Predicting Power Consumption in Households:

# Abstract

1. Energy management is amongst the paramount factors that shape modern existence due to rising energy usage needs and emerging smart homes aspects in addition to sustainable impacts. The application of ML for forecasting of household energy consumption gives a timely insight on how energy can be managed efficiently to reduce expenditure and accommodates renewable energy systems.
2. In studying the use of the ML algorithms in the energy consumption the following are taken into consideration: linear regression, random forest, gradient boosting, and deep learning-LSTM. Some of these key factors are weather, time of day, appliance use and behavior patterns within the houses which are used to develop the models. The models have been trained on open source data sets, for example, ‘The Uplink/Downlink Throughput and Bandwidth Each individual household electric power consumption’; The predicted features include the energy consumption patterns and external environmental factors and seasonal changes in throughputs.

# Introduction

Consumption of energy in the household level contributes to the global energy consumption and challenging factor of stability of electricity system, affecting public services, and environmental footprint. Standard methods of energy forecasting can be unsuitable because the regular statistical approach cannot fully examine all of the interactions between the variables. Machine learning presents an excellent opportunity that focuses on the economic calculation, using volume and complex algorithms to provide high precision and valuable results at industrial scales.This paper discusses the evolution of ML techniques in forecasting household energy, discusses their methods, applications, and limitations. The aim is to offer

# Energy used in a Household Energy consumption timeline

It has relied on manual numerical estimates based on history trends and averages in estimating the frequency of use of energy. The companies for energy in the qualitative modelling used simple forms of statistical forecasting including averages and linear forecast trends of the total energy demand.

The forecasts were very much related to population and industrial growth, and the time of the year.

At the household level, there were rarely any fore casted values since no data on consumption was very much available.

For instance, while the short-term load forecasting technique that has recently risen to prominence is ARIMA. They assume the pattern of energy consumption to mimic the previous usage record in the case of the mentioned equations.

Currently the energy companies have put into production meters that are able provide the household consumption for a month or even a week. These approaches that can use more complicated models such as decision trees, SVMs and ANNs, were employed for the prediction of energy consumption.

These methodologies were found to have the ability to provide higher accuracy in capturing of the non-linear relationships inherent in data.

Weather data such as temperature and humidity integrated energy consumption, with a view of improving their forecasting models.

Algorithms like XGBoost, LightGBM, and DNNs have been developed because the amount and complexity of data that they are asked to handle are massive.

Now, automation in smart home systems is beg in using energy predictions through Nest and Amazon Alexa.

Techniques Indeed, long-short term memory (LSTM) networks where time series are predicted with higher accuracy have been applied.

Submodels included forecasts on the use of renewal energy like the solar panels, and the variability of the household consumption profiles.

## Machine Learning Techniques used on Energyconsumption

Machine learning methods for predicting energy consumption can be broadly divided into traditional and advanced techniques:

1. **Linear Regression (LR):**Estimates the energy consumption by modeling the input variables with non-linear functions of energy consumption linearly.Affords interpretability by devising an organization of the data that can be analyzed under a multitude of hierarchical rules.
2. **Decision Trees:** Provides interpretable results by partitioning data into hierarchical rules.
3. **Support Vector Machines (SVM):**Appropriate for application where the data set is not large and it is easy to identify class boundaries or patterns.
4. **Clustering Models:**One comprises many decision trees in order to increase the accuracy and decrease overfitting.
5. **Deep Learning Models:** Artificial Neural Networks (ANN) and Long-Short-TermMemory (LSTM)

An Evaluation of Selected Scholarly Articles

### Energy consumption forecast by regression model

In the paper entitled “Predicting energy consumption using a regression model” published in July 2016, we consider the prediction of energy consumption using the regression approach analyzing the key parameters which are presented in the form of GDP, population growth and industrial rates.

##### Key contribution:

1. **Regression Model Development:** The authors fitted a regression model on energy consumption and the main economic indicators such as, GDP, population and industrial growth rates in order to forecast future energy consumption patterns.
2. **Energy Consumption Forecast: In** the period of filling this forecast the study employs regression models to predict energy confectionery for 2022 whose predicted value is 209018.1 Mtoe. This, therefore, predicts a dramatic lowering of energy consumption, to which this study attributes a growing embrace of renewable energy for various purposes.

##### Strengths:

1. **Comprehensive Analysis:** The work analyses the correlation between energy use and key econometrics, enabling the understanding of how it can be conceivable that any of those factors influences the level of energy usage.
2. **Emphasis on renewable energy:** For this reason, in the message of the paper, more emphasis is laid on the fact that the option for the renewables would decrease the energy consumption as it mirrors the importance of sustainable in regard to the energy efficiency.

##### Areas for improvement:

1. **Data transparency:** For this reason, the paper is also lacking information on data sources and the methods applied to collect and analyse the collected data. If presented with this information, the reproduction of the study results would be made easier; thus boosting credibility.
2. **Model validation:** In order to make the forecasts more accurate, the text suggests the use of a validation process of the regression model which explains the comparisons of the forecasted results with the …
3. **Consideration of other variables:** As for the other factors that might help to explain energy consumption, apart from GDP, population growth and industrial growth rates, one might include technological advance, changes in policy, energy prices and so on.

Forecasting and appraisal of home energy use

Also in June 2024, Nirbhi Jain and colleagues – Prediction and Analysis of Household Energy Consumption Integrated with Renewable Energy Sources Using Machine Learning Algorithms in Energy Management published in the International Journal of Renewable Energy Research – present an overall analysis of the EMS development for home energy management through the use of machine learning.

##### Key contributions :

1. **Machine learning integration:** In this work, the authors utilize several categories of machine learning towards the identification of energy consumption profiles of homes. It is the study of data collected by thermal, humidity, and usage sensors with the view of making right predictions in energy requirements and thus efficient management of energy.
2. **Integration of renewable energy:** EMS should include renewals. The system shall in turn modify the energy consumption predictions based on availability of renewable energy in order to reduce on the use of non renewable energy hence encourage the cause of sustainable energy use.
3. **Feature Importance Analysis:** According to the findings of the report there are two major aspects that define the process of influencing the energy consumption, namely the environmental factors and usage of appliances. These factors would be useful in the formulation of specific policies for enhancement of energy utilization.

##### Strengths:

1. **Comprehensive data utilization:** The research employs a dataset which is publicly available and contains the information of various sensors in the past which is much more effective in training and testing of the model.
2. **Practical application:** In this regard, by dealing with the actual IoT-based smart home contexts, the given work provides essential knowledge of EMS implementation in contexts that are relevant to the current situation in smart homes.

##### Area of Improvements:

1. **Experimental verification:** Despite the fact that the paper presents a theoretical analysis of the problem, there is no empirical evaluation of the proposed system. However, it would be more effective for the realistic approach of an EMS to be implemented in the real environment, and the performance of the implemented EMS for enhanced practical application from the study.
2. **Implementation challenges:** Essays describe difficulties in the actual use of such systems. These issues, in detail, involving propositions, offered a better view of the comparative actuality of the EMS.

### Statistical Analysis of Energy Use for Commercial Structures

In the paper of “Probabilistic Modeling of Energy Consumption for Commercial Buildings Using Markov Chain Logistic Regression”, Published in 2020 by Guanyu Tian and Qun Zhou, the authors have introduced a new probabilistic modeling method of energy consumption in commercial buildings.

##### Key contributions :

1. **Logistic Regression Markov Chain (LRMC) Model:** Using exogenous inputs, the authors put forward an enhanced LRMC model for superseding previous models based on Markov chain with constant transition matrices. This integration is thus able to enable the model take into consideration uncertainty and dynamics in energy consumption.
2. **Improved prediction accuracy:** While pattern energy consumption can be predicted with reasonable certainty in dwelling units, LRMC model brings out wallet and clock external variables and time dependent behavior for more accuracy in managing and optimizing energy in commercial building.

##### Strengths:

1. **A comprehensive approach:** This combines the logistic regression with Markov Chain Model which is a strong modeling for highly volatile energy consumption behaviours and time varying factors which were not considered in prior models.
2. **Practical Implications:** This means that the current model will assist in the accurate prediction of energy consumption, they may be useful for managing energy utilization and enhancing the performance of buildings thus assisting building and policy managers in formulating appropriate strategies for saving energy.

##### Area of Improvements:

1. **Validation with different datasets:** The model has potential but expanding it to other commercial building types and other geographical locations would further enhance the generalization and usefulness of the model.
2. **Consideration of other variables:** It might also be useful to consider other factors affecting the energy consumption, including the occupant behavior, weather conditions and characteristics pf specific buildings for even better performance of the model.

A regression context of energy utilization in smart cities

This paper titled, Regression Framework for Smart City Energy Consumption with Recurrent Neural Network Encoder-Decoder by Berny Carrera and Kwanho Kim and published in Energies in November 2023 informs the reader about an improved method in smart city energy consumption forecasting.

##### Key contributions :

1. **Deep Learning Application:** aTo show that the model is able to capture the temporal patterns of energy consumption, the authors use a recurrent neural network encoder- decoder for the 48 hour ahead energy consumption prediction.
2. **Songdo, South Korea Case Study:** The verification of the proposed framework is performed with data obtained from Songdo, a smart city in South Korea, which provides the experience of using the proposed research in actual circumstances.
3. **Performance Evaluation:** It presents high R² value, low Mean Absolute Error and RMSE to illustrate the performances of the proposed model and some basic regressors in the work.

##### Strengths:

1. **Comprehensive data analysis:** The presented framework highlights the data requirements needed to produce energy statistics for the microcities, enhancing energy behaviour analysis of structures that constitute the architecture of microcities.
2. **Scalability:** The method of construction of the framework helps adapt it to different smart city environments, thus enhancing its likelihood of widespread application.

##### Area of Improvements:

1. **Transparency of data sources:** Regarding improvements on the current paper, more details on the data used and how it was collected, and analysed would enhance the actual study results credibility and inter-study generalizability.
2. **Taking other variables into account:** The addition of other variables like occupants behavior, weather conditions and some other building related features could enhance the accuracy of the proposed model.

### Predicting energy consumption in low energy buildings

Priya Vijayan, published a paper in 2022, which explains the use of ML and AI in the estimation of energy use in low- energy buildings for enhanced energy efficiency.

##### Key contributions :

1. **Application of ML and AI techniques:** As part of this study, different ML and a variety of AI approaches to energy consumption forecast with the view of enhancing the precision of load forecasting in low-energy buildings are discussed.
2. **Focus on energy efficiency:** Accurate estimation of energy use is important and helps in enhancing low-energy structures for integrated resource efficiency and sustenance, enhanced management of demand and supply stability and energy systems.

##### Strengths:

1. **A comprehensive approach:** The paper presents a comprehensive literature review of the different ML and AI techniques, along with relevant information about their effectiveness in estimating the energy consumption in low energy buildings.
2. **Importance for energy efficiency:** The emphasis on enhancing the energy utilization efficiency devoid of compromising on requirements is synchronous with the current trend of global endeavors towards energy conservation and efficient use in construction.

##### Area of Improvements:

1. **Detailed methodology:** Additionally, the current paper seems to lack an adequate description of the various ML & AI used, the algorithms applied, data used as well as the method of training and validation of the models used.
2. **Performance metrics:** To clarify the identification of the factorical and excellentivity of the models in prognosis of energy consumption additional quantitative performance of the metrics that involved, accuracies, precision, recall or mean absolute error could be provided.
3. **Bench marking:** I agree with Svetlana and Elena that benchmarking with traditional forecasting methods might also strengthen the proposal of using ML and AI approaches by indicating some of the weaknesses of the classical methods.

## Conclusions and Contributions to the field from the Literature Review

Overall Contributions:

1. **Technology integration:** Using IoT, ML and artificial intelligence to enhance the prediction and optimization of the amount of resources that is to be used.
2. **Focus on sustainability:** The promotion of electric power generation from renewable energy as well as energy conservation provisions. Innovative models: Spectral pseudo- margins used in LRMC, product of feature statistics used in MSVM-DAG-FFO, sequence to sequence learning of RNN encoder-decoder.
3. **Practical applicability:** Actualizations of the relevance and applicability of the study from real-life situations and scenarios are another reason for using case studies.
4. Altogether these research works, extend the pool of knowledge in their respective disciplines and offer solutions regarding to modern issues in agriculture, energy management and the advancement of urban structures.

# Benefits of Predicting Household energy consumption

#### Energy Efficiency

* + **Optimized Usage:** Aids the households in determining what constitutes as peak and off peak usage and assists in controlling the energy during off-peak times.
	+ **Reduced Wastage:** Detects cycle of wasteful energy consumption and allows appropriate adjustments like switching off an appliance when idle.

#### Cost Savings

* + **Lower Bills:** They can always incorporate energy saving ways such as using appliances during off-peak periods, the tariffs are cheaper.
	+ **Smart Budgeting:** Makes it possible to estimate future consumption thus providing accurate budgeting for energy expenditure.

#### Sustainability

* + **Reduced Carbon Footprint:** Through avoiding wastage of power used in lighting and other appliances, the residences are said to be playing part in minimizing green house gas emission.
	+ **Renewable Energy Alignment:** Assists consumers within the household to work out the correlation between power usage and renewable sources like solar and wind.

#### Enhanced Energy Management

* + **Smart Home Integration:** Some possible uses of predictive models are to cooperate with IoT equipment in an effort to perform automated energy saving actions such as turning off lights or adjusting temperature devices.

# Energy prediction has the following disadvantages and challenges

*Data Privacy and Security Risks:* Predictive systems can share many similarities with RH systems, utilizing the discrete data relating to the energy consumption of households, which can raise privacy issues regarding the collection, storage and treatment of corresponding data.

*High Implementation Costs:* The adoption of energy control mechanisms such as monitoring systems, IoT and analytical tools may be expensive to deploy at first.

*Limited Accuracy:* In most cases, forecasts do not succeed to integrate changes in behavior, weather conditions or even malfunctions of professional equipment.

# Conclusion

The methodology used to reconcile consumptions by household is unique and has enormous value proposition for optimising energy use, minimizing costs and advancing sustainability. Machine learning, IoTs as well as AI are capable of providing insight towards the consumption behaviour and consumption patterns of households; as well as delivering a more sustainable energy consumption than before. Analysed, people can regulate their consumption by running costs and adapting to peak yield periods, probably in their households.

This tool assist households in saving by unearthing instances where energy is employed wastefully or by charging tariffs outside of the peak period.

Accurate forecasting is useful for-I for incorporating the renewable sources, decreasing the use of non-renewable sources of energies, and carbon traces.

# Soil Monitoring:

Scope in the Future

There are immense benefits of prediction in the energy consumption of the household many of which are provided below fueled by increasing awareness of sustainability, advances in the technology’s, and using machine learning. The areas of opportunity created by smart homes and related energy-efficient technologies include, but are not limited to

##### Integration with Smart Homes and IoT:

Future systems will integrate perfectly with smart home technologies with the ability to independently take actions that lead to energy saving by adjusting the thermostat, lighting and appliances in compliance with the overall consumption forecasts. It will enable completely separate and fully flexible energy consumption and supply systems with continuously readjusting behaviours for the residents and the specifics of the climate and of the condition of the grid.

##### Artificial Intelligence and Machine Learning Advancements:

With time, AI and ML algorithms will become more precise in terms of energy usage forecast propensity to certain predictors Confederation such as occupancy, changes in lifestyle, weather intelligence, and other forces of extras such as holidays, power blackouts.

##### Integration with Renewable Energy and Smart Grids:

PSmart grid applications will be possible by

enhancing and developing predictive models to better incorporate renewables as solar and wind, estimate when they will be available and match household demand to supply. Directing households to automatically use clean energy where easily obtainable was also provided as a possible way of minimizing the use of fossil energy.

# References

1. *Zhao, X., & Yang, F. (2020). >Energy consumption information is a significant factor for customers choosing their providers since it demonstrates their ability to deliver across various dimensions of the smart homes market. Renewable and Sustainable Energy Reviews, 120, 109646.*
2. *Chong, A. S., & Tan, Y. (2019). “Energy prediction for smart homes: An A Survey.” Energy Reports, 5, 877-887.*
3. Wang, L., & Xu, L. (2021). "Smart Grid and Energy Consumption Forecasting: Dataanalyse und maschene Learning: Die Rolle Der Sektionschizophrenie.” IEEE Transactions on Industrial Informatics, vol. 17, no. 4, pp. 2482–2491.
4. Sadeghi, M., & Akbari, R. (2020). Smart Home Devices and IoT (Internet of Things) application: Energy Consumption and Sustainability. Journal of Cleaner Production 248, 119267.
5. Díaz Pérez, Heyley & González Miranda, Evelyn (2018). Alcorn : 2009, ‘A Review of Predictive Energy Consumption Models for Residential Buildings’ Renewable and Sustainable Energy Reviews, 91, 679– 696.