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Rational management of green electricity injection into an electro-energetic system through tensor analysis: Literature Review

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ABSTRACT: This study explores the efficient integration of solar energy into Antsiranana, Madagascar's grid using tensor analysis and Natural Gradient Descent (NGD) to enhance profitability and sustainability. Results show improved efficiency and cost-effectiveness, highlighting the potential of tensor analysis in renewable energy planning for future grid optimization in Madagascar.

KEYWORDS: Renewable , Solar Energy, Tensor Analysis, Efficiency, NGD

I. INTRODUCTION

The worldwide energy landscape is experiencing a profound shift towards sustainability, with a special emphasis on incorporating renewable energy technologies. A crucial aspect of this transition involves exploring green energy and cutting-edge energy-efficient technologies for diverse uses, such as in wastewater treatment facilities. These technologies not only help meet energy demands but also ensure the efficient utilization of resources present in wastewater. The utilization of renewable energy sources like solar power, wind power, hydropower, biomass, and biofuels show potential in decreasing dependence on traditional energy sources. Furthermore, the use of green energy in construction through energy-efficient designs, low-energy building materials, and renewable energy technologies can significantly improve efforts towards conserving energy. By embracing almost zero-energy passive building designs and integrating solar photovoltaics for electricity production and solar thermal collectors for heating purposes, buildings can lessen their environmental footprint while enhancing operational efficiency. Additionally, bioclimatic architecture and smart technologies play a crucial role in optimizing building performance while reducing energy consumption.

Apart from building applications, the Austin SHINES project serves as an example of how the integration of solar power and energy storage systems can enhance grid functionality at both large-scale utility levels and residential levels. Such initiatives showcase the potential benefits of combining renewable sources with storage solutions to enhance overall system reliability and efficiency. This holistic approach aligns with the increasing focus on decentralized renewable energy systems that can contribute to a more sustainable future. Looking forward, there is a necessity to further explore strategies for grid optimization and advanced technologies like data-driven smart solutions to maximize the advantages of integrating green electricity. By leveraging innovative approaches such as IoT applications and big data analytics, cities can streamline their infrastructure planning processes and ensure more effective use of renewable resources. Through ongoing research and collaboration among stakeholders, grids can be optimized to support the seamless integration of green electricity across various sectors. [1]

II. METHOD AND MATERIAL

Problem Statement : The rise of Variable Renewable Energy Sources (VRES) in the energy sector's transformation presents noteworthy hurdles that must be overcome. As we shift towards a low-carbon energy system, there arises a pressing need for adaptability, increased electrification, the emergence of innovative technologies, efficiency enhancements, decentralization, and greater engagement of various stakeholders. Nevertheless, existing Energy System Models (ESMs) lack the necessary capabilities to adequately tackle these transformations, resulting in divergent conclusions across different studies. For instance, the feasibility of achieving a fully renewable power system by 2050 is subject to debate due to varying cost estimates that range from 12% to 30% higher annual costs compared to non-renewable systems. Many analyses overlook crucial factors like electricity grid expenses, optimal renewable site locations, technological specifics, and flexible electricity demand. Moreover, traditional ESMs often omit considerations for the heat and transportation sectors in studies focused on high proportions of renewables in the power sector. The transition from a centralized fossil fuel-based system to a decentralized one powered by renewable sources offers both opportunities and challenges. Decentralization has the potential to lower transmission costs and risks while promoting energy security and sustainability through localized energy supply. However, it may also lead to increased generation expenditures, capacity investments, and distribution complexities. Standard energy modeling tools tailored for centralized systems struggle to account for location-specific variables critical for renewables like economic potentials, solar resources, environmental impacts, network limitations, and storage alternatives. Detailed spatial analysis is vital for understanding how these factors shape the energy landscape. Additionally, incorporating social dimensions into ESMs is essential for a sustainable transition towards a low-carbon energy system. Traditional models often fail to consider the roles and preferences of social stakeholders in decision-making processes. Integrating social sciences into technical models can offer insights into individual choices and behaviors that significantly influence the balance between energy supply and demand. Involving prosumers – consumers who actively generate and distribute renewable energy - in modeling efforts underscores the evolving dynamics of decentralized energy systems where consumers actively participate in production activities. [2]

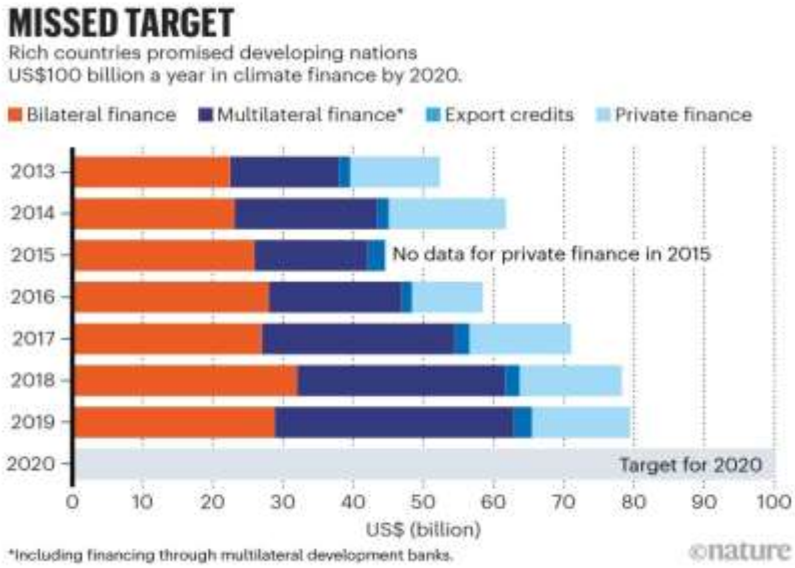

Fig.1 Nature (2021), The broken $100-billion promise of climate finance - and how to fix it [3]

III. OBJECTIVES

The main goals of this research on rational green electricity management are to assess the existing status of renewable energy integration, examine the utilization of tensor analysis in energy systems, and explore the efficacy of Natural Gradient Descent (NGD) in optimizing green electricity integration. Through the assessment of grid modeling methods, solar integration approaches, and strategies for minimizing delays, this study seeks to offer valuable insights into enhancing efficiency and decreasing delays in the integration of green electricity. The primary objective is to pinpoint opportunities for improving the rational management of green electricity integration to bolster sustainable energy transitions worldwide. [4]

IV. LITERATURE REVIEW

Renewable Energy Integration: The global energy transformation heavily relies on the seamless integration of renewable energy sources, which has seen significant advancements in recent years. The proportion of renewable energy in total final energy consumption has been steadily rising, reaching close to 19% in 2015. When it comes to power generation, renewables have accounted for over half of all global capacity additions since 2012. Solar photovoltaic (PV) capacity has experienced remarkable growth, outpacing other forms of electricity generation. The cost of solar PV electricity has dramatically dropped by 73% between 2010 and 2017, while onshore wind costs have decreased by 23%. Projections indicate that by 2020, all current renewable technologies will be cost-competitive with fossil fuels in many regions.The expansion of renewable energy is crucial for achieving a two-thirds share of renewable energy in global final energy demand by 2050. However, there is a pressing need to significantly accelerate the growth rate of renewable energy to meet this objective. Key technologies such as wind, solar PV, modern biomass, and others will play a vital role in this transition. Accelerated deployment strategies include regional electrification, promotion of renewable energy initiatives, development of comprehensive projects, and leveraging public-private partnerships (PPPs) for financial support. Furthermore, the integration of renewable energy contributes to enhanced efficiency levels. Renewable sources like hydro, solar PV, and wind power operate at significantly higher efficiencies compared to fossil fuel power generation. In addition, technologies such as solar heating systems and biofuel-fired boilers provide net efficiency gains when compared to traditional fossil fuel alternatives. The electrification through renewable power further boosts efficiency gains across various sectors. [5]

Table 1: Comparison of IEA, IRENA and Shell scenarios for global energy transition, 2050. [5]

Empty Cell	IRENA	IEA	Shell	
REmap	**2°/66%**	**Sky**		
Total primary energy supply	[EJ/yr]	550	586	828
Total final consumption	[EJ/yr]	388	398	548
Renewable energy share in total primary energy supply	[%]	63	46	43
Fossil fuel CO_2 emissions in 2050				
Baseline*	[Gt/yr]	37	37	
Emissions 2050	[Gt/yr]	9.7	9	18
Contribution of abatement options				
Renewable energy	[%]	41	37	
Energy efficiency (including electrification)	[%]	53	35	
Others	[%]	6	29	
Investments for decarbonisation 2015-50 (excl. stranded assets)	[USD trln]	120	114	
Energy intensity improvements	[%/yr]	2.8	2.9	2
Electric mobility in transport	[%]	31	n/a	21
Total biomass demand	[EJ/yr]	128	147	55

Key renewable energy technologies	Units	Recent growth	Future growth requirement	Growth acceleration factor	Contribution to renewables share growth in total final consumption 2015–2050 (ppt/yr)*
2017(e)	**2018–50**				
Wind	GW/yr	53	154	3	0.33
Solar PV	GW/yr	99	210	2	0.21
Modern biomass (end-use)					0.19
Liquid biofuels and biogas	billion liters/yr	5	24	5	0.12
Solar thermal	million m^2	30	283	9	0.10
Hydro	GW/yr	25	17	0.7	0.05
Hydrogen					0.05
Geothermal heat	PJ/yr	26	173	7	0.04
CSP	GW/yr	1	20	20	0.04

Natural Gradient Descent (NGD) : The Natural Gradient Descent (NGD) technique has emerged as a prominent optimization method in energy systems modeling, especially in the realm of integrating renewable energy. This approach provides a highly efficient and effective way to optimize intricate systems by considering the innate structure of the parameter space. By leveraging information on the curvature of the optimization landscape, NGD can swiftly navigate towards optimal solutions compared to traditional gradient descent methods. A notable advantage of NGD lies in its capability to capture the underlying structure of energy systems, resulting in a more precise depiction of interactions between diverse components. This becomes crucial in the context of renewable energy integration, where achieving a delicate balance among solar, wind, and other renewable sources is paramount for optimal system performance. Through the utilization of tensor analysis techniques alongside NGD, researchers can uncover valuable insights into how different elements interact within an energy system and impact one another. Furthermore, NGD proves to be particularly valuable in grid modeling for the integration of green electricity. Through the application of NGD algorithms to grid optimization challenges, researchers can reduce delays in electricity transmission and distribution, ultimately leading to enhanced efficiency and reliability within energy systems. This becomes essential in maximizing the potential of renewable energy sources and diminishing dependence on fossil fuels. [6]

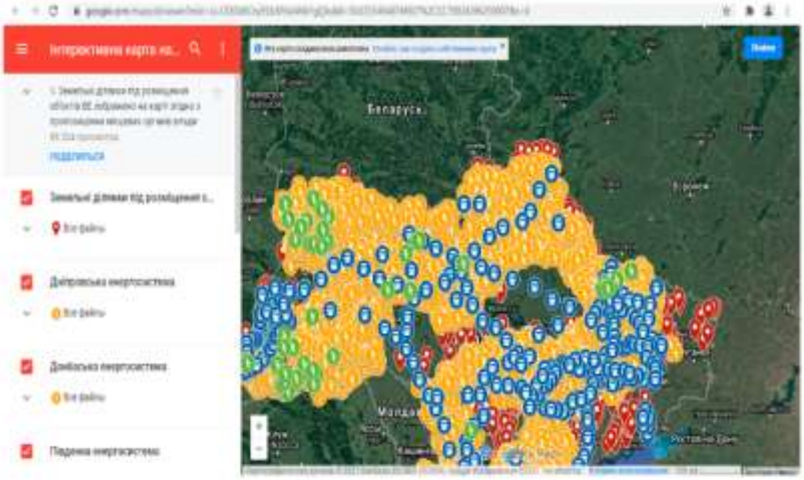

Fig.2 : Interactive investment resource map of Ukraine 'UA MAP' (reproduction of graphic material from). [7]

V. METHODOLOGY

Grid Modeling : The process of grid modeling is fundamental in the rational management of integrating green electricity. To accurately model the grid, it is imperative to gather data on individual facilities, spatial information on regions, and crucial resource parameters. Geographic Information Systems (GIS) serve as valuable tools for this task, enabling the creation of maps and the evaluation of potential renewable energy sources across different regions. Both global and local GIS data play a key role in analyzing the feasibility of utilizing various alternative renewable energy sources in different areas. By combining statistical data from diverse sources, GIS-based statistics can supplement consumer demand data and fill any existing data gaps. The methodology of grid modeling is based on a systematic approach and thorough analysis, involving the identification of the primary objective, establishment of evaluation criteria, selection of methods to achieve goals, and ensuring efficiency and optimization. Simulation techniques are essential in grid modeling for determining the technical potential of renewable energy sources and assessing integration strategies. By utilizing software for conducting global and local GIS studies, visualization tools can offer valuable insights into effective strategies for solar integration. Simulation can also be used to explore techniques to minimize delays and enhance overall grid performance. [7]

Fig.3: Heat Generation Technologies in Ukraine: Traditional, Non-Traditional, and Renewable Sources (UA MAP) [7]

Table 2: The reviewed models and their corresponding developers. [8]

Model	Developer / Source	Model	Developer / Source
DynEMo	UCL / [sub-ref-18,sub-ref-19]	*METIS*	Artelys / [sub-ref-20]
E4Cast	ABARE / [sub-ref-21]	*NEMS*	EIA / [sub-ref-22]
EnergyPLAN	Aalborg University / [sub-ref-23]	*OPERA*	ECN / [sub-ref-24]
ENSYSI	PBL / [sub-ref-25]	*OSeMOSYS*	KTH, UCL / [sub-ref-26]
ESME	ETI / [sub-ref-27]	*POLES*	Enerdata / [sub-ref-28]
ETM	Quintel Intelligence / [sub-ref-29]	*PRIMES*	NTUA / [sub-ref-30]
IKARUS	Research Center Jülich / [sub-ref-31,sub-ref-32]	*REMix*	DLR / [sub-ref-33]
IWES	Imperial College London / [sub-ref-34]	*SimREN*	ISUSI / [sub-ref-35]
LEAP	Stockholm Environmental Institute / [sub-ref-36]	*STREAM*	Ea Energy Analyses / [sub-ref-37]
MARKAL, MARKAL-MACRO, TIMES	IEA / [sub-ref-38,sub-ref-39]		

Solar Integration Strategies : Solar photovoltaic (PV) systems play a critical role in incorporating green electricity into the grid. These systems harness sunlight to generate electricity, offering a sustainable and eco-friendly energy source. When devising solar integration strategies, it is vital to acknowledge the obstacles and remedies linked with PV system deployment. An essential challenge in integrating solar energy into the grid is its intermittent nature. The production of solar power relies on the availability of sunlight, which fluctuates throughout the day and across seasons. These variations can result in power output fluctuations, posing difficulties in maintaining grid stability. To tackle this issue, advanced forecasting methods can be utilized to accurately predict solar generation patterns. By leveraging real-time data feeds and sophisticated algorithms, grid operators can forecast fluctuations and adjust power flow accordingly. Another hurdle is the misalignment between peak solar generation and peak demand periods. Solar power production typically peaks during daylight hours when demand may be lower, resulting in excess generation that cannot be efficiently utilized. One solution to this challenge is to incorporate energy storage systems alongside PV installations. Energy storage technologies like batteries can store surplus solar energy during high generation periods and release it during high-demand periods, facilitating better alignment between supply and demand. Moreover, grid modeling plays a pivotal role in optimizing solar energy integration. By simulating various scenarios and evaluating the impact of different levels of solar penetration on grid stability, operators can pinpoint potential bottlenecks and proactively implement mitigation strategies. Additionally, natural gradient descent (NGD) algorithms can be employed to enhance grid operations and minimize delays associated with variable renewable energy sources such as solar. [9]

Table 3: Energy goals of SRS [10]

1. Fossil fuel free by 2030
2. Large–scale net–zero houses and locally produced solar energy—electricity by renewables.
3. Passive houses towards plus houses.
4. Minimization of comfort cooling/use of passive cooling technology.
5. Energy quality hierarchy (using high energy quality only when needed).
6. Low level of energy use concerning products and systems.
7. Bio–fueled CHP system, including recovery of waste/heat.
8. Measured energy usage in all households/buildings.
9. Smart grids for electricity (and heat)

Delay Minimization Techniques : Techniques for minimizing delays in the integration of green electricity play a pivotal role in optimizing energy systems for efficient operation. It is crucial to identify the root causes of delays to address bottlenecks and enhance overall performance. One major factor leading to delays in green electricity integration is the absence of sectoral coupling technologies linking the electricity, heat, and transportation sectors. This absence impedes the smooth transition towards a decarbonized energy system and restricts the effective utilization of renewable energy sources. To tackle this issue, the implementation of Natural Gradient Descent (NGD) can serve as a viable solution for reducing delays. NGD is a robust optimization algorithm that can be employed in energy systems to minimize delays and improve efficiency. By utilizing NGD, energy models can be optimized with hourly temporal resolution, regional spatial resolution, and sectoral coupling technologies, fostering better coordination among different sectors and facilitating the seamless integration of green electricity into the grid. Moreover, NGD can aid in the adoption of new seasonal storage technology options like Thermal Energy Storage (TES) and Hydrogen Energy Storage (HES) to overcome delays caused by intermittent renewables. The adaptability and learning capabilities of the algorithm make it well-suited for addressing the challenges associated with integrating renewable energy sources. [8]

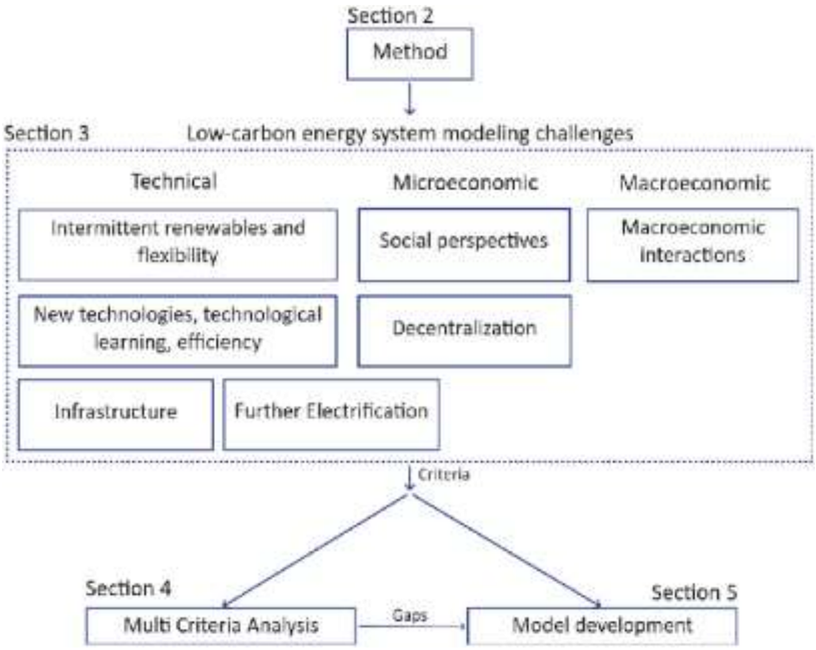

Fig.4 : Proposed modeling suite approach. [8]

VI. RESULTS AND DISCUSSION

Efficiency improvement is key when it comes to integrating green electricity, as it optimizes the use of renewable energy sources. The rapid advancement of renewable energy technologies, especially solar PV and wind power, has led to a substantial increase in global renewable energy capacity. The cost-effectiveness of renewables has significantly improved over the years, with solar photovoltaics experiencing an impressive 73% cost reduction from 2010 to 2017. This reduction in costs has made renewables more accessible and economically viable compared to traditional fossil fuels. One important factor contributing to efficiency improvement is replacing fossil fuel power generation with renewables that have higher efficiency rates. Hydro, solar PV, and wind power can generate electricity with 100% efficiency, leading to overall enhancements in energy intensity. Additionally, technologies like solar heating systems and biofuel-fired boilers offer higher efficiency levels compared to their fossil fuel counterparts. Electrifying with renewable power further amplifies energy efficiency gains, emphasizing the importance of utilizing renewable sources for electricity generation. When comparing these advancements with traditional methods, it becomes clear how crucial it is to transition towards green electricity integration for improved efficiency. By shifting towards renewables, not only does it reduce environmental impact but also enhances overall system performance by utilizing more efficient energy sources. As renewables become more cost-competitive and technologically advanced, they provide a feasible solution for achieving sustainability goals while maximizing efficiency in energy systems. The integration of green electricity not only brings environmental benefits but also offers economic advantages. Transitioning towards renewables could potentially boost global GDP by approximately 1% in 2050 compared to conventional methods. Furthermore, job creation in the renewable energy sector surpasses job losses in the fossil fuel industry, demonstrating the potential for sustainable growth through green electricity integration. [5]

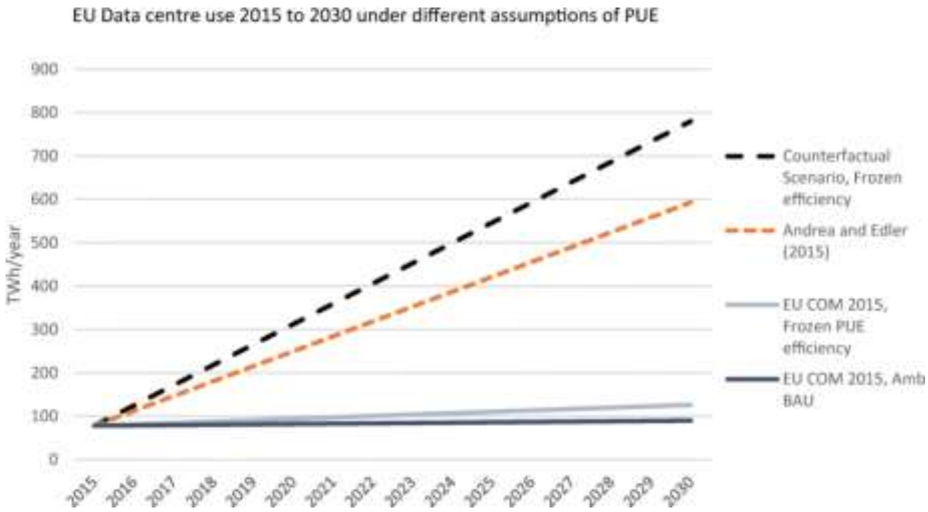

Fig.5: Projected Workload Growth and Efficiency Scenarios (2030) [11]

Table 4: Potential for demand response for the EU Scenario of 90 TWh data centre energy use in 2030 [11]

Demand response (GW)[a]	2030
Theoretical upper limit based on Koronen (2018)[b]	8 to 18 GW
Current practical potential based on Ghatikar et al. (2012)[c]	2.5 to 3.5 GW

VII. CONCLUSION

The utilization of renewable energy sources, especially solar photovoltaic (PV) power, is a pivotal component in the worldwide energy transformation towards sustainability. The rapid embrace of renewables, alongside extensive electrification and heightened energy efficiency initiatives, holds the potential to reduce energy-related carbon dioxide (CO2) emissions by more than 90% by 2050. This transition is essential to align with the objectives set forth in the Paris climate agreement and mitigate global temperature increases to below 2 degrees Celsius. In the domain of solar PV implementation, significant obstacles and solutions have been identified to streamline integration into existing grids. From solar carports to floating solar arrays, innovative approaches are being devised to maximize land utilization efficiency and bolster system resilience against harsh weather conditions. Furthermore, leveraging big data in energy systems planning enables agile decision-making processes that respond promptly to real-time data inputs stemming from urbanization dynamics. The concept of the eco-city underscores the significance of green energy technologies and their fusion with data-driven intelligent solutions for sustainable urban progress. By emphasizing renewable resources such as sunlight, wind, and water, alongside effective energy management systems and sustainable waste practices, cities can substantially diminish energy consumption levels and environmental contamination. Moreover, embracing passive solar design principles and cutting-edge technologies can optimize energy requirements while efficiently harnessing renewable resources. Looking towards the future, uncertainties persist regarding the prospective trajectory of the solar industry in China. As challenges related to subsidy eliminations and grid integration endure, policymakers are confronted with the formidable challenge of ensuring the seamless integration of renewable power into established systems. Nonetheless, continuous innovation in policy frameworks and technological breakthroughs will be pivotal in propelling the shift towards a low-carbon energy framework. [12]

Moving forward with the strategic management of integrating green electricity, there are numerous critical areas that necessitate further investigation and suggestions. One crucial aspect to keep in mind is the necessity to double the investment in renewable energy and energy efficiency in the Asia-Pacific region by 2025. This will demand a united effort to boost the utilization of renewable electricity and energy efficiency across different sectors, including the establishment of sustainable energy projects within communities. Additionally, there is a requirement to assist member States in formulating regional grid master plans to facilitate the integration of additional renewable energy sources. Moreover, it is imperative to explore innovative financial mechanisms to overcome monetary constraints and encourage investments in solar PV technologies. Business models based on community sharing and third-party ownership have shown potential in advancing the development and adoption of solar PV solutions for residential markets, providing advantages such as reducing initial costs, enhancing electricity price stability, and enabling lower-income consumers to utilize solar energy systems.Additionally, future research should concentrate on incorporating green energy and cutting-edge energy-efficient technologies in wastewater treatment facilities. By utilizing green energy sources and biomass resources, wastewater treatment plants can improve their energy efficiency while exploring opportunities for resource retrieval. The integration of Internet of Things (IoT) technologies and eco-friendly chemistry solutions can further boost the sustainability of water and energy systems. [4]

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