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Forecasting of nuclear energy trends in Romania using XGBoost

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ABSTRACT

The energy demand continues to rise due to the exponential growth of the world's population. In today's world, every aspect of life, including industry, education, household, transport, and healthcare, relies on energy. Generating power in an environmentally friendly manner is a major concern. Predicting nuclear energy production depends on various factors. Researchers used the extreme gradient boost (XGBoost) machine learning algorithm for prediction. The study revealed that the RMSE validation value is 25.10810, while the training value is 15.01759 after 2000 iterations. According to the study, Romania has the potential to produce 1,300 MW of electricity in a single day through nuclear energy. Nuclear energy production can be a viable solution for decarburization and meeting energy needs. The prompt of nuclear energy in the present world is harnessing to the utmost level so that energy crisis can be mitigated for a long run. This paper tries to show the potentiality of nuclear energy in Romania predicting the future trends with the help of time series analysis.

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1. INTRODUCTION

The record-breaking rise in temperature of the earth in the past few decades is a serious threat to the existence of the planet. This rise of temperature warms the globe and ultimately causes climate change. Burning excessive conventional fuel releases huge amounts of GHG into the atmosphere which is behind global warming. According to, the intergovernmental panel on climate change (IPCC), the world's temperature must not be 20C (1.50C is better) above the preindustrial level at the end of this century to save the planet. To cope with the climate change impact there is no alternative to green energy and net-zero emission by 2040. Besides this, traditional energy (oil, gas, coal) is projected to run off by the end of this century. So it is urgent to transform the traditional energy into a clean energy. Renewable energy sources like Hydro, wind, bio-energy, and nuclear energy should be future energy solutions. Though nuclear energy is treated as a clean energy it releases negligible carbon compared with traditional energy [1], [2]. Nuclear energy is indirectly responsible for greenhouse gas production as the input to the upstream system needs fossil fuel [3]. In addition, it is also a low greenhouse gas emitting energy source compared with other green energy regarding the life cycle [4]-[8]. Nuclear energy is a great source of electricity production. Nuclear energy comes from the nucleus through nuclear fission and nuclear fusion where fission is caused by splitting the solid atom into several parts and fusion is by the fuse of two light nuclei together. According to the

International Energy Agency (IEA) world's 11% of electricity came from nuclear energy in 2018 from 442 nuclear power plants [9], [10]. Electricity production from nuclear energy is 146.5 TWh in June 2024 which is 6% higher than the June previous year [11]. China, the USA, India, the European Union, and the Russian Federation are the most GHG emitters (60%) in 2021. These five nations and 140 countries already set their target to obtain net zero goals by 2050 by reducing 88% emissions [12]. In Europe, 22% of electricity was produced from nuclear energy in the year 2022 [13]. So enhancing the consumption of nuclear energy can play a very positive role in obtaining the net zero emission goals [14]. Nuclear energy is the second largest renewable energy source in terms of low emission [15]. In the United Kingdom (UK) nuclear energy will play a major role in obtaining net zero emission goals in the near future [16]. Forecasting production of nuclear energy by various machine learning approaches has gradually increased in recent years. However, researchers working in machine learning algorithms are facing some obstacles in predicting energy production by time series [17]. Forecasting of nuclear energy is vital before going to nuclear energy production. Recently ensemble machine-learning techniques have been used for nuclear power energy [17].

In this study, nuclear power energy is forecasted by extreme gradient boosting (XGboot) which is very impressive in terms of RMSE value. Though the forecasting nuclear energy is not an easy task to handle, this research study would help us to navigate the importance as well as the potentiality of nuclear energy to mitigate the crisis of fossil fuel in this present world.

2. NUCLEAR POWER IN ROMANIA

Nuclear power in Romania represents a significant component of the country's energy mix, contributing to both its electricity generation and broader efforts to reduce greenhouse gas emissions. Romania's journey into nuclear energy began in the mid-20th century, during a period when many nations were exploring nuclear technology as a viable option for generating electricity. Today, Romania is one of the few countries in Eastern Europe that successfully operates a nuclear power plant, namely the Cernavodă Nuclear Power Plant. Located in the southeastern part of the country, on the banks of the Danube River, Cernavodă has played a critical role in Romania's energy policy since it began operations.

Figure 1 shows the preview of Cernavoda Nuclear Power Plant in the Romania. The European Commission has given a favorable assessment regarding the technical and nuclear safety aspects of the proposed construction of Units 3 and 4 at Romania's Cernavodă Nuclear Power Plant. According to the current schedule, Unit 3 is expected to be operational by 2030, with Unit 4 following in 2031. In accordance with the Euratom Treaty, developers of nuclear projects are required to inform the European Commission about their investment plans and ensure adherence to stringent nuclear safety protocols. Energonuclear, a fully owned subsidiary of Romania's state-owned utility Nuclearelectrica, formally notified the Commission in May 2023 regarding its intention to build two CANDU-6 pressurized heavy water reactors—technology originating from Canada—for Units 3 and 4 at Cernavodă. The Commission's positive response, as highlighted by Nuclearelectrica, followed a comprehensive review process, which involved a thorough analysis of the technical data provided by Romania, on-site inspections at Cernavodă, and a series of technical consultations over the course of 13 months. The commission concluded that the project aligns with the objectives outlined in the Euratom Treaty, supporting the completion of Units 3 and 4 [17].

Figure 1. Units 3 & 4 in Cernavoda Nuclear Power Plant [17]

Spent nuclear fuel requires secure storage over an extended period due to the continuous release of decay heat and radiation. To mitigate these effects, it is advisable to allow spent fuel to remain in storage for a specific duration before its permanent disposal. The two most commonly used storage methods are wet storage and dry storage. In South Korea, pressurized light water reactors (PWRs) have been utilized for wet storage, while the recent establishment of temporary dry storage facilities at the Kori site represents the country's first implementation of dry storage. Given this, analyzing the behavior of nuclear fuel within the initial dry storage cask is a critical and valuable task. The nuclear fuel used in domestic PWRs varies in burnup levels. Historically, burnup levels in PWR fuel were relatively low, but to enhance power generation efficiency, uranium enrichment increased, and fuel replacement cycles were extended, leading to higher burnup rates. Consequently, a substantial amount of spent nuclear fuel classified as "high burnup," exceeding 45,000 MWD/MTU, is now stored in spent fuel pools. Additionally, the cooling periods in spent fuel pools are set at 5, 10, 15, and 30 years to analyze fuel behavior under different conditions. A key parameter in this evaluation is the oxide layer thickness, which significantly influences the characteristics of spent nuclear fuel in dry storage. By conducting these assessments, it becomes possible to determine the safety of temporary dry storage, which is expected to last approximately 50 years [18]. Due to their high power density, extended operational lifespan, and ability to function independently of solar illumination, space nuclear power systems (SNPs) are regarded as the optimal propulsion choice for future space missions [19]. Given the constraints of launch vehicle capabilities, the mass of SNPs must be minimized while ensuring equivalent performance, requiring an integrated optimization of various components. However, developing detailed designs for these components and using their aggregated masses for iterative optimization can be both costly and time-consuming, particularly in the early stages of research and development (R&D). Therefore, a precise and efficient model is essential to enable accurate mass estimation and assess the influence of design parameters on overall system mass [20]. Most estimation methods rely on assumptions such as a constant shielding mass or fixed proportionality coefficients between shielding mass and reactor power [21]-[25].

3. METHOD

The dataset used in this study was obtained from online source Kaggle which contains 46,011 samples. This dataset is from Romania. 20% data was kept for validation work. In this dataset, there are several features including wind, gas, hydroelectric, oil, coal, production, consumption, nuclear, biomass, and solar. We considered here nuclear energy production. The machine learning approach extreme gradient boost (XGBoost) was employed to predict the growth trends. Root mean square error (RMSE) was calculated to check the error. This nuclear dataset has been checked up for fitting ability with the time series model, since data coherence in terms of variance is very important to judge. The RMSE error calculation has been carried out to see the probable performance of the time series model in terms of prediction accuracy. On top of this, the iterations for measurement of accuracy performance play a vital role for achieving the probable prediction capability. For this purpose, the total epochs have been considered as two thousand which proves the prediction accuracy in terms of the validation loss.

4. RESULT ANALYSIS

Correlation of features in the dataset is shown in Figure 2. It is seen in this figure that oil and gas, biomass has a strong correlation with the nuclear energy production. Consumption of nuclear energy varied from 4,000 MW to 9,000 MW in the year of recent five years from 2019 to 2024 which is shown in Figure 3 and it is found in the study average consumption of nuclear energy was 6,587 MW whereas the production of nuclear energy varies from 3,315 to 9,886 MW as represented in Figure 4 with standard deviation 986.

Production of nuclear energy is measured on an hourly, daily, and monthly basis. Which is reflected in the Figures 5-7. It is seen that production is maximum at 6 hours and no production at 10 hours. Week-based production is highest on Saturday which is 1,300 MW. In Figure 4 monthly production graph shows that January to April and September to December are between 1,300 MW to 1,400 MW. The RMSE is defined in the following way:

$$\mathrm{RMSE} = \sqrt{\frac{\sum(\mathrm{y_i} - \hat{\mathrm{y}}_\mathrm{i})}{\mathrm{N} - \mathrm{P}}}$$

Where y_i is the actual value of the observation, $\hat{y}_i$ is the predicted value of the i-th observation, N=number of observations, P=number of parameters estimate with constant.

It has been observed that the validation and training datasets have very similar profiles, as shown in Figure 8. Additionally, it has been noted that as the number of iterations increases, the RSME decreases, and at 2000 iterations, the RSME value becomes very small. Using the extreme gradient boost algorithm, 450 days of nuclear energy production (shown in red) have been predicted from the 5.5 years dataset (shown in green), as illustrated in Figure 9.

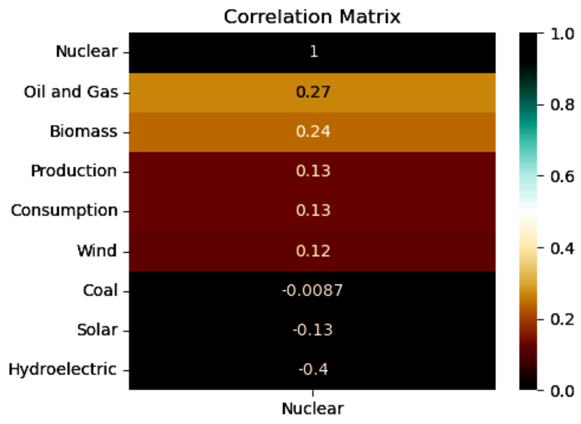

Figure 2. Correlation of the features in the dataset

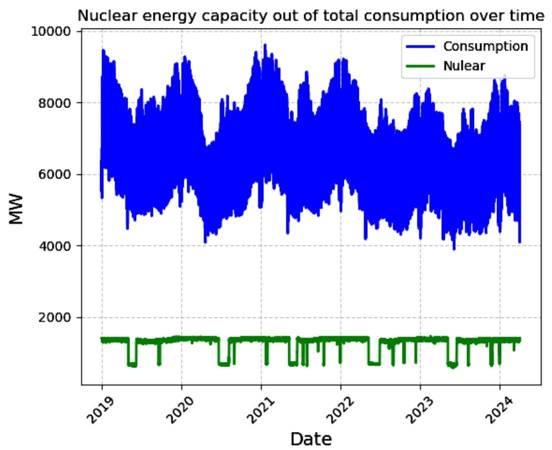

Figure 3. Consumption of nuclear energy (2019-2024)

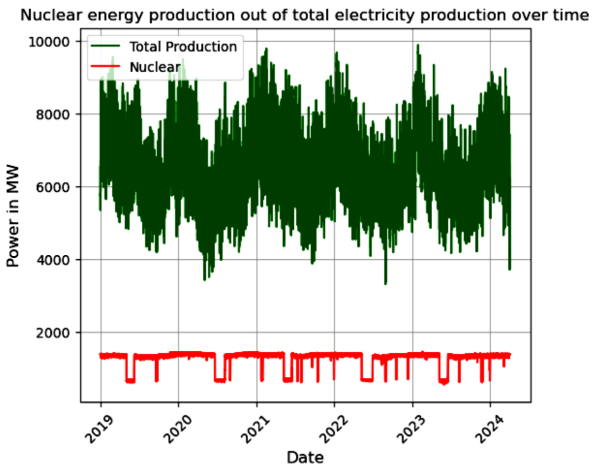

Figure 4. Share of nuclear energy of electricity production

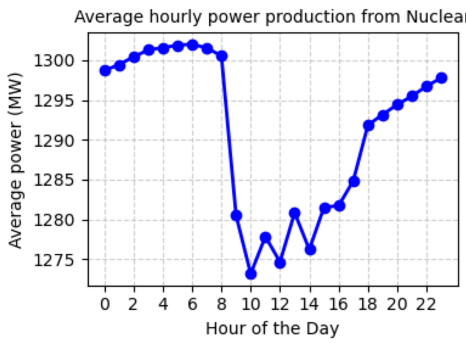

Figure 5. Hourly nuclear energy production

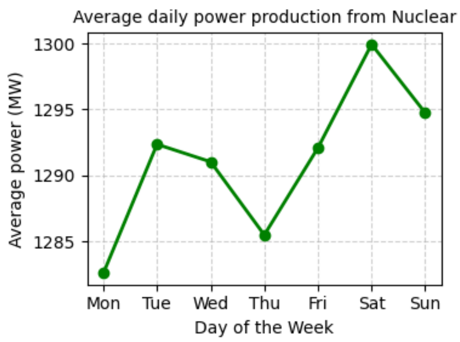

Figure 6. Average daily nuclear power production

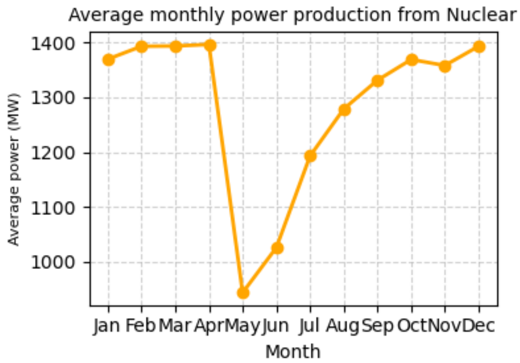

Figure 7. Daily average nuclear energy production

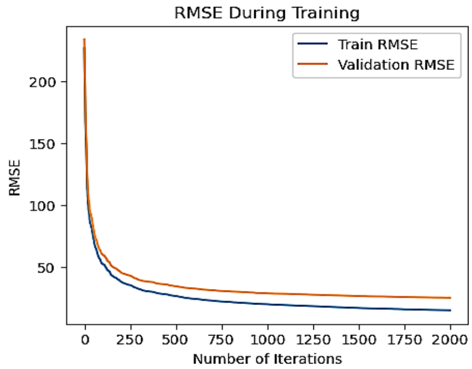

Figure 8. Diagram of RSME for validation and train dataset

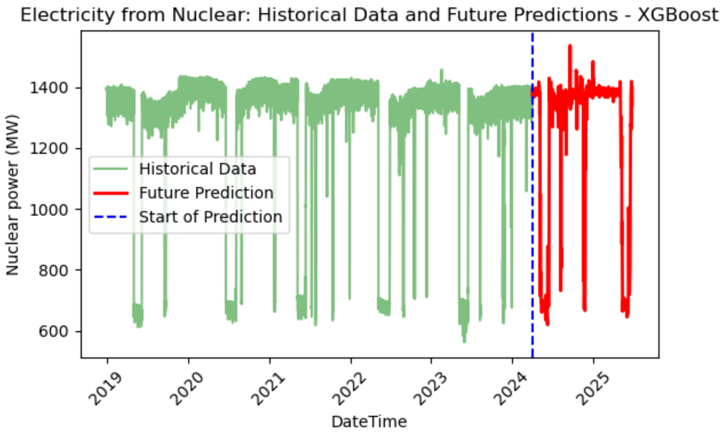

Figure 9. Prediction of electricity production form nuclear energy

4. CONCLUSION

Access to electricity is essential for development and survival. It is crucial to stop traditional energy production in order to achieve net zero emission goals and address the energy crisis. The expansion of renewable energy has been promoted in recent decades to reach the net zero emission by 2050, and increasing nuclear energy production is significant in this regard. According to the dataset simulation, the maximum predicted electricity production from nuclear power plant is around 1,400 MW. It is imperative to take action to confront the energy challenge. Future studies could involve analyzing more data to forecast the trends in nuclear energy for electricity production. Various potential algorithms need to be synthesized in the research study so that more appropriate precision and accuracy may be acquired in the decision making process harnessing the potential future aspect of nuclear energy production.

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Dilip Kumar Das		✓		✓	✓	✓			✓	✓			✓	✓

C : **C**onceptualization
M : **M**ethodology
So : **So**ftware
Va : **Va**lidation
Fo : **Fo**rmal analysis
I : **I**nvestigation
R : **R**esources
D : **D**ata Curation
O : Writing - **O**riginal Draft
E : Writing - Review & **E**diting
Vi : **Vi**sualization
Su : **Su**pervision
P : **P**roject administration
Fu : **Fu**nding acquisition

CONFLICT OF INTEREST STATEMENT

We authors are declaring that there is no conflict of interest.

DATA AVAILABILITY

The data that support the findings of this study are available on request from the corresponding author, [suman@iubat.edu]. The data, which contain information that could compromise the privacy of research participants, are not publicly available due to certain restrictions.

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