Framework of Data-Driven Methods to Enhance Renewable Energy in Smart Cities

[1]Kuldeep Singh Kulhar, [2]A Rengarajan, [3]Mr. Rishi Sikka, and [4]Dinesh Kumar

[1]*Professor, Civil Engineering, Vivekananda Global University, Jaipur, India*
[2]*Professor, Department of Computer Science and Information Technology, Jain (Deemed to be University), Bangalore, India*
[3]*Assistant Professor, Department of Electronics, Sanskriti University, Mathura, Uttar Pradesh, India*
[4]*Assistant Professor, Maharishi School of Engineering & Technology, Maharishi University of Information Technology, Uttar Pradesh, India*

Abstract: As the quest for intelligent and eco-friendly urban progress gains momentum, the integration of renewable energy resources within smart city infrastructures becomes increasingly pivotal. This comprehensive review article delves into the confluence of data-driven methodologies and renewable energy solutions within the realm of smart cities. We embark on an exploration of the intricate frameworks devised to enhance the efficiency of renewable energy generation, distribution, and meticulous management in these urban ecosystems. By elucidating the multifaceted strategies and techniques underpinning this synergy, we shed light on the transformative potential it holds for the sustainable and intelligent evolution of our cities, paving the way for a greener and smarter urban future.

keywords:Renewable energy, potential, Smart cities, Hydroelectric power plants, artificial intelligence

1.Introduction

The phenomenon of urbanization has reached an unprecedented level in the 21st century, as over half of the world's population currently resides in urban areas. This dramatic shift towards urban living brings forth both opportunities and challenges that demand innovative solutions for the well-being of urban inhabitants and the planet. In response to this urban influx, the concept of "smart cities" has emerged as a beacon of hope, representing a vision of urban development that is not only technologically advanced but also environmentally sustainable [1]. At the heart of this vision lies the recognition that traditional urban infrastructure and energy systems are no longer adequate to meet the needs of burgeoning urban populations while mitigating the adverse effects of climate change. Smart cities

Corresponding Authour:[1]k.singh@vgu.ac.in
[2]a.rengarajan@jainuniversity.ac.in
[3]rishisikka.ec@sanskriti.edu.in
[4]*patelmnnit11@gmail.com*

represent a paradigm shift, harnessing cutting-edge technologies to create urban environments that are efficient, resilient, and ecologically responsible. One of the most crucial pillars of sustainability within smart cities is the integration of renewable energy sources [2]. Renewable energy, derived from sources such as wind, sunlight, and water, holds the promise of providing a clean and inexhaustible energy supply, reducing the carbon footprint of cities, and ensuring a more sustainable future for urban residents. The need to transition from fossil fuels to renewable energy sources is not merely a matter of choice; it is an imperative to combat the challenges of climate change and resource depletion. However, the integration of renewable energy into the urban fabric is a multifaceted challenge. It involves not only the generation of clean energy but also its efficient distribution, storage, and consumption. This complexity is where data-driven artificial intelligence (AI) methods come into play, offering a powerful set of tools to optimize every facet of renewable energy systems within smart cities [3,4].This perspective article points towards the intricate relationship between data-driven AI methods and renewable energy solutions within the context of smart cities. This article aims to provide a bird eye view on the potential, benefits, challenges, and future prospects of this transformative synergy.

1. Smart Cities and Renewable Energy Integration

Currently the renewable energy grids largely span across (a) Wind (b) Solar (c) Hydroelectric power plants. These sources of energy are intermittent in nature.

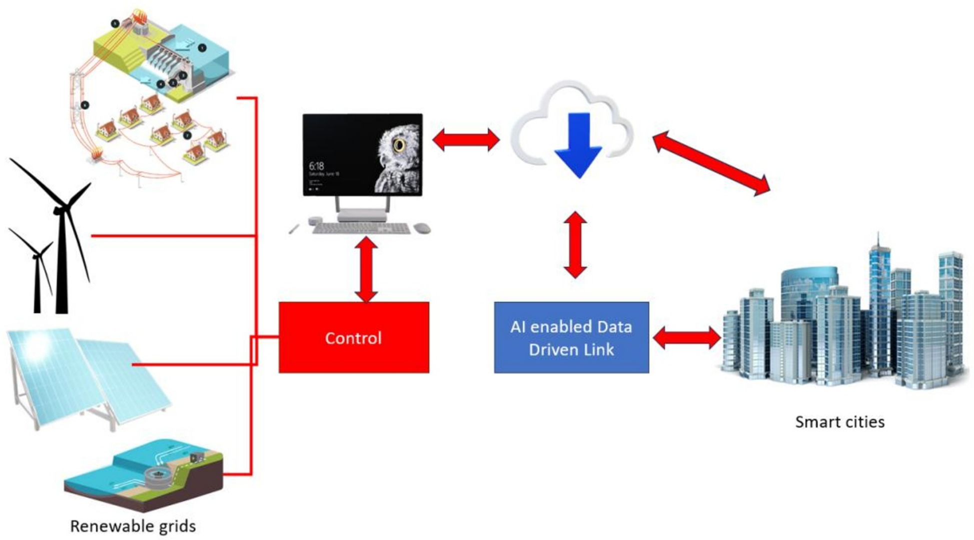

Figure.1. Data driven AI enabled integration of grids with cities framework.

The figure 1 shows the framework of AI enabled data-driven framework that has been proposed by researchers [4-7]

1.1. Smart Cities: A Sustainable Vision

The paper scrutinizes the role of smart city practices in contributing to sustainable urban outcomes, specifically focusing on carbon dioxide emissions in 15 UK cities from 2005 to 2013 [8]. The findings indicate a non-linear relationship between city smartness and carbon dioxide emissions, which remains consistent over time. This underscores the need to align smart city strategies for concrete sustainable outcomes. The study highlights the importance of further investigations to assess the actual outcomes of existing smart city projects and emphasizes the necessity of developing smart city agendas that genuinely deliver sustainability [8].

The study by Shamsuzzoha et al. 2021, critically reviews the smart city research paradigm, comparing initiatives across countries and cities. The study reveals that the existing research on smart cities fails to adequately tackle the intricacies, contradictions, and interconnections of smart city goals. Furthermore, the assessment of smart cities' success is made difficult by the significant variations in evaluation methods and rankings. The study emphasizes the need for a more comprehensive understanding of smart city initiatives and their impact, highlighting potential knowledge gaps and opportunities for further research and development in the field [9].

1.2. Renewable Energy in Smart Cities and Need for Advanced Solutions

In 2015 an article appeared that covered the integration of renewable energy into smart cities. This article delves into the close connection between intelligent grids and urban areas, with a specific emphasis on incorporating renewable energy sources, electric vehicles, energy storage solutions, and advanced lighting technologies within environmentally-friendly smart cities. It discusses the components of smart cities, emphasizing the role of energy infrastructure in achieving sustainability goals. The integration of renewable energy and energy storage is seen as essential for improving energy management and reducing carbon footprints in urban environments. The article also highlights new business models for Distribution System Operators (DSOs) in the context of prosumers and microgrids. Additionally, it discusses the potential of electric vehicles and smart lighting in enhancing urban mobility and energy efficiency in smart cities [10].

1.3. Data-Driven Artificial Intelligence Methods for integration

It was found that the integration of artificial intelligence (AI) into the renewable energy (RE) sector meant the following important things [11]:

AI Integration into RE: The research examines the use of AI in the RE sector, focusing on how AI technologies are being adopted and applied. It investigates how AI can optimize energy production and distribution, improve forecasting, and enhance the efficiency of RE systems.

Macro-Economic Factors: The study considers macroeconomic factors that influence the adoption of AI in the RE sector. This includes analyzing the economic benefits of AI integration, such as increased energy efficiency and reduced costs, as well as the impact on job productivity and investments in the sector.

Smart Energy Infrastructure: The integration of AI into the RE sector is seen as a crucial step toward the development of smart energy infrastructure. This infrastructure can enable more sustainable and economically efficient energy systems, particularly in the context of smart cities.

2.Frameworks of integration

1.4. User Behaviour Models for predicting smart grid demand and supply.

Numerous time-critical applications within the realm of smart cities, including connected vehicles and smartphone functionalities, necessitate instantaneous or nearly instantaneous data analysis. To cater to these needs, there is a demand for innovative analytical frameworks that support both advanced and streaming data analytics [12]. The Figure 2 shows the Behavior-oriented time segmentation (BOTS) that was proposed by [12]. The technique is useful for predict an electronic gadget user behaviour, this can be extended to grid demand and supply based on consumer behaviour.

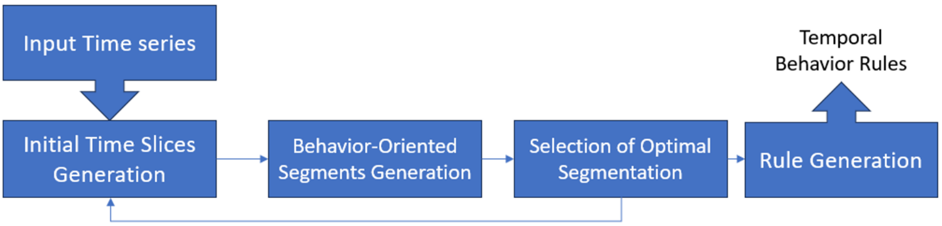

Figure 2. Behavior-oriented time segmentation (BOTS) technique [12].

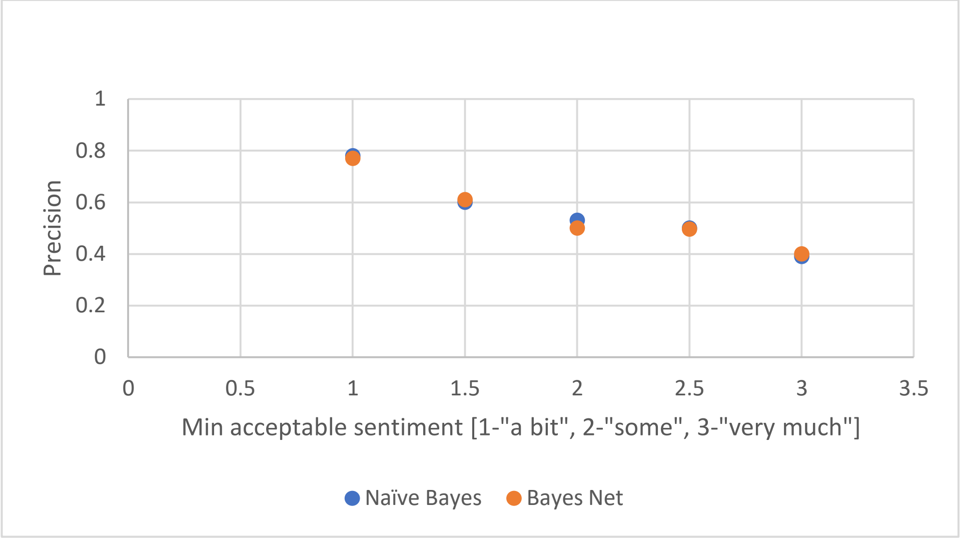

Figure.3. Response and reaction sentiment.

Frameworks that were developed for predicting human behaviour with reference to mobile phone usage and user responses to interruptions from phone notifications. It was proposed that the same can be used for predicting demand and supply in smart grids [13].

1.5. Mixed integer linear programming

Mixed-integer linear programming (MILP) plays a crucial role in optimizing and managing various aspects of smart grids [14]. This paper addresses post-disaster electric grid recovery by developing a versatile microgrid formation model. It extends previous work to accommodate undirected power flows in future high-renewable systems. Key contributions include a flexible model for radial and meshed topologies, integration of mobile and fixed distributed generation, and explicit handling of demand-responsive loads. The objective is to maximize load pickup while considering load criticality. Dispatchable loads enhance resource allocation efficiency, and linearization constraints address nonlinearity. Case studies validate the model's effectiveness, and it's implemented in AMPL and solved with CPLEX 12.6. This adaptable approach shows promise for real-world grid recovery efforts. [14].

MILP is used to solve OPF problems in smart grids. It helps determine the optimal dispatch of generation units, including renewable energy sources, to meet the load demand while considering constraints such as power line limits, voltage levels, and generation costs. MILP-based OPF can maximize grid efficiency and minimize [15]. The mathematical modelling heavily relies on discretization of known laws e.g., KVL.

Gaing in 2005, introduced an efficient mixed-integer particle swarm optimization (MIPSO) approach tailored for solving constrained optimal power flow (OPF) problems involving a combination of continuous and discrete control variables, as well as discontinuous fuel cost functions. The MIPSO method employs a novel representation of individuals, accommodating both continuous and discrete variables, and introduces two mutation schemes to handle these variable types separately. Various objective functions, including those accounting for valve-point loading effects constraints, were tested to assess the method's robustness. The approach's feasibility was demonstrated using 9-bus and 26-bus power systems, and it was compared favorably to other stochastic methods in terms of solution quality, convergence behavior, and computational efficiency. The results highlight the MIPSO-based OPF method's effectiveness and robustness in addressing constrained mixed-integer OPF challenges. [16].

1.6. Stochastic linear programming

Stochastic linear programming research addresses the optimization of power systems with a focus on incorporating renewable energy sources (RESs). The study introduces the Flow Direction Algorithm (FDA) to tackle the complex optimal power flow (OPF) problem, which becomes more intricate when stochastic RESs like solar, wind, and small hydropower generators are integrated. The FDA algorithm strategically divides the search process between global and local searches, leading to more precise OPF solutions. Monte Carlo simulation is employed to handle uncertainties in wind speed and solar irradiation, while small hydropower units are treated as fixed power sources. The algorithm is tested on various IEEE bus systems and outperforms state-of-the-art algorithms. This research contributes by presenting a novel optimization approach for OPF with RESs, addressing uncertainties, prohibited operating zones, and valve point loading effects. [17].

3.Conclusions

In conclusion, this paper underscores the critical role of renewable energy integration in the context of smart cities to address the challenges posed by urbanization and climate change. It emphasizes the need for innovative solutions to ensure sustainable urban development. The paper highlights the intricate relationship between data-driven artificial intelligence (AI) methods and renewable energy solutions within smart cities, emphasizing their potential benefits and challenges. The discussion on smart cities reveals the importance of aligning smart city strategies with concrete sustainability goals to effectively reduce carbon emissions. It also calls for a more comprehensive understanding of smart city initiatives and their impacts. The integration of renewable energy sources into smart cities is crucial for achieving sustainability objectives. The paper discusses the significance of smart grids, energy storage systems, electric vehicles, and smart lighting in this context. It also explores new business models and emphasizes the role of energy infrastructure in smart cities. Furthermore, the paper delves into data-driven AI methods for renewable energy integration, highlighting their ability to optimize energy systems and enhance sustainability. It acknowledges the macroeconomic factors influencing AI adoption in the renewable energy sector. The frameworks discussed include user behavior models for predicting smart grid demand and supply, mixed-integer linear programming (MILP) for optimizing smart grids and solving constrained optimal power flow (OPF) problems, and stochastic linear programming for addressing uncertainties in renewable energy integration.

Overall, this paper provides a comprehensive overview of the intricate relationship between data-driven AI methods and renewable energy solutions in smart cities. It underscores the potential benefits of this synergy in creating more sustainable and efficient urban environments while acknowledging the challenges that must be addressed to realize this vision.

4.Reference

1. UN Report 2018, "68% of the world population projected to live in urban areas by 2050". https://www.un.org/development/desa/en/news/population/2018-revision-of-world-urbanization-prospects.html
2. Bibri, S.E. A novel model for data-driven smart sustainable cities of the future: the institutional transformations required for balancing and advancing the three goals of sustainability. Energy Inform 4, 4 (2021). https://doi.org/10.1186/s42162-021-00138-8
3. Lăzăroiu, G., & Harrison, A. (2021). Internet of things sensing infrastructures and data-driven planning technologies in smart sustainable city governance and management. Geopolitics, History & International Relations, 13(2).
4. Kaluarachchi, Y. (2022). Implementing data-driven smart city applications for future cities. Smart Cities, 5(2), 455-474.
5. Hunter, M.; Guensler, R.; Guin, A.; Saroj, A.; Roy, S. Smart Cities Atlanta—North Avenue. City of Atlanta Research Project (2019). Available online: http://realtime.ce.gatech.edu/RenewAtlanta-GeorgiaTech-Final-Report.pdf (accessed on 16 March 2022).
6. Husár, M.; Ondrejička, V.; Varış, S.C. Smart Cities and the Idea of Smartness in Urban Development—A Critical Review. In IOP Conference Series: Materials Science and Engineering; IOP Publishing Ltd.: Bristol, UK, 2017; Volume 245.
7. Roller, L.H.; Waverman, L. Telecommunication Infrastructure and Economic Development: A Simultaneous Approach. Am. Econ. Rev. 2001, 91, 909–923.
8. Yigitcanlar, T., &Kamruzzaman, M. (2018). Does smart city policy lead to sustainability of cities?. Land use policy, 73, 49-58.
9. Shamsuzzoha, A., Nieminen, J., Piya, S., & Rutledge, K. (2021). Smart city for sustainable environment: A comparison of participatory strategies from Helsinki, Singapore and London. Cities, 114, 103194.
10. Atasoy, T., Akınç, H. E., &Erçin, Ö. (2015, November). An analysis on smart grid applications and grid integration of renewable energy systems in smart cities. In 2015 international conference on renewable energy research and applications (ICRERA) (pp. 547-550). IEEE.
11. Şerban, A. C., & Lytras, M. D. (2020). Artificial intelligence for smart renewable energy sector in europe—smart energy infrastructures for next generation smart cities. IEEE access, 8, 77364-77377.
12. Petrović, N., &Kocić, Đ. (2020). Data-driven framework for energy-efficient smart cities. Serbian Journal of Electrical Engineering, 17(1), 41-63.
13. Khan, M., Silva, B. N., Jung, C., & Han, K. (2017). A context-Aware Smart Home Control System based on ZigBee Sensor Network. KSII Transactions on Internet & Information Systems, 11(2).
14. K. S. A. Sedzro, A. J. Lamadrid and L. F. Zuluaga, "Allocation of Resources Using a Microgrid Formation Approach for Resilient Electric Grids," in IEEE Transactions on Power Systems, vol. 33, no. 3, pp. 2633-2643, May 2018, doi: 10.1109/TPWRS.2017.2746622.
15. Ferreira, R. S., Borges, C. L. T., & Pereira, M. V. (2014). A flexible mixed-integer linear programming approach to the AC optimal power flow in distribution systems. IEEE Transactions on Power Systems, 29(5), 2447-2459.
16. Zwe-lee Gaing, "Constrained optimal power flow by mixed-integer particle swarm optimization," IEEE Power Engineering Society General Meeting, 2005, San Francisco, CA, USA, 2005, pp. 243-250 Vol. 1, doi: 10.1109/PES.2005.1489134.

17. Maheshwari, A., Sood, Y. R., & Jaiswal, S. (2023). Flow direction algorithm-based optimal power flow analysis in the presence of stochastic renewable energy sources. Electric Power Systems Research, 216, 109087..