Performance Analysis of Biomass Energy using Machine and Deep Learning Approaches

Shagun Sharma¹, Partha Khanra² and K R Ramkumar¹

¹Department of Computer Science & Engineering, Chitkara University Institute of Engineering and Technology, Chitkara University, Punjab, India
²Department of Applied Sciences, Chitkara University Institute of Engineering and Technology, Chitkara University, Punjab, India.
Email: shagun.sharma@chitkara.edu.in

Abstract. Nowadays, fossil fuels such as petroleum, diesel and coal are being used as an energy source in every modern machinery but these are non-renewable and available in certain domain of nature only. Additionally, excess use of such fuels can cause environmental pollution, damage of human inhaling process and increase the dependency on other oil rich countries. These challenges could be avoided by using Biomass Energy, which is clean and renewable. Precisely, Biomass Energy is based on hydrocarbon materials which could come from both animal and plant derivatives. There are three forms of Biomass Energy: (i) Gases- methane, ethane etc.; (ii) Liquid- ethanol, biodiesel etc., and (iii) Solid-biochar and activated carbon. These energies are acknowledged for cost effectiveness, renewable nature and less emerging pollutants as compared to fossil fuels. At the present time, these renewable Biomass Energies are useful to operate large number of advanced machines, along with which, the challenge is to estimate the production of Biomass Energy from the available biomass sources without hampering the biodiversity. Therefore, in this study Machine and Deep Learning algorithms are used to calculate the Biomass Energy. Moreover, this work introduces number of Machine and Deep Learning approaches to compute the Biomass Energy production along with Machine Learning tools to analyze the performance of Biomass Energy.

Keywords. Machine Learning, Biomass Energy, Biofuel cells, Deep Learning, Organic Gas, Biodiesel Oil

1. Introduction

With increasing technology advancement and side by side improvement of social impact, every country is seeking on adequate energy to run their daily lives [1], whereas, till present fossil fuel is the major source of energy generation. Noticeably, fossil fuels are dramatically decreasing to fulfill the energy demands of daily life. Unfortunately, remaining limited resources could destabilize the economy of the country, because it is not renewable. It is worth to note that burning of fossil fuel results a harmful emission of pollutant gasses, such as Carbon monoxide (CO), Carbon Dioxide (CO₂), Nitrogen Oxide (NOₓ), Volatile Organic Compounds (VOC), Particulate Matter (PM) etc. can badly impact on the environment. As alternative resources like solar energy, wind energy and water energy are very popular nowadays, however these sources are not available in every geographical context. Interestingly, Biomass Energy (BE) which is based on Hydrocarbon (HC) molecules are very efficient and cost effective for every technological aspect. Therefore, to handle the issues of using fossil fuels, renewable BE and its development have come into limelight as a renewable energy source, which could be developed repeatedly from animal waste and plant derivatives [2]. Nowadays, this alternative energy is playing leading role for every developed and developing country. These BEs are flourished in the point of commercial assessments such as cost effective and improve the combustion efficiency by mixing the biofuels, sustainable, improves the government revenue by local economic growth, high possibility of industrial investments, proper utilization of agricultural waste, reduces petroleum
dependency along with international competition [3]. Moreover, it also has some positive environmental effects such as renewable and mass resources, reduction in amount of greenhouse gases emission, PM and pollution as compared to fossil fuel. Process of BE utilization is shown in Figure 1. The biogas, is another form of BE which can be generated from bio-waste materials through different biochemical processes such as trans-esterification, anaerobic fermentation, alcoholic fermentation, etc. Noticeably, trans-esterification reactions are conducted in animal fats, vegetable oils, waste and used oils/fats and microbial oils with methanol and ethanol/butanol and results in biodiesel production, which has opened a new horizon for transport applications. Microalgae is another effective source of renewable bioenergy and viable bio product [4]. It consumes solar energy and renovies CO$_2$ to bio renewable energy (bio Hydrogen (H$_2$), biodiesel and food flavours). In addition, with above BE another solid biomass is also available like paper, municipal solid waste, activated carbon, industrial solid waste, sawdust and wood [5]. This biomass is transformed to syngas, which is the combination of CO$_2$, water vapours, H$_2$, CO and methane. Among the BE, the bio-oil are the most promising product for the development of combustion engine and heavy machineries. There are many bio-oils i.e. Soybean, rapeseed, sunflower, cotton, palm and corn seeds which could be used as biodiesel [6]. Rapeseed and other vegetable seeds are more likely used in Europe and USA as a source of biodiesel. It was observed that rapeseed oils emit the low HC as compared to sunflower seed oil. Additionally, mixture of vegetable oil and diesel can improve properties of lubrication due to reduced instability and viscosity. Therefore, many studies are required to clarify the potential value of BE. Various analysis can be performed to toestimate the BE by using laboratory methods, density function theoretical study along with Artificial Intelligence (AI) techniques [7], precisely Machine Learning (ML) and Deep Learning (DL) methods. The goal of using ML approaches is that, they are currently making a domination imprint in different areas of basic sciences and also in many advance technologies.

![Figure 1. Process of biomass energy](image_url)

ML is the attractive science, used to extract the information from mass datasets and making it helpful for the real time processing [8], with research output varying from the exploration of the molecular reaction pathways and accurate prediction of molecular energies. For example, to model the gasification process [9] ML approaches are broadly utilized for the model development to estimate the understanding of complex challenges with respect to different fields of science. To achieve more accuracy, ML approaches are divided into DL and furthermore Recurrent Neural Network (RNN), Artificial Neural Network (ANN), Convolutional Neural Network (CNN) etc. ANN is one of the common DL approaches, which could be used as an estimation model in the field of basic sciences. In brief, the importance of ML and DL approaches are described below:
1.1. Role of machine and deep learning in biomass energy prediction

ML and DL algorithms play a major role when dealing with BE prediction as it handles optimization, modelling and production [1]. The need of ML and DL in the field of BE is changed with the increase in time as shown in Figure 2.

![Figure 2](image)

**Figure 2.** Use of machine and deep learning in biomass energy prediction

In case of producing the anticipated product requirements, it is very important to choose an effective model. ML and DL might be used as modelling methods to achieve the accurate results with high accuracy along with less errors. It could solve many challenges of BE prediction like estimation of physical features of compounds [2] through which the prediction of compound properties is easy. Hence, this technique is helpful in the estimation of behavior and features of chemical mixtures in the biofuel and makes it easy to measure the density of HCs, alcohols and esters to achieve the consistent results. Other features of these techniques are reproduction of BEs and measuring the performance of biofuel cells [4,5]. A ML approach called Support Vector Machine (SVM) is used to solve the issues of regression and classification [10]. Where classification is used to forecast the class labels and regression is used to predict continuous values called ranges [11]. Applying SVM on BE reduces the inaccuracy of test samples and increases the performance due to fast validation. To get the performance prediction of BE, SVM is widely used as it could solve the challenges of binary as well as multiclass classification [12]. It identifies a hyperplane to divide the classes and increases the distance between them [10]. The feature of using SVM is that it has a kernel function which handles non-linear classes by doing the transformation of data and results in high accuracy. Other effective approaches such as Extremely Randomized Tree (ERT) regression and Random Forest (RF) are also used to predict the performance of BE crop modelling [13]. This modelling technique is used to do the experiments and evaluates the potential of BE production from bioenergy resources and reduces the cost and time of performing the experiments in laboratories.

In continuation with introduction, the remaining structure of the article is described in various parts where, Section 2 consists of the information about ML and DL approaches which are being used to get the performance of BE, Section 3 consists of literature review of ML and DL approaches on BE prediction. Summary of existing work for the prediction of BE is described in Section 4. Finally, the conclusion and future scope are stated in Section 5.

2. Biomass energy prediction using machine and deep learning approaches

This section describes various ML approaches which can be used to measure the performance of BEs. A number of ML approaches [6] are given in Figure 3.
2.1. Biomass energy prediction models

ML and DL approaches are being used in forecasting weather, health issues, marketing and sales along with improving machine reading comprehension systems [14-18]. Similarly, numerous approaches are utilized in the field of BE to determine the energy prediction. In the case of dealing with BE prediction, a number of algorithms perform better.

2.1.1. Recurrent Neural Networks. This approach can be used as a prediction model for immeasurable variables in between methane and H₂ release by using the anaerobic digestion procedure [1].

2.1.2. Artificial Neural Networks. ANN is a ML method which works on the basis of human brain working mechanism [7]. The structure of the information process system is similar to the structure of the human mind. This method is used in many fields for solving prediction issues. It predicts the challenges of discrete and continuous variables. This algorithm could be used in the application domain of biofuel production and evaluation of variables [1]. It predicts the number of outputs by using a single model [7]. It also allows absorption of vegetable oil in diesel oil [6]. ANNs are used as the modelling technique for gasification procedures [9]. The schematic diagram of the ANN system is shown in Figure 4.
2.1.3. Partial Least Squares Discriminant Analysis (PLS-DA). This method is used as a classification technique which classifies the biofuel energies [10]. It is a modification of the PLS approach, utilized for solving classification problems. PLS-DA is also used in case of chemometric applications in the concept of getting classified wood based fuels.

2.1.4. Support Vector Machine. It is a ML method which is used for classification purpose and classifies biofuels in BE prediction [1]. In the production process, SVM could be used to predict the release of batch H₂ [5]. SVM is utilized in chemometric applications in the concept of getting classified wood based fuels [10].

2.1.5. Principal Component Analysis Linear Discriminant Analysis (PCALDA). It is a classification technique which is used for classifying biofuels [1]. This method is utilized to classify the prediction problems [10].

2.1.6. Decision Tree (DT). It is a ML method, which is used to deal with classification as well as regression problems [5]. It generates a tree like structure as shown in Figure 5, in which it divides the dataset into small subparts called decision nodes and gives the classification or regression result in a leaf node. The top node of the tree is called as root node. This approach deals with categorical as well as quantitative data. It is an analysis in which rules can be developed for the detection of situations to improve accuracy [12]. This algorithm can be used for modelling H₂ values [5].

![Figure 5. Schematic diagram of decision tree system](image)

2.1.7. K-Nearest Neighbours (KNN). It is a ML technique which is used for classification and regression [5]. It identifies the distance between k- neighbours and the target value by using Euclidean equation (1) and Manhattan equation (2) distance calculator. This algorithm is used for the prediction of non-parametric challenges [19] and finds the accuracy of biogas production.

\[
D = \sqrt{\sum_{i=1}^{k} (x_i - y_i)^2} \quad (1)
\]

\[
D = \sum_{i=1}^{k} |x_i - y_i| \quad (2)
\]
Where,

\[ k \text{- Number of neighbours} \]
\[ x_i \text{- Predicted Value} \]
\[ y_i \text{- Actual Value} \]

2.1.8. Multi-Layer Perceptron (MLP). It is a ML approach which is found as the configuration of ANN [2]. It is used in get the prediction accuracy along with the human reliability on BEs [1].

The main goal of using the above ML and DL approaches is to evaluate the BE prediction error and accuracy. The mentioned algorithms were found as the best techniques to handle modelling, optimization and production of BE in the field of basic sciences.

3. Literature Review
A survey of ML and DL approaches has been presented on biofuel cells [1], and various ML approaches excluding ANNs were studied for the purpose of analyzing the accuracy of biofuels. As a conclusion, ML along with DL approaches were found as the magnificent and effective techniques for handling and improving the performance of biofuel cells.

Four algorithms such as Adaptive Network based Fuzzy Inference System (ANFIS), Radial Basis Function ANN (RBF-ANN), Least Square SVM (LSSVM), MLP-ANN have been applied to measure the density of biofuel cells [2]. The results have mentioned, LSSVM as the best suited algorithm for prediction as compared to other three algorithms. Where Mean Absolute Relative Error (MARE) and R values were analyzed as (0.678, 0.65096), (0.376, 0.52067), (0.056, 0.847) and (0.371, 0.57385) for ANFIS, RBF-ANN, LSSVM and MLP-ANN as plotted in Figure 6 and Figure 7 respectively.

Figure 6. Biofuel density plot for mean absolute relative error value
Operational and collection techniques were applied to identify the quality of biogas production [3]. The results have been analyzed where feed characteristics were found as the major cause for increasing and decreasing the quality and quantity of anaerobic digestion produced gas.

A framework called data driven surrogate model was invented [4] to analyze and optimize the performance of difficult bio system models. This framework was used to detect operating situation and configurations for biofuel cell productions. Another framework called Integrated Kinetic- CFD was constructed to guarantee the correctness of data driven surrogate model.

To predict and analyze the \( \text{H}_2 \) construction through BE gasification process, different ML algorithms such as KNN Regression, SVM Regression (SVMR), Linear Regression (LR) and DT Regression were used [5]. As a conclusion, it has been found that \( \text{H}_2 \) concentrations were effectively reflected and \( R^2 \) was estimated as highest i.e. 0.99 in LR.

A DL based ANN model has been proposed for identifying the relationships between percentage of vegetable oil mixed in fuel [6]. Tribological performance analysis was made on two different bio oils i.e. sunflower and rapeseed oils.

Three algorithms such as Support Vector Regression (SVR), ANN and Polynomial Regression have been used to analyze and predict the accuracy of syngas construction [7]. The results have found ANN, SVR and Polynomial Regression as the worst, medium and best algorithms for predicting accuracy of syngas respectively.

Various ML and DL approaches such as ANN, kernel based method and LR have been applied to predict the production of BE [8] and resulted that ML and DL models perform best in the field of material science with the highest prediction performance of BE accuracies.

To analyze co-gasification procedure, a ML based regression method has been proposed [9]. Six different types of ML approaches were utilized and resulted, Linear and Polynomial Regression as worst and Gaussian Regression as the best approach in case of getting accurate predictions. On the other hand, SVR was also found non-suitable approach as its performance decreased on the taken dataset and DT Regression was better as compared to SVR due to increased performance on the dataset. Another, algorithm called AI based regression requires more cost for computations.

Three different ML algorithms such as PCA-LDA, SVM and PLS-DA were compared to identify the best suited approach for getting the prediction results to measure the quality of biofuels [10]. The results have concluded SVM, PCA-LDA and PLS-DA as the best, better and average algorithms for dealing with biofuel prediction respectively.

---

**Figure 7.** Biofuel density plot for \( R^2 \) value
For the development of prediction models and heuristics in perovskite solar cells devices [12], many patterns and database have been analyzed by utilizing ML techniques. ML algorithms were implemented to get the accuracy of BE predictions [13] which resulted ERT regression and RF as robust algorithms to deal with bioenergy yield modeling. A method has been proposed for predicting the performance outcome of biogas [19]. Five ML algorithms such as Logistic Regression, SVM, RF, Extreme Gradient Boosting and KNN regression were utilized to get the accuracy and resulted KNN as the least accurate approach having an accuracy of 87% on the dataset.

ML and Hybrid Meta Heuristic(HMH) algorithms have been combined to get the efficiency results of renewable energy systems[20]. As a conclusion, the combination of Particle Swarm Optimization(PSO) and Genetic Algorithm(GA) was found as the most popular and efficient model for predicting BEs.

**Figure 8.** Prediction of wind energy in the form of root mean squared error value

In Figure 8, it has been found that Fuzzy Rough Sets model performed better when compared with ML approaches to predict wind energy of biomass. Where RMSE value was found the least i.e. 0.0318.

**Figure 9.** Prediction of wind energy in the form of mean absolute error

In Figure 9, the kernel ridge regression has been found as the best approach for predicting biomass wind energy having the least value of Mean Absolute Error as compared to other ML approaches.
For the prediction of biogas construction rate ANN model has been utilized [21] and integrated with selected variables like Ant Colony Optimization (ACO) and GA. As a result, in the integrated model the prediction error rate and $R^2$ values were identified as 6.24% and 0.9% respectively.

A comparison has been made on number of algorithms such as MLP, Polynomial Regression, DTR and SVR to predict the BE using biomass gasification procedure [22]. A K-fold technique was applied to each approach and resulted DT and MLP as best methods having the $R^2$ value greater than 0.9.

Authors have mentioned the release of CO, CO$_2$, CH$_4$ (Methane), H$_2$ and Higher Heating Value (HHV) in the form $R^2$ and RMSE value.

![CO Production Prediction Error Rate](image)

**Figure 10.** Prediction of carbon monoxide in biomass

In Figure 10, MLP has been found as the best approach for predicting CO concentration in biomass with respect to RMSE and $R^2$ values.

![CO$_2$ Production Prediction Error Rate](image)

**Figure 11.** Prediction of carbon dioxide in biomass
In Figure 11, DTR technique was found as the best approach for predicting the concentration of CO₂ in the biomass with respect to RMSE and R² values.

![CH₄ Production Prediction Error Rate](image1)

**Figure 12.** Prediction of methane in biomass

In Figure 12, DTR technique has been found as the best approach for predicting the concentration of CH₄ in the Biomass with respect to RMSE and R² values.

![H₂ Production Prediction Error Rate](image2)

**Figure 13.** Prediction of hydrogen in biomass

In Figure 13, MLP has been found as the best approach for predicting the concentration of H₂ in the Biomass with respect to RMSE and R² values.
In Figure 14, MLP has been found as the best approach for predicting the concentration of HHV in the Biomass with respect to RMSE and $R^2$ values.

4. Summary of State of Art

This section summarizes existing literature work on summary, techniques/ tools/ methods along with algorithms used for identifying the BE prediction as shown in Table 1.

| Reference | Year | Summary | Techniques/Tools/ Methods | Algorithms |
|-----------|------|---------|----------------------------|------------|
| [1]       | 2019 | ANN is the most used algorithm for analysing the accuracy of biofuels. Where both testing and training data have best accuracies along with a limitation of lower processing time. | Hybrid Sparse Bayesian Based Extreme ML | ANN, SVM, MLP, DT, RF, SVR |
| [2]       | 2020 | LSSVM performs better in case of predicting density of biofuel cells. MARE values were calculated as 0.678, 0.379, 0.056, and 0.371 for ANFIS, RBF-ANN, LSSVM and MLP-ANN respectively. | LSSVM model | ANFIS, RBF-ANN, LSSVM, MLP-ANN |
| [3]       | 2018 | Operational and collection techniques were experimented to analyse the quality of biogas production. | Operational Collection | - |
| [4]       | 2019 | Data Driven Surrogate Model was developed to analyse the performance of bio systems. In comparison of biofuel with bisabolene production, error rate for local biofuel production was 1.5% lesser as compared to bisabolene production. | Response Surface Model(RSM), Data Driven Surrogate Model, Integrated Kinetic-CFD | Hybrid Stochastic Optimization Algorithm |
| [5]       | 2019 | ML algorithms were applied to | | - |
analyse and predict the $H_2$ release through BE gasification procedure. The accuracy for classification model was found as 83%.

[6] 2019 Tribological study was done on rapeseed and sunflower oil. After experimenting ANN and GA the training error value was analysed as 28% in both.

[7] 2019 Polynomial Regression performed better as compared to ANN and SVR models where $R^2$ value between actual and predicted model is observed as 0.99.

[8] 2019 Authors have analysed various ML tools to solve the problem domain of BE prediction. It has been found that ML performs an important role in material science and deals with production and optimization.

| Reference | Year | Summary | Techniques/Tools/Methods | Algorithms |
|-----------|------|---------|--------------------------|------------|
| [9]       | 2019 | When accuracies of various algorithms were compared to each other, Gaussian Regression was found as the outperformed approach. The optimization process was used by implementing ANN algorithm in which friction coefficient value was recognized as 0 for rapeseed and 4% for sunflower oil. | Cross Validation Technique, Regression Technique | SVM, ANN, Genetic Programming, Polynomial Regression, Gaussian Regression, LR |
| [10]      | 2019 | In concept of predicting the quality of biofuel SVM performed better as compared to PCA-LDA and PLS-DA. | Classification Technique | PCA-LDA, SVM, PLS-DA |
| [12]      | 2019 | Many databases and patterns were analysed to develop prediction models for perovskite solar cells. The performance measurements of PLS-DA was calculated and found best with an increase from 0.83 and 0.79 to 0.93 and 0.92 respectively. | Random Sampling Method | Apriori Algorithm, DT classification |
| [13]      | 2020 | ERT and RF approaches performed better in case of getting accuracy of biomass productions. RF and SVM was recognized as the highest accurate algorithms with an accuracy of 0.97 and 0.95 respectively. | Regression Technique, Tree based modelling Technique, Linear Prediction Technique | ERT, RF, SVM |
| [19]      | 2019 | In comparison of five different algorithms KNN has been found as the best approach with an accuracy of 87%. | Traditional Statistical Method, Non Parametric Statistical Methods | LR, SVM, RF, KNN, Extreme Gradient |
The combination of HMH and ML algorithms was found as the best model for getting better accuracy of renewable energy models. The accuracy of ANN for predicting wind energy was detected as 89.24%.

For the prediction of biogas construction ANN model was used and for the implementation ACO and GA techniques were utilized. ANN was applied to predict biogas production and RMSE values for training and testing were detected as 4.81% and 9.66% and R² values were identified as 0.90 and 0.80 respectively.

After applying K-fold cross validation technique on each data, DTR and MLP were found as the best performing algorithms.

| Year | Methodology | Techniques Used |
|------|-------------|-----------------|
| 2019 | The combination of HMH and ML algorithms | Traditional Statistical Method, Boosting, HMH, GA, PSO, ANN |
| 2019 | For the prediction of biogas construction | Variable Selection tool, Optimization tool, Multivariate Statistical tool, Meta Heuristic tool, ACO, GA, ANN |
| 2020 | After applying K-fold cross validation technique on each data | K-fold cross validation technique, Regression Technique, MLP, Polynomial Regression, DTR, SVR |

Table 1. Summary of existing works for the prediction of biomass energy.

5. Conclusion and Future Work
The focus of this work is on ML, DL and renewable energy sources. The total amount of biomass availability is very rich in nature and found as the fourth largest source of energy all over the world. The BE is the outcome of biodegradable waste, plants and animal’s derivatives. The increase in the plantation process increases the production of BE. The BE is safe to use as it does not have any leaks and explosion challenges, it has wide applicability because of its uses for the production of biodiesel, biogas and fuel alcohol. It contains low amount of nitrogen and sulphur, which leads it to produce low pollution due to less release of NOₓ and sulphur containing compounds. Along with the features of BE, it is an important task to measure the amount of energy, which could be generated from a particular biomass. Hence, ML and DL algorithms perform a significant role in measuring the correct prediction of energy. The goal of using such techniques is to get the knowledge about effectiveness of different biomass energies. This article provides number of approaches to analyse the performance and density of biofuel cells, finding out the release of CO, CO₂ and NOₓ along with performance of BE. The existing work on BE recognizes that numerous ML and DL approaches perform differently on different biomass energies. In this article, the ML and DL approaches were analysed and compared to find out the most efficient approach for getting the prediction performance of BE. As a result, the algorithms such as ANN, LSSVM, SVM, PLS-DA, KNN, RF, DTR-MLP and GA are found as the most suitable algorithms for analysing the prediction performance of BE. In comparison of all above mentioned algorithms the ANN is found as the better approach but integration of ANN and GA performed more efficiently as compared to ANN alone. Hence, this work identifies the significance of using ML and DL algorithms in the field of BE.

Further, this study can be useful for students and well as researchers to get the knowledge about implementing ML and DL on BE and biofuel cells. For the future work, there is a necessity to create a model, which could accurately predict the energy production from biomass, and implementation of ML approaches on the large datasets is needed. By getting the results in the form of error predicting metrics, it is must to conclude the best suited ML approach so that the performance could be improved for future implementation. The feature selection methods should be improved to train the model faster.
and reduction of the complexity. Choosing the right dataset can improve the performance of the model in the future.

References
[1] Ardabili S, Mosavi A and Várkonyi-Kóczy AR 2020 Engineering for Sustainable Future Vol 101, ed Annamária R. Várkonyi-Kóczy (udapest, Hungary) p 19-32
[2] Nabipour N, Daneshfar R, Rezvanjou O, Mohammadi-Khanaposhtani M, Baghban A, Xiong Q, Li LK, Habibzadeh S and Donarhegardi MH 2020 Renewable Energy 151 p 1086-98
[3] Arshad M and Abbas M 2018 Perspectives on Water Usage for Biofuels Production, ed Muhammad Arshad(Lahore, Pakistan) p 107-121
[4] del Rio-Chanona EA, Wagner JL, Ali H, Fiorelli F, Zhang D and Hellgardt K 2019 AIChE Journal 65 p 915
[5] Ozbas EE, Aksu D, Ongen A, Aydin MA and Ozcan HK 2019 Int. J. Hydrogen Energ. 44 p 17260
[6] Humelnicu C, Ciortan S and Amortila V 2019 Lubricants 7 p 1
[7] ELMAZ F, YÜCEL Ö and MUTLU AY 2020 International Journal of Advances in Engineering and Pure Sciences 32 p 8
[8] Deringer VL, Caro MA and Csáni G 2019 Advance Materials 31 p 1902765
[9] Elmaz F, Yücel Ö and Mutlu AY 2019 Mugla Journal of Science and Technology 5 p 1
[10] Mancini M, Taavitsainen VM and Toscano G 2019 J. Chemom. 33 p 1
[11] Kanupriya V, Sahil B, Resham A, Islam UL, Megha B, Ashok K and Piyush S 2019 International Journal of Innovative Technology and Exploring Engineering 8 p 18-23
[12] Odabaşçi Ç and Yıldırım R 2019 Nano Energy 56 p 770
[13] Huntington T, Cui X, Mishra U and Scown CD 2020 Biofuel. Bioprod. Bior. 14 p 566
[14] Nosratabadi S, Mosavi A, Duan P, Ghamisi P, Band SS, Reuter U, Gama J and Gandomi AH 2020 Mathematics 8 p 1799
[15] Chen YW and Jain LC 2020 Deep Learning in Healthcare Vol 171, ed Yen-Wei Chen, Lakhmi C. Jain (Liverpool, UK)
[16] Hossain MS and Mahmood H 2020 IEEE Access 8 p 172524-33
[17] Archana B, Anita B and Megha B 2020 International Journal of Advanced Science and Technology 29 p 9692-9710
[18] Monika M, Ashok K, Vaishali M, Megha B and Sachi NM 2022 Real-Life Applications of the Internet of Things: Challenges, Applications, and Advances ed Monika Mangla p 477
[19] De Clercq D, Jalota D, Shang R, Ni K, Zhang Z, Khan A, Wen Z, Caicedo L and Yuan K 2019 J. Clean. Prod. 218 p 390
[20] Houssein EH 2019 Advanced Control and Optimization Paradigms for Wind Energy Systems, ed Essam H. Houssein (Minya, Egypt) p 165
[21] Beltramo T, Klocke M and Hitzmann B 2019 Information Processing in Agriculture 6 p 349
[22] Elmaz F, Yücel Ö and Mutlu AY 2020 Energy 191 p 116541