

Proceeding paper

Energy Optimized Edge Computing Framework for the Sustainable Development of Modern Agriculture [†]

Neha Bhende and Rupa Kesavan*

Department of Computer Science and Engineering, Sri Venkateswara College of Engineering, Sriperumbudur, Chennai, Tamil Nadu, India.; 2020cs0459@svce.ac.in

* Correspondence: rupakesavan@svce.ac.in

† Presented at The 4th International Electronic Conference on Applied Sciences, Online, and 27 Oct–10 Nov 2023

Abstract: Implementation of smart agriculture is confronted with various challenges such as lack of infrastructure and isolation from networking facilities that are required for the smooth operation of the Wireless Sensor Network established. The sensors and imaging systems present in the cropland generate large amounts of data that need to be processed in an affordable and scalable manner even with a limited internet connection. This paper proposes the use of agricultural waste to power edge devices being deployed in a given crop land. In order to ensure efficient energy usage and processing we implement the K-Means clustering algorithm integrated with the FPKM algorithm to efficiently denoise the collected data and an offloading mechanism that ensures efficient usage of computational resources by enabling parallel computation to minimize errors and delays in actuator instructions that could increase the crop productivity and significantly diminish the possibility of crop loss.

Keywords: Edge Computing; Sustainable Development; Smart Agriculture; Internet of Things; FPKM algorithm; Clustering Algorithms; Microgrids

1. Introduction

In order to successfully incorporate Wireless Sensor Networks (WSN) in agriculture and to fully utilize its benefits, it is crucial to take into account certain features of the environment in which the nodes will be placed. Factors like crops, machinery, temperature, humidity, rainfall, high solar radiation, and shading by plant leaves can interfere between the nodes and can lead to discrepancies and errors in the data transferred. As the nodes are battery operated, and are placed in croplands where finding a suitable power supply replacement is difficult, ensuring efficient power supply lifetime is a challenge. In using a wireless network, it is difficult to safeguard the deployed nodes from interference of devices operating and communicating in the neighborhood. This could lead to tremendous inconsistencies and unreliability of the inferred data and control signals. Ensuring interoperability among the multiple technologies and standards implemented can be a grueling task due to the number of devices used and the wide range in variety of technologies applied. Although cloud computing was introduced to tackle the “Big” data problem by handling the large amounts of edge network data, maintaining an optimal balance between the storage and processing of this acquired data can be cumbersome. Furthermore, it is vital to ensure a good trade-off between the computational workload and the high costs and latency that accompany it. Wireless communication can cause inconsistencies in sensed data due to the unavoidable presence of noisy data. This adds more pressure on the preprocessing processes implemented in the service layer to clean the data and offer more reliable inferences. The FPKM algorithm, conventionally used in quantification of gene expression levels in RNA sequencing data analysis can be applied

Citation: Bhende, N.; Kesavan, R, Energy Optimized Edge Computing Framework for the Sustainable Development of Modern Agriculture . *Eng. Proc.* **2023**, *52*, x. <https://doi.org/10.3390/xxxxx>

Academic Editor: Nunzio Cennamo

Published: date



Copyright:© 2023 by the authors. Submitted for possible open access publication under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

to the agricultural data due to the similarity of it. It is essential in ensuring data integrity, outlier removal and normalization of data to accommodate variations in the experimental environment. Deploying agricultural sensors, robots, drones, and other tools and technologies requires significant investment, high-skilled manpower, and heavy maintenance costs. High-bandwidth continuous internet connectivity, HD cameras for crop satellite imagery via sensors and drones, and a huge capacity server are also necessary to store regular logs related to crops and other activities [1]. Creating a consistent and energy-efficient environment is critical for secure information transmission to stakeholders. As per a study cloud data centers make up 2.4 percent of the global electricity consumption and this is estimated to increase. Authors in [2] have suggested reducing the data to be sent to the data centers for processing to minimize the energy consumption. As given in the proposed architecture, integration of microgrid with edge computing improves the efficacy of using renewable energy effectively to meet the IoT energy requirements.

2. Methods

Our proposed architecture utilizes Microgrids as a way to reuse agricultural waste so as to enable an independent power grid capable of safeguarding the edge devices from power shortages/ disruptions even when the crop land is located off-grid.

2.1. Valorisation of Agricultural Waste Using Microgrids

The Indian Council of Agricultural Research conducted a study wherein they examined the agricultural waste produced after every harvest cycle. On an average, about 350 million tonnes of waste is produced which includes crop residues that have a rich bioactive compound content. This waste can be revalued to harness renewable energy in order to power edge devices. This can be done in various ways including biogas generation using anaerobic digestion, biomass energy to produce heat and electricity that can power edge devices through electrical generators, biofuel production, thermal energy, microgrids etc.

Microgrids are systems that can incorporate several renewable energy sources and efficiently distribute the power generated to edge devices in a WSN. They are small-scale and localized in the sense that are capable of generating, storing and distributing energy only to a fixed area or a group of edge devices. They play a major role in valorisation of agricultural waste as shown in Table 1.

Table 1. Microgrid Applications in Waste to Energy Processes.

Method	Role of Microgrid	Benefit	Reference
Energy Generation from Waste	Host biogas digesters, gasification units or boilers	Converts agricultural waste into heat, electricity and energy	[3]
On-site Energy Production	Processes the waste on-site instead of a distant facility	Reduced transportation cost and loss in energy due to transport of waste to and from processing facility	[3]
Energy Efficiency	Optimization of processes involving energy conversion by using CCHP systems	Capturing of heat generated while using CCHP systems	[4]
Energy Storage	Storing the renewable energy when the power demand is low	Utilization of the stored energy cuts down on the process of regenerating brown energy in the power grid	[2]

Independence of the Grid	Allows the grid to work independently of the main power supply	Supports agricultural practices in off-the grid or more remote areas, while securing continuous and reliable energy	[5]
Excess energy Utilization	The excess energy generated at low-peak hours can be fed-back to charge batteries or monetized by selling it at high cost	Contributes to energy supply and acts as a potentially revenue generating activity	[2]

2.2. Integrating Micro-grid and Edge Computing

Our proposed work integrates microgrids with edge computing [6] so as to establish an environment that supports management of energy, decision making and processing of data. The biggest advantage of this integration is the enhancement of energy and computing efficiency and reliability. Furthermore, this results in an energy infrastructure that is more responsive, efficient and secure. When we deploy edge computing devices within a microgrid infrastructure such as a renewable energy site, they act as computing nodes in the microgrid. They can be used to dynamically monitor the energy generation, consumption and distribution in a real time agricultural environment.

Within a microgrid infrastructure, we can deploy energy-aware nodes like substations or distributed energy resources (DERs) which can host edge servers and process sensed data while being powered by the microgrid itself. These nodes can manage, monitor and optimize their own energy usage and track their consumption pattern. The principle behind the architecture of these nodes is to bring down the overall energy consumption per processing task which will in turn reflect in the extended lifetime of these devices. These energy-aware nodes possess the capability of dynamically adjusting operating parameters such as voltage and clock cycle depending on the energy available and the work demand. In the low-demand periods they adopt power management techniques like sleep modes, dynamic voltage modification and power gating to restrict the energy usage in these times.

Smart agriculture involves smart irrigation, smart fertigation and pest control systems that utilize sensors to measure temperature, humidity, NPK content and intrusion detection systems based imaging systems that use deep neural networks to detect pests. Several technologically advanced farms tend to have hundreds or thousands of sensors deployed to collect this data. Keeping in mind the amount of energy that is required to power these devices, for various processing tasks we list the advantages of integrating microgrids with edge computing devices.

Evaluation of irrigation, fertigation etc. requirements is done by sending the sensed data to a centralized cloud data center followed by sending all actuator instructions from the data centers to the actuators deployed. This requires a tremendous amount of energy and can lead to latency due to the time taken to transmit the data to and from the IOT devices and analyze it. Further due to limited network connection and bandwidth in these lands, the data is vulnerable to external forces that may produce erroneous or corrupt results. The concept of edge computing can be implemented to minimise the risk associated with wireless data transmission. With the help of microgrids all computation and processing is done locally on the designated edge devices for a set of WSN nodes. Thus, diminishing the possibility of latency and improving the response time.

In some cases, edge analytics can be implemented to establish patterns in energy usage, irrigation, fertigation and intrusion to reduce the energy used in computing the requirements for every unit of sensed data.

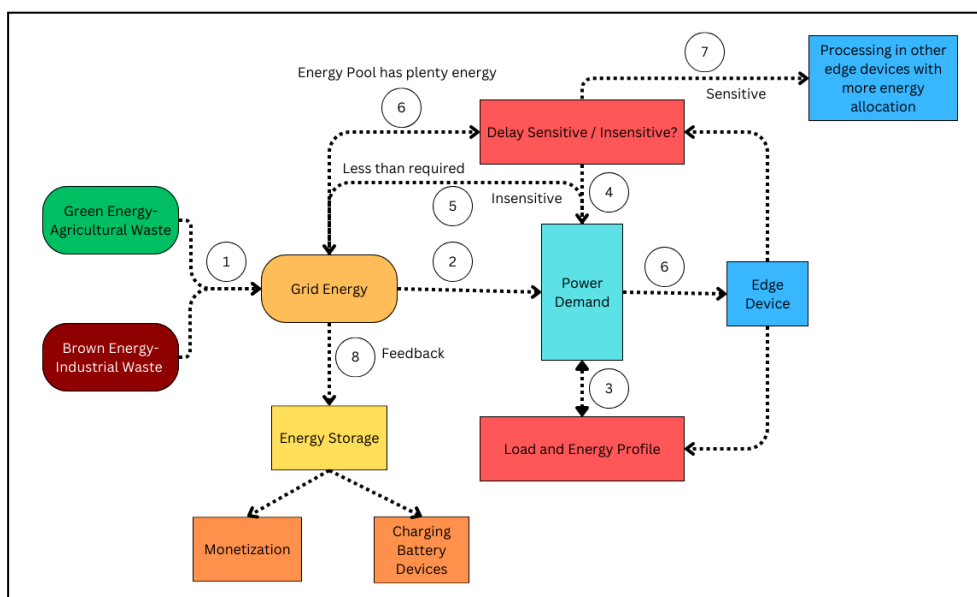


Figure 1. Integration of Microgrid with Edge Computing.

2.3. Clustering using FPKM and K-means

In modern agriculture, an abundance of data is collected from the sensors deployed on the agricultural lands. The type of data is shown in Figure 2.

Due to wireless transmission of data to and from the edge devices and sensors/actuators, presence of redundant data, inconsistent as well as null value rich data are familiar issues with original and raw data and thus data preprocessing is an essential phase in the data mining procedure. Extracting the accurate data from all the sensed data improves the accuracy of the system in determining irrigation, fertigation and pest control requirements. We propose a denoising methodology used in RNA sequencing to detect anomalies in the collected data, isolate them and then dump them. FPKM and K-means clustering as determined by authors in [7] is suited to data that has varying sizes and randomness.

Apart from denoising the data, clustering [8,10] plays a crucial part in ensuring efficient energy consumption by utilizing optimization techniques to distribute computing tasks and processing resources amongst the edge devices.

Consider a single cluster of devices in an agricultural area, in order to determine the irrigation and fertigation requirements we must read at least 15 parameters [9] for every single crop in the area, access the water and NPK requirements from the data base, compare it with the read values and utilize a series of IF-THEN rules to initiate the process. With the help of clustering, these tasks can be distributed amongst the edge devices in a single cluster, this reduces instances of overburdening and idle devices which can lead to excessive energy consumption and resource wastage at the same time.

Due to the variety of processing tasks involved with varying resource requirements, for example NPK requirements tasks, these tasks can be offloaded to those edge devices that are equipped enough and have the appropriate resource allocation to perform them. Further, in order to reduce the distance of data transmission, clustering ensures that the data is processed at the closest edge device.

Other benefits include; dynamic resource allocation, energy aware scheduling, predictive analysis to determine resource allocation during predicted peak workload hours eg. Irrigation time and monitoring energy usage.

<p>WEATHER</p> <ul style="list-style-type: none"> • Temperature • Precipitation • Humidity • Wind speed and direction • Solar radiation • Evapotranspiration 	<p>SOIL</p> <ul style="list-style-type: none"> • Soil moisture content • Soil temperature • Soil pH levels • Soil nutrient levels (e.g., nitrogen, phosphorus, potassium) • Soil texture and composition
<p>CROP</p> <ul style="list-style-type: none"> • Crop growth stages • Crop health and vigor • Crop yield data • Crop pest and disease data 	<p>IRRIGATION</p> <ul style="list-style-type: none"> • Irrigation scheduling and timing • Water usage and application rates • Soil moisture levels before and after irrigation
<p>REMOTE SENSING</p> <ul style="list-style-type: none"> • Satellite imagery • Aerial imagery (drones or UAVs) • Spectral data (e.g., NDVI for vegetation health) • Infrared imagery for temperature monitoring 	<p>ENVIRONMENTAL</p> <ul style="list-style-type: none"> • Air quality data (relevant for livestock farming) • Water quality data (relevant for aquaculture and irrigation) <p>Crop Management</p> <ul style="list-style-type: none"> • Planting dates and methods • Fertilizer and pesticide application rates and timing • Harvesting dates and yield per acre
<p>FARM INFRASTRUCTURE</p> <ul style="list-style-type: none"> • Information on farm buildings and structures • Storage capacities for crops and livestock products • Energy consumption data 	

Figure 2. Type of agricultural data collected by IOT sensors.

3. Experimental Setup

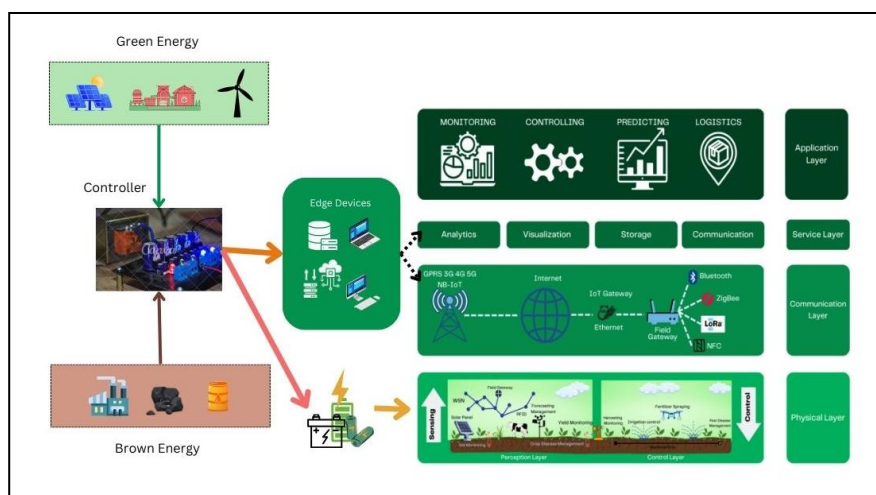


Figure 3. Experimental Set up.

Our system architecture is a small-scale prototype consisting of: DHT11 sensors to monitor temperature and humidity of the soil, ZigBee Communication Protocol, Dell 1U server equipped with a 3.3 GHz Intel Xeon CPU, 8 GB RAM, and a 1 TB SATA hard drive, having per-server maximum and static power consumption 260 W and 120 W respectively. The edge computing platform is eclipse ioFog paired with kubernetes as the cloud service provider. As the source of renewable energy we have chosen 2 solar photovoltaic cells having peak output of 65 W. We use a DC-DC converter. And we include a battery to store excess energy produced.

3. Results and Discussions

When we integrate Microgrids with edge computing in an agricultural wireless sensor network we obtain an energy secure infrastructure that combines task handling capabilities such as energy management, renewable energy production and monitoring energy usage of deployed IoT and edge devices. The energy storage component of the proposed architecture serves as a sustainable way to efficiently utilize the produced energy, securing future resource requirements and a way to monetize and use the energy produced in cases where it exceeds the edge device requirements. The energy aware nodes deployed at essential points of the microgrid possess the capability of energy

monitoring, dynamic load balancing and energy distribution for real-time and continuous data. Enhanced energy management and real-time decision making, contribute to the sustainable and robust farming practices. The use of the FPKM algorithm integrated with the K-means clustering algorithm ensure robust preprocessing to minimize the latency and discrepancy in actuator instructions thereby minimizing the risk of improper irrigation and fertigation that could lead to widespread crop failure. Clustering in edge computing optimizes task distribution, allocation of resources and efficient device utilization to enable offloading mechanisms and parallel computation. The renewable energy generation for solar and wind was obtained from a statewide energy c

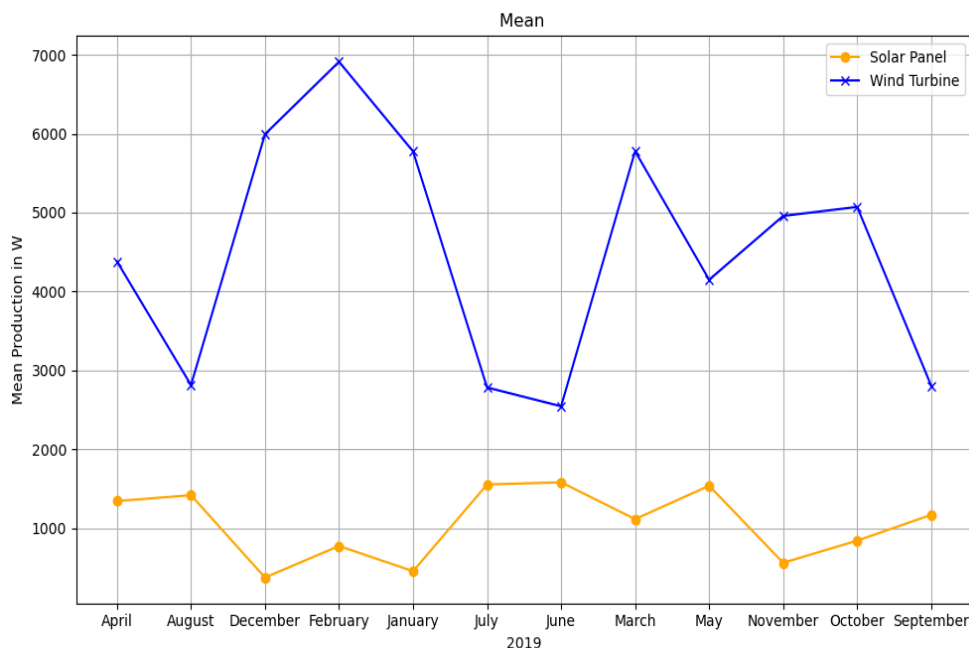


Figure 4. Renewable Energy Generation[11].

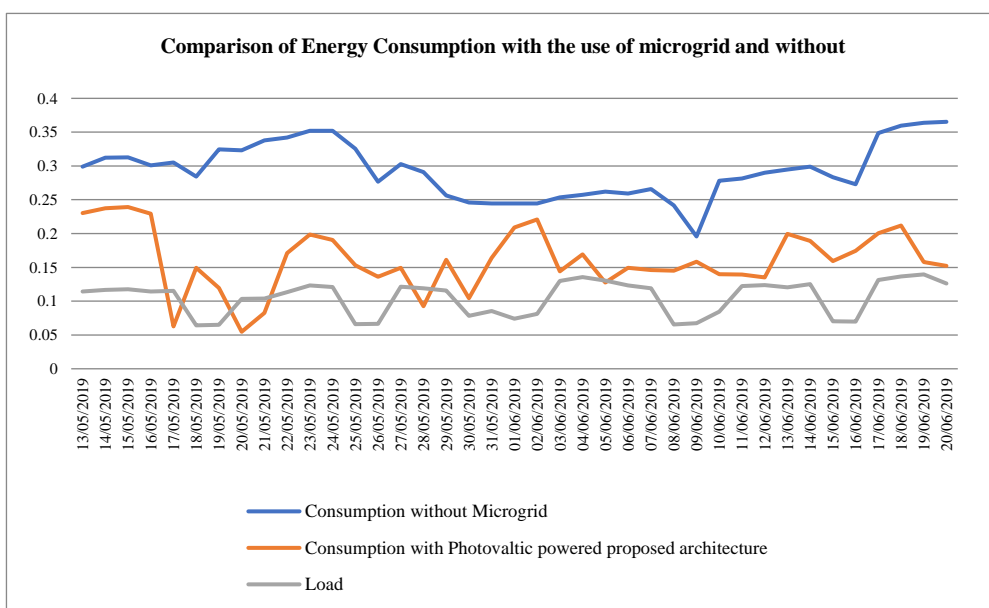


Figure 5. Comparison of Energy Consumption with the use of microgrid and without [12-14].

The energy consumption of the edge devices and the IOT sensors was monitored, collecting two sets of data: With microgrid integrated, Without microgrid integrated. The

results along with the load of the network was plotted on a graph using MATPLOTLIB libraries on Jupyter Notebook. The graph shows significant reduced energy consumption when using microgrid infrastructure to power the devices. Additionally shows minimal difference in the energy required and energy consumed when compared to a traditional system. Thus ensuring minimal energy wastage through heat dissipation.

4. Conclusion

Thus we have proposed an edge computing framework that addresses the issue of efficient energy usage by integrating it with a microgrid infrastructure that produces renewable energy from agricultural (green energy) waste and industrial waste (brown energy). Our work plays an important role in the sustainable development of the agricultural sector by providing solutions to limited network connectivity, off-the-grid location of crop lands and abundance of noise that affects the actuator instructions. Furthermore, we highlight the importance of the FPKM algorithm in the preprocessing stage and the essential role of the K-Means clustering algorithm in edge computing to support data analysis, management of resources, offloading and load balancing to develop an optimized computing environment, safeguarded from latency and excess traffic issues all while utilizing resources efficiently. Further research in the field of smart agriculture to ensure efficient energy usage and securing maximized crop yield to provide food security must be done for an ever-increasing population like ours. Future work entails incorporating edge caching mechanisms to further improve the spectral efficiency of the architecture.

Author Contributions: Conceptualization, methodology, data curation, writing—original draft preparation, NB.; writing—review and editing, validation, supervision, RK

References

1. Ojha, Tamoghna, Sudip Misra, and Narendra Singh Raghuvanshi. "Wireless sensor networks for agriculture: The state-of-the-art in practice and future challenges." *Computers and electronics in agriculture* 118 (2015): 66-84.
2. Li, W., Yang, T., Delicato, F. C., Pires, P. F., Tari, Z., Khan, S. U., & Zomaya, A. Y. (2018). On enabling sustainable edge computing with renewable energy resources. *IEEE communications magazine*, 56(5), 94-101.
3. Beyene, Y. B., Worku, G. B., & Tjernberg, L. B. (2023). On the design and optimization of distributed energy resources for sustainable grid-integrated microgrid in Ethiopia. *International Journal of Hydrogen Energy*.
4. Tooryan, Fatemeh, Hamid HassanzadehFard, Vahid Dargahi, and Shuangshuang Jin. "A cost-effective approach for optimal energy management of a hybrid CCHP microgrid with different hydrogen production considering load growth analysis." *International Journal of Hydrogen Energy* 47, no. 10 (2022): 6569-6585.
5. Tahir, Kawakib Arar, Montserrat Zamorano, and Javier Ordóñez García. "Scientific mapping of optimisation applied to microgrids integrated with renewable energy systems." *International Journal of Electrical Power & Energy Systems* 145 (2023): 108698.
6. Jalali, Fatemeh, Arun Vishwanath, Julian De Hoog, and Frank Suits. "Interconnecting Fog computing and microgrids for greening IoT." In *2016 IEEE Innovative Smart Grid Technologies-Asia (ISGT-Asia)*, pp. 693-698. IEEE, 2016.
7. Zaguia, Atef. "Smart greenhouse management system with cloud-based platform and IoT sensors." *Spatial Information Research* (2023): 1-13.
8. Nadig, Deepak, Sara El Alaoui, Byrav Ramamurthy, and Santosh Pitla. "ERGO: A scalable edge computing architecture for infrastructureless agricultural internet of things." In *2021 IEEE International Symposium on Local and Metropolitan Area Networks (LANMAN)*, pp. 1-2. IEEE, 2021.
9. Ullah, Ihsan, and Hee Yong Youn. "Task classification and scheduling based on K-means clustering for edge computing." *Wireless Personal Communications* 113 (2020): 2611-2624.
10. Hao, Yongsheng, Jie Cao, Qi Wang, and Jinglin Du. "Energy-aware scheduling in edge computing with a clustering method." *Future Generation Computer Systems* 117 (2021): 259-272.

11. https://docs.google.com/spreadsheets/d/1kxwyjiAaMD2wgvY6LS-cXAh8mV_UytKB8v2u4XvWIZ0/edit?usp=sharing Link to the renewable energy data set for solar and wind power
12. https://docs.google.com/spreadsheets/d/1J4ihXDJObM8_HGOAF6W6FPU6ZwGaSPzs3NQmivzamVk/edit?usp=sharing Link to the raw data having the Load of the Edge device
13. https://docs.google.com/spreadsheets/d/1ohAVnxL6HLv3hfj5_xQGpE3CcbKtTiI8J1MBz35vQM/edit?usp=sharing Link to the raw data having energy consumption of the edge device with microgrid integration
14. https://docs.google.com/spreadsheets/d/1Or4s7zk6i7AbeHzqUOhXLU9SulljYvpIOIVjIW_uGec/edit?usp=sharing Link to the preprocessed and clustered data with comparison of energy consumption

Disclaimer/Publisher's Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of MDPI and/or the editor(s). MDPI and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.