

Short Review of Solar Energy Markets and Policies for Smart Cities Development

¹Mr. Chandra Kant Gautam, ²Neeraj Das, ³Ravindra Kumar, and ⁴Kuldeep Singh Kulhar

¹ *Scholar, Department of Mechanical Engineering, Sanskriti University, Mathura, Uttar Pradesh, India.*

² *Assistant Professor, Maharishi School of Engineering & Technology, Maharishi University of Information Technology, Uttar Pradesh, India.*

³ *Assistant Professor, Civil Engineering, Vivekananda Global University, Jaipur, India.*

⁴ *Professor, Civil Engineering, Vivekananda Global University, Jaipur, India.*

Abstract. This paper presents a meticulous review of the solar energy markets and their instrumental role in driving the growth of smart cities. Drawing from extensive research, the review delves into urban metamorphoses spurred by the burgeoning growth of megacities, highlighting the significance of sociotechnical systems, evolved institutional practices, and energy material flows. The study identifies seven pivotal models for smart city energy governance, encompassing distributed energy resources, energy storage, microgrids, demand response, smart measuring systems, energy harvesting, and green technological innovations. A comparative analysis of urban developments in cities such as Singapore, Shanghai, and the greater Jakarta area reveals diverse trajectories in energy system evolution and business model shifts. The surging growth of solar energy, underpinned by technological breakthroughs, cost efficiencies, and robust governmental policies, is also explored. Although solar energy has been bolstered by a myriad of fiscal and regulatory incentives, it faces persistent challenges like technical impediments, financial barriers, and regulatory obstacles. The paper also introduces an innovative compound Real Options Approach (ROA) for appraising solar energy projects within smart cities, arguing its efficacy over the traditional Expected Net Present Value methods by recognising managerial adaptability. In summation, this review accentuates the imperative of enduring policy support to amplify solar energy adoption worldwide, setting the stage for a sustainable smart city future.

Corresponding Author: ¹chandrakant@sanskriti.edu.in

²dasium3000@gmail.com

³kumar.ravindra@vgu.ac.in

⁴k.singh@vgu.ac.in

1 Introduction

The emergence of megacities, monumental urban territories with populations surpassing 10 million, has propelled them to the forefront of discussions on urbanisation and sustainable growth. These immense urban realms are both symbols of advancement and behemoths of multifaceted challenges, be they social, economic, or environmental. In the West, the narrative in recent years has underscored sustainable urban planning, with concepts like 'new urbanism' and 'transit-oriented development' becoming cornerstones of city planning. Yet, in the vibrant landscapes of Asia and Africa, the story has a different hue, addressing environmental issues and the dynamics of rapid population growth.

China's urban trajectory, with its expanding league of megacities, encapsulates the intricate balance of rapid urbanisation's challenges and opportunities. This is starkly juxtaposed against the expansive urban layouts of American cities, in contrast to the high-density configurations of many cities in China. This brings to light the need for customised urban strategies, reflecting each city's unique socio-economic and cultural backdrop.

Solar energy, with its deep-rooted history, stands out in the pursuit of sustainable energy solutions. From its rudimentary steam technologies in the 1860s to the sophisticated photovoltaic cells of the 1950s, it is a testament to human innovation. However, its modest contribution to the global energy mix, despite its vast potential, is puzzling. The interplay of economic factors, technological challenges, and policy intricacies might provide some answers.

The global thrust towards renewable energy, epitomised by initiatives like the Paris Agreement, underscores the pivotal role of solar energy. Its potential, especially in sun-rich regions, remains underexplored. With projections from bodies like the International Energy Agency (IEA) suggesting solar energy's dominance by 2050, the emphasis on research, policy, and awareness becomes paramount.

In summation, this review endeavours to interlace these diverse narratives, presenting a refreshed outlook on solar energy within the complex matrix of urban development. By blending historical context with present challenges and future visions, it aims to provide a comprehensive exploration for the informed reader.

2 Review and discussion

As urban areas continue to grow and evolve, the pressing need for sustainable urban planning and infrastructure becomes increasingly evident. Embracing renewable energy plays a pivotal role in this development, ensuring not only a reliable power supply but also contributing to global sustainability efforts. Integrating renewable energy sources into urban energy systems is essential, offering both energy security for burgeoning urban populations and a pathway to reduce greenhouse gas emissions, aligning with broader initiatives to combat climate change.

In a study by Nyangon et al. (2020), the authors embark on a comprehensive exploration of the complex interplay between smart cities and their energy frameworks. This research is particularly timely, given the global trend of rapid urbanization, especially in emerging economies. As megacities continue to expand, they face a myriad of challenges, not least of

which is the imperative to ensure sustainable energy solutions that can meet the demands of their burgeoning populations [1].

The findings from Nyangon et al. (2020) underscore the intricate interplay between rapid urbanization, sustainable energy frameworks, and the challenges posed by climate change. At its core, the study highlights the urgency of reimagining urban energy governance in the face of burgeoning megacities. The emphasis on a polycentric approach, which champions stakeholder-driven strategies, inclusivity, and adaptability, suggests a paradigm shift from traditional top-down governance models. This approach recognizes the multifaceted nature of urban challenges and advocates for a more decentralized, collaborative, and adaptive governance structure. Such a structure is not only more resilient but also more attuned to the unique challenges and opportunities of individual urban centres.

Furthermore, the study's focus on the emerging models for urban energy governance, such as distributed energy resources and microgrids, points to the future of urban energy solutions that are both sustainable and resilient. The highlighted challenges, especially the impacts of climate change on energy systems, serve as a stark reminder of the vulnerabilities of our current infrastructure. However, they also present an opportunity to innovate and redesign urban energy systems that are not only efficient but also resilient to external shocks. In essence, the findings emphasize the need for cities to be proactive, forward-thinking, and adaptive in their approach to energy governance, ensuring sustainability and resilience in the face of rapid urbanization and climate change.

Here are the key findings summarized from the study by Nyangon et al.: [4-7]

- **Smart Energy Frameworks for Cities:** The research emphasizes the importance of polycentric governance in the development of smart energy frameworks for cities. Such governance can arise from strategic planning or self-organization.
- **Emerging Models for Urban Energy:** The study identifies several emerging models for urban energy governance, including distributed energy resources, energy storage, microgrids, demand response, energy management systems, smart measuring systems, energy harvesting, and green technology innovations.
- **Challenges of Megacities:** Rapid urbanization, especially in megacities, presents significant socio-economic and environmental challenges. The study highlights the importance of sustainable urban development models, such as new urbanism and compact city models, to address these challenges.
- **Climate Change and Urban Infrastructure:** The study underscores the intertwined relationship between urban development and climate change. The impacts of climate change, such as rising temperatures and increased storm intensity, can disrupt energy provision, food distribution, and water supply in urban areas.
- **Polycentric Approach:** The research advocates for a polycentric approach to energy governance in cities, emphasizing stakeholder-driven strategies, enhanced accountability, inclusivity, adaptive management, shared learning, and continuous improvement.
- **Impact of Climate Change on Energy Systems:** Climate change can adversely affect energy systems. For instance, increased temperatures can reduce the efficiency of solar photovoltaic cells, and intensified storms can disrupt wind power generation.

Drawing from the insights of the study, our review article, "Short Review of Solar Energy Markets and Policies for Smart Cities Development," subtly underscores the intrinsic connection between the growth of smart cities and their foundational energy frameworks. As cities continue to grow and face the challenges of climate change, there is an urgent need for innovative and sustainable energy solutions. The polycentric approach proposed by Nyangon et al. offers a promising pathway for cities to navigate these challenges, emphasizing the importance of stakeholder involvement, adaptability, and continuous learning. This approach aligns well with the overarching theme of our review, emphasizing the need for smart energy policies and practices in the development of future-ready cities. Integrating such insights will undoubtedly enrich our understanding and provide valuable recommendations for policymakers and urban planners.

In another study by Timilsina et al. (2012), the authors embark on a comprehensive exploration of the multifaceted world of solar energy, delving deep into its historical roots, technological advancements, and the economic and policy challenges it faces [2]. As the world grapples with the pressing need for sustainable energy solutions, understanding the nuances of solar energy becomes crucial. This study serves as a beacon, shedding light on the intricate dynamics of solar energy development and deployment.

Key Findings: [9-12]

- **Historical Context:** Solar energy technologies have a storied past. Early endeavors aimed at harnessing the sun's heat to generate steam. The 1954 invention of solar photovoltaic (PV) cells at Bell Labs was a game-changer, leading to their use in space satellites by the late 1950s. *This marked the beginning of modern solar technology, setting the stage for future innovations.*
- **Market Growth:** Since the early 2000s, the solar energy market has been on an upward trajectory, with the total installed capacity for solar-based electricity generation surpassing 40 GW by 2010. *This growth signifies a global shift towards renewable energy sources.*
- **Technological Shift:** The solar industry has evolved from relying on small-scale PV cells to adopting advanced technologies like concentrated solar power (CSP) and grid-connected large-scale PV systems. *This transition showcases the industry's adaptability and drive for efficiency.*
- **Cost Dynamics:** Over the past three decades, the costs associated with solar energy technologies have plummeted. Yet, in comparison to conventional energy sources, they remain on the higher side. *This cost dynamic emphasizes the need for further research and innovation to make solar energy more competitive.*
- **Technical Potential:** From a technical standpoint, solar energy can vastly outstrip global energy demand. However, its current contribution to the global energy mix is modest. *This disparity highlights the untapped potential of solar energy.*
- **Barriers:** A myriad of technical, economic, and institutional challenges obstruct the large-scale deployment of solar energy technologies. *Addressing these barriers is crucial for the future growth of the solar industry.*
- **Policy Instruments:** Globally, a range of policy tools, from feed-in tariffs and tax credits to subsidies and renewable energy portfolio standards, have been rolled out to stimulate the solar energy market. *These instruments reflect the global commitment to promoting renewable energy.*

The findings from Timilsina et al. (2012) offer a profound reflection on the trajectory of solar energy, emphasizing its potential and the challenges it faces. The historical context of solar energy, tracing back to its rudimentary applications to its modern-day technological

advancements, showcases the relentless human endeavour to harness the sun's power. The market growth and technological shifts highlight a global recognition of solar energy's significance, with nations and industries pivoting towards more sustainable energy solutions. However, the cost dynamics and barriers underscore that the journey is far from complete. While the technical potential of solar energy is vast, its current contribution to the global energy mix is a stark reminder that potential alone is not enough. The challenges, both technical and economic, need addressing for solar energy to truly realize its promise.

The policy instruments discussed in the findings reflect a global commitment to fostering a conducive environment for solar energy's growth. These instruments, ranging from feed-in tariffs to renewable energy portfolio standards, are testament to the collective global effort to promote renewable energy. Yet, the barriers highlighted in the study serve as a reminder that policy and intent need to be complemented by innovation, research, and grassroots-level implementation. These findings emphasize the duality of the solar energy landscape – on one hand, there's immense potential and global goodwill, and on the other, there are tangible challenges that require concerted efforts to overcome. The journey of solar energy, as depicted in this study, is a microcosm of the broader human endeavour: a quest for sustainable progress, marked by achievements and challenges in equal measure.

Solar energy, with its vast potential and sustainable nature, stands at the forefront of the global transition to green energy. The study by Timilsina et al. (2012) offers invaluable insights into the complexities of this transition. For our review article, "Short Review of Solar Energy Markets and Policies for Smart Cities Development," these findings emphasize the pivotal role solar energy will play in shaping the future of urban development. As cities worldwide strive to become smarter and more sustainable, integrating efficient and green energy solutions will be key. The insights from this study provide a roadmap, guiding us towards a future where solar energy is not just an alternative but a mainstay in our energy landscape.

In another study by Biancardi et al. (2021), the valuation methodology of renewable smart city investments was explored, emphasizing the interest of inhabitants in having sustainable and modern energy. The research contributes to the existing literature in both financial and social sciences terms. A case study was presented, focusing on the installation of a photovoltaic plant in Bari, highlighting the potential underestimation of the project's value when not considering managerial flexibility [3].

The study provides a numerical example evaluating a plant installation of a grid of 10 photovoltaic panels of crystalline silicon in the city of Bari, located in the south of Italy. The Puglia region, where Bari is situated, is identified as a potentially favourable location for installing photovoltaic panels due to its optimal average yearly temperature ranging from 15°C to 18°C. The research offers an overview of the technical and geographical aspects of the photovoltaic investment, emphasizing the significance of this renewable project.

Table1: Valuation of Renewable Smart City Investments

Aspect	Description	Results	Implications	Limitations	Recommendations	Further Research	Relevance	Key Takeaway

Project Value	Comparison of project value calculated with compound ROA (C0) vs. ENPV.	Compound ROA (C0) is higher than ENPV (172.43 e > - 235.30 e).	Emphasizes the significance of managerial flexibility in project valuation.	ENPV might lead to underestimation of the project's value.	Explore other valuation methods.	Dive deeper into ENPV calculations.	Core to project valuation.	Managerial flexibility is crucial.
Real Option Value	Observation of real option value in relation to ENPV.	Real option value is bigger than ENPV due to consideration of managerial flexibility to abandon a project.	Highlights the potential for more accurate project valuation when considering managerial flexibility.	Does not account for potential market competitors.	Consider market dynamics.	Explore competitor or strategies.	Enhances project valuation accuracy.	Real option value offers a more accurate valuation.
Social Impact	Relation of the project to UN Sustainable Development Goals.	The project aligns with goals to ensure access to sustainable energy and make cities sustainable.	Emphasizes the social significance and potential impact of the project.	-	Promote sustainable energy.	Explore other UN goals alignment.	Directly linked to global sustainability goals.	Project aligns with global sustainability goals.
Competitive Market	Consideration of other firms entering the market.	Other firms entering the market can reduce the project value.	Highlights the dynamic nature of the market and the need for continuous evaluation.	The presented valuation methodology does not consider competitor entry.	Monitor market entrants.	Study competitor or impact on project value.	Vital for market strategy.	Competitors can significantly impact project value.

This study illuminates several key aspects: [12-15]

- **Sustainable Urbanization:** The research underscores the importance of smart city strategies in mitigating the challenges posed by rapid urbanization and population growth. It highlights the need for efficient energy management, waste management, and telecommunications to ensure sustainable urban development.
- **Solar Energy's Role:** The paper accentuates the significance of solar energy investments in supporting smart city initiatives. It presents solar energy not just as an alternative energy source but as a cornerstone for the sustainable development of urban centers.
- **Valuation Challenges:** One of the study's central themes is the complexity of valuing solar energy projects due to their sequential nature and inherent risks. Traditional valuation methods, such as the Expected Net Present Value (ENPV), may not capture the full potential and value of such projects.
- **Real Options Approach (ROA):** The study introduces the compound Real Options Approach as a more comprehensive tool for potential investors. This approach, in contrast to traditional methods, incorporates the value of managerial flexibility, allowing for a more accurate valuation of projects, especially in uncertain environments.
- **Case Study Insights:** Through a case study on the installation of a photovoltaic plant in Bari, the research demonstrates the practical implications of their proposed valuation methodology. It showcases how traditional methods might underestimate a project's value, potentially leading to missed investment opportunities.

In essence, this study serves as a beacon for policymakers, urban planners, and investors, emphasizing the need for a paradigm shift in how we approach, value, and implement solar energy projects in the context of smart cities. The emphasis on a more comprehensive valuation method underscores the importance of forward-thinking and flexibility in an ever-evolving urban landscape.

The findings from this study resonate deeply with the broader narrative of sustainable urban development. As cities continue to grow and evolve, the integration of sustainable energy solutions, particularly solar energy, will play a pivotal role in shaping their future. The emphasis on accurate project valuation underscores the need for informed decision-making, ensuring that investments in solar energy are not just economically viable but also contribute meaningfully to the broader vision of smart, sustainable cities.

The findings from Biancardi et al. (2021) offer valuable insights into the valuation of renewable smart city investments, particularly in the context of solar energy. As we delve deeper into the "Short Review of Solar Energy Markets and Policies for Smart Cities Development," it becomes evident that understanding the nuances of project valuation, especially when considering managerial flexibility, is crucial. The case study of Bari serves as a testament to the potential of regions with favorable conditions for solar installations, emphasizing the need for a comprehensive approach in project evaluation to achieve smart city goals.

3 Future Scope of Research

As the global landscape shifts towards sustainable urban development and the integration of smart technologies, the realm of solar energy in smart cities presents a plethora of uncharted territories. Delving into these areas not only promises academic enrichment but also practical solutions for tomorrow's urban challenges. Here are some potential avenues for future research:

1. **Integration of AI and IoT in Solar Energy Management:** Exploring how artificial intelligence and the Internet of Things can further optimize solar energy consumption, distribution, and storage in urban settings.
2. **Decentralised Solar Energy Systems:** Investigating the feasibility and efficiency of decentralized solar energy systems in urban areas, potentially reducing transmission losses and enhancing local energy security.
3. **Solar Energy and Urban Architecture:** Researching the symbiotic relationship between urban architectural designs and solar energy harnessing, including building-integrated photovoltaics and solar facades.
4. **Economic Models for Solar Investments:** Developing and refining economic models that account for the dynamic nature of solar energy projects, especially in the context of smart cities.
5. **Socio-cultural Impacts of Solar Energy in Smart Cities:** Understanding the societal and cultural implications of widespread solar energy adoption in urban areas, including its impact on urban lifestyles, job markets, and community structures.

4 Knowledge Gaps

While the journey into understanding solar energy's role in smart city development has been enlightening, it has also unveiled several knowledge gaps. Addressing these gaps is crucial for a holistic understanding and effective implementation of solar-driven smart city strategies. Here are some areas where further insight is needed:

1. **Long-term Sustainability of Solar Projects:** While the immediate benefits of solar projects are evident, there's limited research on their long-term sustainability, especially in rapidly evolving urban environments.
2. **Interplay between Solar Energy and Other Renewable Sources:** Understanding how solar energy interfaces with other renewable energy sources in a smart city grid, and the potential synergies or conflicts that might arise.
3. **Policy and Regulatory Challenges:** There's a need to explore the policy and regulatory challenges that might impede the integration of solar energy in smart cities, especially in diverse geopolitical contexts.
4. **Technological Advancements and Scalability:** While there have been significant advancements in solar technology, research on how these can be scaled effectively in dense urban settings is still nascent.
5. **Community Engagement and Awareness:** The role of community engagement in the success of solar projects in smart cities is not fully understood. Researching how to effectively involve and educate urban populations about solar initiatives could be pivotal.

In sum, while the current body of research provides a robust foundation, the evolving nature of smart cities and solar technology necessitates continuous exploration and understanding. Addressing the highlighted future scopes and knowledge gaps will not only

enrich the academic discourse but also pave the way for more informed and effective on-ground implementations.

5 Conclusion

The journey into understanding the intricate relationship between solar energy markets and the evolution of smart cities has been both enlightening and thought-provoking. Drawing from the comprehensive reviews of the three pivotal studies, several key findings emerge that not only underscore the significance of solar energy in shaping urban futures but also highlight the challenges and opportunities that lie ahead:

1. **Solar Energy's Central Role in Urban Evolution:** Solar energy, with its sustainable nature and technological advancements, stands at the heart of the urban metamorphosis, especially in the context of burgeoning megacities.
2. **Diverse Trajectories in Energy Evolution:** Cities like Singapore, Shanghai, and Jakarta exemplify the varied paths urban centres can take in integrating solar energy, each presenting unique challenges and opportunities.
3. **Significance of Sociotechnical Systems:** The evolution of smart cities is deeply intertwined with sociotechnical systems, emphasizing the need for a harmonious blend of technological innovations and societal adaptations.
4. **Innovative Valuation Methods:** The introduction of the compound Real Options Approach (ROA) offers a fresh perspective on valuing solar energy projects, recognizing the value of managerial flexibility and adaptability in uncertain environments.
5. **Persistent Challenges:** Despite the undeniable growth and potential of solar energy, it faces a myriad of challenges, from technical and financial barriers to regulatory obstacles, underscoring the need for continuous research and innovation.
6. **Enduring Policy Support:** The growth and integration of solar energy in smart cities necessitate unwavering policy support, ensuring that solar energy transitions from an alternative source to a mainstay in the global energy landscape.

In summation, this review has endeavoured to provide a holistic perspective on the role of solar energy markets in driving the growth of smart cities. The findings resonate deeply with the transformative power of solar energy in shaping sustainable urban futures. As cities worldwide continue their journey towards becoming smarter and more sustainable, the insights from this review serve as a guiding light, illuminating the path forward and setting the stage for a brighter, more sustainable tomorrow.

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