs (genetic algorithms). Ceylan and Ozturk [37] and Canyurt et al. [38] utilized GAs to estimate energy demand and electricity consumption for Turkey. Ceylan et al. [39] developed a GA model to estimate future energy production and consumption in Turkey. Ceylan and Ozturk [40] estimated the hydraulic and thermal energy production from 2000 to 2023 using a GA with time series approach.

Hybrid models in energy modeling have received a great deal of recent attention. Cinar et al. [13] presented a hybrid model, which improved the forward feeding back propagation model with GA to forecast annual hydroelectric power generation in Turkey. Kiran et al. [41] proposed a new hybrid method for estimating energy demand in Turkey using particle swarm optimization and ant colony optimization. Similarly, Kiran and Gunduz [42] developed a hybrid approach based on particle swarm optimization and the ABC algorithm, and applied it for the same purposes.

The ABC algorithm, which is a new, simple, and robust optimization algorithm, has been used to train feed forward ANNs [43]. ANN success is highly dependent on the performance of the training process, and hence the training algorithm [44]. ANN training has traditionally been performed using the back propagation gradient descent algorithm [43], however limitations have been recognized in the method, including local minima trapping, over fitting, and weight interference, which makes ANN training difficult [45]. The ABC algorithm has a balanced exploration and exploitation capability, and therefore does not get stuck in local minima [46]. Numerous studies [46–48] have recently been conducted to train ANN with ABC and back propagation optimization algorithms. Results were congruent with previous studies [46–48], which indicated the ABC algorithm showed superior performance compared to the back propagation algorithm in training ANN. Although ABC is a new technique, it has already been employed in different engineering fields. However, in the context of energy modeling, only two studies are available. Gurbuz et al. [49] presented a model using the ABC algorithm to predict electricity energy consumption in Turkey. The ABC algorithm was applied to develop linear and quadratic models, and to train ANN models. Kiran et al. [50] developed two new models based on ABC and particle swarm optimization techniques to estimate electricity demand in Turkey.

Only three of these studies [13,33,40] were related to forecasting hydropower energy generation. The remaining [27–32,34–39,41,49,50] were associated with prediction of energy demand, production, and consumption predictions. Furthermore, prior study results [46–49,51,52] concluded the ABC algorithm performed better than other algorithms, including the BP algorithm in training ANN. In the present study, an ANN model with a new novel algorithm, the ABC algorithm was applied to estimate hydropower generation in Turkey. We are not aware of any published study indicating the capability of the ANN–ABC technique in modeling and estimating hydropower generation.

3. Variable selection and data employed

3.1. Predictor variable selection

The input parameters (predictor variables), which affect the outputs, should be determined as the first step in the network architecture design [53]. Hydroelectric generation is the final ANN output. Many factors affect hydroelectric energy generation, including climatic, socio-economic, and demographic, among others. Global climate change, drought, precipitation, evaporation, runoff (stream flow), temperature, humidity, radiation, wind speed, and soil moisture are some of the generally accepted climatic regimes that affect hydroelectric generation [54]. Population, employment, TI (total import), TE (total export), IIP (index of industrial production), oil and electricity prices, and GDP (gross

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