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Optimizing behavioral and economic strategies for the ubiquitous integration of wireless energy transmission in smart cities

Kelvin Edem Bassey [1, *], Shahab Anas Rajput [2], Olaniyi Oluwaseun Oladepo [3] and Kabir Oyewale [4]

[1] *University of Hull, England.*
[2] *Illinois State University, Illinois.*
[3] *Babson College, USA.*
[4] *University of North Alabama.*

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Abstract

This research explores the optimization of behavioural and economic strategies for the seamless integration of wireless energy transmission (WET) technologies into smart cities. As urban centres evolve towards greater connectivity, efficiency, and sustainability, the adoption of WET offers immense potential for powering Internet of Things (IoT) devices, electric vehicles, and infrastructure without physical connections. However, the widespread implementation of WET faces significant barriers, including public scepticism, economic feasibility, and the high costs of infrastructure development. This study addresses these challenges by examining the psychological and economic factors influencing the adoption of WET. Key behavioural obstacles such as resistance to change, safety concerns, and lack of awareness are analyzed, alongside potential interventions like educational campaigns, gamification, and trust-building initiatives. In parallel, economic barriers such as infrastructure costs, regulatory hurdles, and uncertainties regarding return on investment are investigated. The research proposes innovative economic strategies, including public-private partnerships, dynamic pricing models, and financial incentives, to support widespread adoption. By integrating behavioural and economic approaches, this research develops an optimized framework for promoting the ubiquitous integration of WET in smart cities. Case studies of successful technological adoptions provide insights into how similar strategies can be applied to WET. Furthermore, the research identifies opportunities for patentable innovations that combine behavioural incentives with economic models, fostering the development of new technologies and policies. This multidisciplinary approach offers a roadmap for cities seeking to harness WET for sustainable urban growth, emphasizing the importance of addressing both psychological and economic barriers.

Keywords: Optimizing Behavioral; Economic Strategies; Wireless Energy; Smart Cities

1. Introduction

Smart cities represent a transformative approach to urban living, leveraging digital technologies, data analytics, and automation to enhance the quality of life, sustainability, and efficiency of urban spaces (Bibri, 2019; Kumar *et al.*, 2020). At the core of a smart city is the integration of Information and Communication Technology (ICT) with physical infrastructure, allowing for real-time monitoring and management of resources such as transportation, energy, and public services. Smart cities are characterized by their ability to optimize operations, improve energy efficiency, and promote citizen engagement through connected devices and systems (Belli *et al.*, 2020). Some key features of smart cities include the use of the Internet of Things (IoT), renewable energy integration, smart grids, and intelligent transportation systems. Energy systems play a crucial role in smart city infrastructure, as they provide the foundation for many of the technologies and services that enable the city to function efficiently (Hoang and Nguyen, 2021). Smart

* Corresponding author: Kelvin Edem Bassey

energy systems often incorporate renewable energy sources, such as solar and wind power, to reduce reliance on fossil fuels and minimize environmental impact (Ahmad and Zhang, 2021). These systems also include smart grids, which can manage energy supply and demand dynamically, optimizing energy distribution and reducing waste. Efficient energy management is essential for powering smart devices, autonomous vehicles, and public infrastructure, making energy systems a central element of any smart city initiative (O'Dwyer *et al*., 2019).

Wireless Energy Transmission (WET) refers to the transfer of electrical energy from a power source to a device without the need for physical connections like cables or wires (Li, 2022). This technology has been under development for over a century, with notable progress made in recent decades due to advances in electromagnetics, resonant induction, and microwave transmission. The key advantage of WET is its ability to provide power to devices that are mobile or difficult to connect to the electrical grid, offering greater flexibility and convenience (Guan *et al*., 2022). Current applications of WET are mostly found in consumer electronics, such as wireless charging for smartphones, wearables, and electric vehicles. In urban settings, WET has the potential to revolutionize the way energy is distributed and consumed (Radini *et al*., 2021). It could be used to power IoT devices scattered throughout the city, enable the wireless charging of autonomous vehicles, and provide energy for street lighting, traffic signals, and other essential services. Additionally, WET could contribute to the development of microgrids, allowing decentralized energy generation and distribution within neighbourhoods or city districts (Considine *et al*., 2021). The future potential of WET in smart cities is vast. As cities become more connected and reliant on smart technologies, the demand for flexible, efficient, and scalable energy systems will grow. WET could reduce the need for costly and complex wiring infrastructure, streamline energy distribution, and enhance the overall resilience of urban energy systems (Freed and Zimmerman, 2022). However, for WET to become a ubiquitous feature in smart cities, several challenges must be addressed, particularly in the areas of public acceptance, economic viability, and regulatory support (Paiva *et al*., 2021).

The primary objective of this research is to investigate behavioural and economic strategies for integrating WET into the fabric of smart cities. While the technology offers significant potential, its widespread adoption is hindered by psychological and economic barriers. From a behavioural perspective, the public may have concerns about the safety and reliability of wireless energy, particularly when it comes to invisible energy transfer systems. Additionally, there may be a lack of understanding or awareness of the benefits of WET, leading to resistance to change or slow adoption. Economically, the implementation of WET requires significant investment in infrastructure, and the returns on such investments are not always immediately apparent. Cities and private stakeholders must be convinced that WET is a financially viable solution for their energy needs, which involves developing innovative business models, pricing strategies, and financial incentives. This research aims to explore these challenges and develop strategies to overcome them. By examining both behavioural and economic factors, the study seeks to create a framework that can facilitate the seamless adoption of WET in smart cities. Moreover, the research will identify patentable solutions that combine innovative technological advancements with effective behavioural and economic strategies. These patentable solutions could serve as a blueprint for cities looking to implement WET and pave the way for the widespread use of this technology in urban environments. The integration of WET into smart cities requires more than just technological advancement; it demands a comprehensive approach that addresses human behaviour, economic considerations, and legal frameworks. By focusing on these aspects, this research will contribute to the development of practical, scalable solutions for future urban energy systems.

2. Technological Overview: Wireless Energy Transmission in Smart Cities.

Wireless Energy Transmission (WET) has a long history of development, tracing its origins back to the early experiments of Nikola Tesla in the late 19th century (Maloberti and Davies, 2022). Tesla's work on wireless power transfer laid the theoretical groundwork for many modern WET technologies. He envisioned the transmission of energy across long distances using electromagnetic waves, aiming to deliver electricity wirelessly to homes and industries as explained in Figure 1 (Perera *et al*., 2017). However, technological limitations at the time, along with the rise of wired infrastructure, relegated WET to theoretical research for much of the 20th century. It wasn't until the early 21st century that significant breakthroughs in materials science, electronics, and electromagnetics rekindled interest in WET. Two key advancements enabled this resurgence: resonance-based power transfer and microwave energy transmission. Resonance-based power transfer, which works by using electromagnetic fields to induce current in receiving devices, allows energy to be transmitted over short to medium distances without physical contact (Khan *et al*., 2020; Jiang *et al*., 2021). This technology is at the heart of many consumer products, such as wireless charging pads for smartphones and electric vehicles. Microwave transmission, on the other hand, uses directed microwave beams to transmit energy over longer distances. Though still in the experimental phase for large-scale applications, microwave-based WET has demonstrated success in niche areas like satellite power systems and remote energy transmission. In recent years, laser-based WET has emerged as a potential breakthrough for the transmission of energy over even greater distances with high precision. This technology could allow for energy transmission from satellites to Earth or between urban grids without significant energy loss.

WET holds immense potential for transforming energy management in smart cities. One of its most immediate applications is in powering Internet of Things (IoT) devices. The rise of IoT devices in smart cities, from traffic sensors to environmental monitoring systems, requires a distributed and reliable energy source (Raj *et al*., 2022). WET could eliminate the need for constant battery replacement or extensive wiring, enabling uninterrupted operation of these devices. For example, a city equipped with wireless charging zones could power its network of air quality monitors, public security cameras, and smart traffic lights seamlessly. Another major application is in smart vehicles and autonomous transportation systems. Currently, electric vehicles (EVs) rely on plug-in chargers, which limit their range and usability. WET could enable wireless charging of EVs at designated spots across the city or even while they are in motion (Karki *et al*., 2020). A 2022 study estimated that wireless charging infrastructure could reduce EV downtime by 30%, increasing the overall efficiency of urban transportation systems.

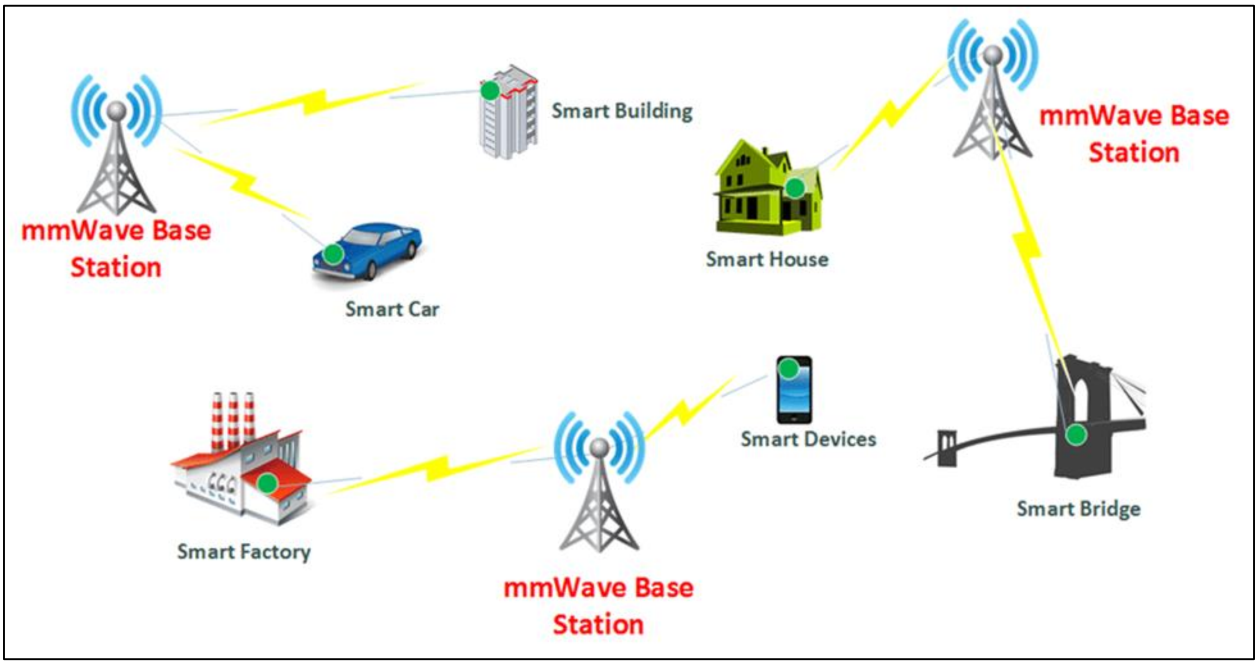

Figure 1 An mmWave-enabled wireless power transfer scheme for smart cities (Perera *et al*., 2017)

WET can also enhance the functionality of energy-efficient buildings. In commercial and residential buildings, wireless energy systems could be used to power lights, HVAC systems, and appliances without the need for complex electrical wiring (Ramalingam and Shanmugam, 2022). Combined with solar power and smart grid technologies, WET could further optimize energy use in buildings, contributing to reduced energy consumption and lower carbon emissions. The integration of WET in urban grids would allow for more flexible and decentralized energy distribution. Microgrids could be established to distribute wireless power within specific areas, allowing for localized energy management in neighbourhoods or city districts.

Despite its potential, WET faces several technical and infrastructural challenges, particularly when it comes to large-scale implementation in smart cities (Gupta *et al*., 2021). One of the primary technical limitations of WET is the distance over which energy can be transmitted. Most current technologies can only transmit energy effectively over short distances (a few meters). For large-scale urban deployment, this limitation would require either highly localized energy hubs or significant advancements in long-range wireless power transfer, such as microwave or laser-based systems. WET systems are often less efficient than traditional wired systems due to energy losses during transmission. This issue is particularly acute in longer-range systems where energy dissipates before reaching the receiver (Agupugo *et al*., 2024). For instance, resonance-based systems often operate at around 85% efficiency, while wired systems can reach 99% efficiency. Even a small loss in efficiency can become significant when applied to large-scale power needs in a smart city. There are concerns regarding the safety of WET systems, particularly those that involve electromagnetic radiation or microwave transmission. Regulatory standards and safety measures would need to be established to ensure that these systems do not pose health risks to the public (Filip *et al*., 2022). A 2020 report by the International Commission on Non-Ionizing Radiation Protection (ICNIRP) emphasized the need for stringent regulations regarding exposure to electromagnetic fields in urban environments.

The integration of WET into existing cities would require substantial infrastructure changes. This could involve the installation of wireless charging pads in roads, public spaces, and transportation hubs, as well as the construction of localized energy transmission towers. According to a 2021 study, the cost of retrofitting a mid-sized city for WET integration could range from $50 million to $200 million, depending on the extent of the infrastructure needed. For WET to be fully integrated into smart cities, it needs to be coordinated with broader urban planning initiatives. This includes ensuring that WET technologies align with public transport systems, green energy goals, and smart grid infrastructures (Agupugo et al., 2022). Many cities, particularly in the developing world, face challenges in upgrading existing infrastructures, making WET adoption difficult without external funding or public-private partnerships (Li *et al.*, 2020). While Wireless Energy Transmission offers groundbreaking potential for powering smart cities, its widespread adoption faces significant technical, economic, and planning challenges. However, with continued technological advancements and strategic planning, WET could become a key enabler of smart, sustainable urban environments.

2.1. Behavioral Strategies for Widespread Adoption of Wireless Energy Transmission (WET)

Despite the technological advantages of Wireless Energy Transmission (WET), several psychological barriers hinder its widespread adoption. Understanding these barriers is crucial to developing strategies that promote the acceptance and usage of WET systems in smart cities (Ureta *et al.*, 2021). One of the most significant challenges in introducing any new technology, including WET, is public scepticism. People tend to be wary of unfamiliar technologies, particularly when they involve complex scientific principles or operate invisibly, as WET does. The concept of transmitting energy through invisible waves can evoke concerns about its impact on health and safety, similar to early concerns about mobile phone radiation and Wi-Fi signals. A 2021 survey by Pew Research found that 49% of respondents expressed concerns about the safety of wireless technologies, highlighting the need for public education to mitigate fears and build trust in WET. The invisibility of WET makes it difficult for users to comprehend how the technology works, leading to a lack of trust. Many people equate the invisibility of energy transfer with a loss of control over their environment. Additionally, some may perceive potential dangers associated with exposure to electromagnetic fields, even though numerous studies, including a 2020 report from the World Health Organization, have shown no conclusive evidence of harm from non-ionizing radiation (Verbeek *et al.*, 2021). To overcome this, clear communication about the safety and regulatory standards of WET is essential. Human behaviour is often resistant to change, especially when it comes to daily habits and established routines. The transition from traditional wired energy systems to WET requires a shift in mindset, which can be difficult for many people. Behavioral inertia, or the tendency to stick with the status quo, is a well-documented phenomenon in the adoption of new technologies. According to a 2022 study on consumer behaviour, approximately 60% of individuals tend to resist adopting new technologies if they perceive a disruption to their established practices. This resistance can slow the adoption of WET systems, even if they offer long-term benefits. Table 1 outlines essential behavioural strategies for fostering the widespread adoption of Wireless Energy Transmission in both consumer and commercial sectors (Mutule *et al.*, 2021).

Table 1 Essential behavioural strategies for fostering the widespread adoption of Wireless Energy Transmission (Mutule *et al.*, 2021)

Strategy	Description	Key Considerations
Awareness Campaigns	Initiating public awareness initiatives to educate individuals and businesses about the benefits, safety, and functionality of WET.	Focus on highlighting the advantages of convenience, efficiency, and environmental impact. Address potential concerns such as safety and electromagnetic exposure.
User-Friendly Interfaces and Devices	Designing intuitive and accessible user interfaces for WET-enabled devices to ensure a smooth user experience.	Ensure seamless integration with existing smart home or city technologies. Use familiar interfaces and clear instructions to reduce technological resistance.
Incentivization Programs	Offering financial incentives, such as rebates or tax credits, to early adopters of WET technologies.	Implement tiered incentives for households, businesses, and public spaces. Develop long-term reward systems for consistent use of WET.

Social Influence and Peer Learning	Leveraging social influence by promoting case studies and testimonials from early adopters to encourage wider uptake.	Utilize social media, influencers, and community leaders to create positive narratives around WET. Promote adoption through word-of-mouth and peer-to-peer education.
Collaborative Public Demonstrations	Organizing public demonstrations and collaborative events to showcase WET applications in real-world scenarios, such as smart cities or public transportation systems.	Engage local communities and media for maximum outreach. Make demonstrations interactive and participatory to drive curiosity and enthusiasm.
Behavioral Nudges	Introducing subtle cues or nudges to encourage the use of WET, such as reminders in public places, gamification techniques, or energy consumption tracking apps.	Design nudges to be simple, timely, and linked to user preferences. Consider integrating gamification features to reward positive behaviour, like milestones for wireless energy usage.
Social Norming	Establishing WET as a new social norm by embedding the technology into everyday infrastructure (e.g., charging stations in public spaces) and promoting the idea that WET is the standard energy transmission method.	Consistent messaging across advertising, public policy, and corporate communication will be key. Encourage governmental and corporate investment in WET for public visibility.
Community Engagement and Feedback Loops	Engaging communities in the design and implementation process of WET technologies, gathering feedback and adapting strategies based on user experiences.	Create open communication channels for continuous user feedback and rapid adjustment to concerns or suggestions. This fosters a sense of ownership and boosts adoption rates.
Psychological Framing	Framing WET as a future-proof and environmentally responsible technology, aligning with broader environmental sustainability goals to appeal to eco-conscious consumers.	Highlight positive environmental impacts, such as reduced reliance on non-renewable energy sources and lower carbon emissions, to enhance emotional and psychological resonance.
Trust Building Through Transparency	Providing transparent information about the technology, safety standards, and data privacy measures associated with WET, addressing potential fears or concerns among users.	Publish research, safety data, and case studies to foster trust. Open communication from both government and corporate entities is crucial in mitigating concerns around health and safety.

To overcome these psychological barriers, targeted behavioural strategies can encourage widespread adoption of WET in smart cities (Fartash *et al*., 2021). By addressing concerns, educating the public, and creating user-friendly experiences, WET can become a more appealing and accessible option for urban dwellers. One of the most effective ways to address public concerns and build trust in WET is through education and awareness campaigns. These campaigns should focus on explaining the benefits of WET, such as its potential to reduce wiring costs, enhance energy efficiency, and provide greater convenience in daily life. Public demonstrations, workshops, and informative materials can help demystify the technology and showcase its practical applications. For example, a 2021 awareness campaign for electric vehicle (EV) adoption in the United States resulted in a 20% increase in public interest within six months, demonstrating the power of education in driving technological adoption. The design of WET systems should prioritize ease of use and seamless integration into daily life (Lee and Baek, 2021). By offering intuitive interfaces, such as wireless charging pads in public spaces or user-friendly mobile apps for monitoring energy consumption, WET systems can reduce the perceived complexity of the technology. Ensuring that users can interact with the system effortlessly is essential for encouraging adoption. The success of wireless charging systems for consumer electronics, like smartphones, underscores the importance of convenience in driving behavioural change. Studies have shown that user-friendly designs can boost technology adoption rates by up to 25%. Gamification using game-like elements in non-gaming contexts—can be a powerful tool for encouraging the adoption of WET (Ofosu-Ampong *et al*., 2020). Reward systems that incentivize energy-saving behaviours or participation in WET initiatives can motivate users to engage with the technology. For example, users could earn points or rewards for charging their electric vehicles using WET infrastructure or reducing energy consumption in wireless-powered buildings. A 2020 study on gamification in energy conservation found that households using a reward-based system reduced their energy consumption by 15%, demonstrating the effectiveness of such approaches in promoting behavioural change.

The behavioural adoption of WET can be informed by lessons learned from other technological transitions, such as electric vehicles (EVs) and renewable energy systems (Temby and Ransan-Cooper, 2021). The adoption of EVs faced significant behavioural barriers in its early stages, including concerns about range, cost, and charging infrastructure. However, targeted strategies such as public education campaigns, government incentives, and improvements in user experience have helped overcome these challenges. Between 2010 and 2020, the global number of EVs grew from 17,000 to over 10 million, according to the International Energy Agency (IEA). The introduction of financial incentives, such as tax rebates and subsidies, played a key role in accelerating adoption, highlighting the importance of economic incentives alongside behavioural strategies. The shift to renewable energy sources, such as solar and wind power, has similarly faced resistance due to concerns about cost, reliability, and environmental impact. However, as public awareness of environmental issues has grown, so too has the adoption of renewable energy. In the European Union, for example, the share of renewable energy in gross final energy consumption rose from 14.5% in 2009 to 22.1% in 2020. Public education campaigns about the benefits of clean energy, combined with government incentives and subsidies, were instrumental in driving this shift. The parallels between renewable energy and WET adoption are clear: addressing public concerns through education and economic incentives can drive behavioural change. Widespread adoption of Wireless Energy Transmission in smart cities will require a combination of strategies that address psychological barriers and provide clear behavioural incentives (Wang *et al*., 2022). By learning from past technological transitions, policymakers and city planners can design systems that foster trust, convenience, and engagement with WET, ensuring its successful integration into urban environments.

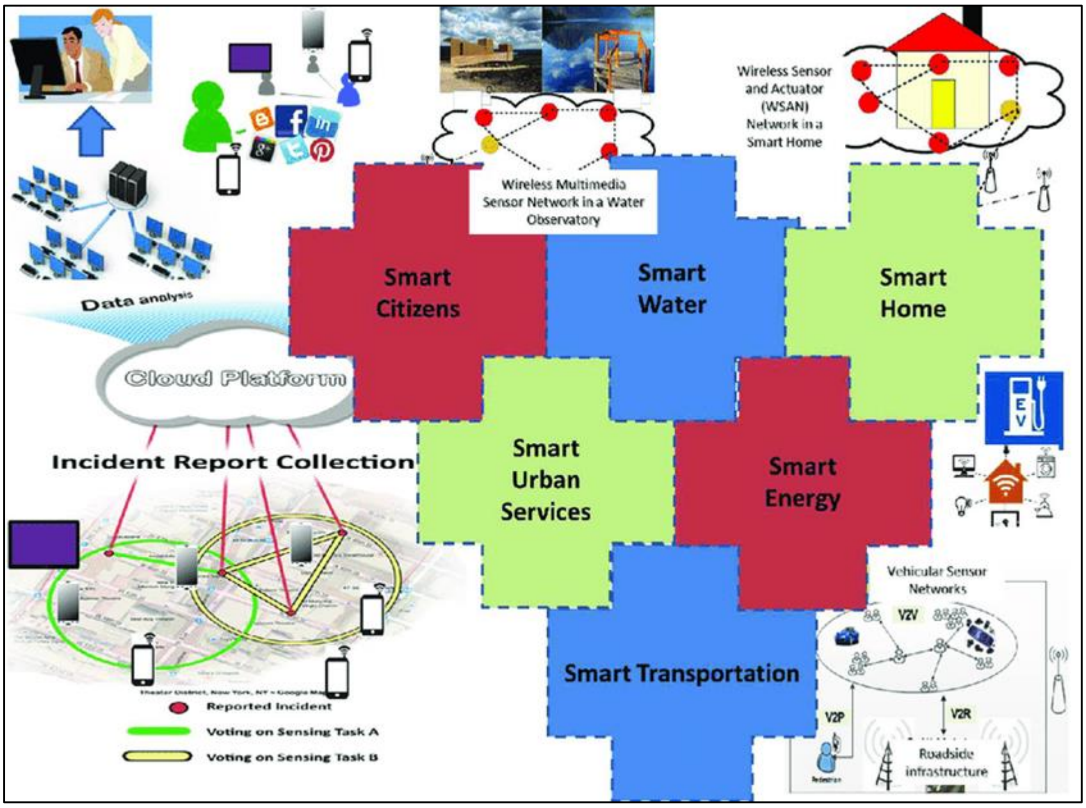

Figure 2 Building blocks of a smart city (Pouryazdan *et al*., 2016)

2.2. Economic Strategies for Facilitating Ubiquitous WET Integration

One of the primary economic barriers to the widespread adoption of Wireless Energy Transmission (WET) in smart cities is the high initial cost of infrastructure (Alnahari and Ariaratnam, 2022). Implementing WET systems requires substantial investments in both hardware and software, including energy transmitters, receivers, and integration with existing energy grids. The installation of wireless charging stations, inductive pads, and transmission hubs, especially in large urban areas, can be capital-intensive. For example, a study by the National Renewable Energy Laboratory (NREL) estimated that the cost of installing wireless energy systems for electric vehicles across a medium-sized city could range from $50 million to $100 million, depending on the scope and scale of the project. These high upfront costs can discourage businesses and municipalities from committing to WET infrastructure, as the long-term returns may seem uncertain compared to traditional wired systems (Beard *et al.*, 2020). Another significant barrier is the concern over the return on investment (ROI) for businesses and local governments. Municipalities and companies may hesitate to invest in WET due to uncertainties regarding adoption rates, energy consumption patterns, and the lifespan of WET technologies. The financial benefits of WET—such as savings on maintenance and reduced dependence on fossil fuels—are often realized only in the long term, which can deter decision-makers from seeking more immediate returns. In addition, businesses may be concerned that consumers will not adopt WET-enabled products quickly enough to justify the investment, exacerbating the challenge of predicting a reliable ROI. The lack of clear policy frameworks and regulatory guidelines for WET implementation is another obstacle. Governments may be slow to develop regulations that govern the use, safety, and distribution of WET in public spaces. For example, questions regarding who owns the transmitted energy, how it is monitored, and how energy providers are compensated must be answered before large-scale deployment can occur. Without regulatory clarity, investors may be reluctant to fund WET projects. Additionally, some cities may face zoning restrictions, environmental regulations, or safety codes that delay or prevent the installation of WET infrastructure (Hobbie and Grimm, 2020).

One of the most effective strategies for overcoming the financial barriers to WET implementation is fostering public-private partnerships (PPPs). Through PPPs, the cost burden of infrastructure development can be shared between governments and private entities, making it more feasible for municipalities to invest in cutting-edge technologies like WET. For example, in 2021, the European Union facilitated several PPP projects aimed at advancing smart city infrastructure, including wireless energy systems for public transportation. Such collaborations help reduce the financial risk for both parties and enable broader access to investment funds (Lerne and Nanda, 2020). Governments can also provide low-interest loans or co-financing schemes to incentivize businesses to invest in WET infrastructure. A dynamic pricing model, which adjusts energy costs based on demand, could be an effective way to promote WET adoption. In smart cities, dynamic pricing allows consumers to benefit from lower energy costs during off-peak hours, encouraging them to use WET-enabled devices like electric vehicles or IoT devices during times when energy demand is lower. This model would not only help balance the load on the energy grid but also provide economic incentives for users to adopt WET technologies. A similar approach has been successfully implemented in smart grids, where dynamic pricing has been shown to reduce energy consumption by 10-15% during peak hours. Applying this model to WET could further enhance its cost-effectiveness. Governments can play a crucial role in facilitating the integration of WET by offering financial incentives (Rasul and Neupane, 2021). Subsidies, tax breaks, and grants for both businesses and consumers can help offset the initial costs of WET systems. For instance, businesses that install WET infrastructure could receive tax credits, while consumers who purchase WET-enabled devices might qualify for rebates. These incentives would make the technology more affordable and accessible, promoting early adoption. A historical parallel can be seen in the renewable energy sector, where government incentives significantly boosted the adoption of solar panels and wind turbines. The U.S. Solar Investment Tax Credit, introduced in 2006, contributed to a 42% annual growth in the solar industry. Similar financial mechanisms could accelerate WET deployment in smart cities (Tabassum *et al.*, 2021).

Despite the high initial costs, WET systems offer significant long-term savings. By reducing the need for extensive wiring and decreasing energy loss during transmission, WET can lead to more efficient energy use in smart cities (Zeb *et al.*, 2022). For instance, wireless energy systems for electric vehicles can reduce downtime and maintenance costs, leading to increased efficiency in transportation networks. Over time, these savings can outweigh the initial investment, especially when coupled with reduced reliance on fossil fuels. As cities transition to cleaner, more sustainable energy sources, WET can play a critical role in reducing carbon emissions and lowering energy costs. A 2020 report by McKinsey & Company estimated that smart city energy solutions, including WET, could reduce energy expenditures by up to $160 billion annually worldwide. The integration of WET into urban areas also offers numerous socio-economic benefits. First, it can promote greater access to clean energy, particularly in underserved communities where traditional energy infrastructure may be lacking. WET can democratize energy access by reducing the need for expensive grid expansions, enabling more equitable energy distribution (Golding, 2021). Furthermore, WET-enabled smart cities could create new economic opportunities by fostering innovation and attracting tech-driven industries. The deployment of WET infrastructure could lead to the creation of jobs in engineering, construction, and energy management, further contributing to local economic growth. Additionally, WET's ability to integrate seamlessly with renewable energy sources like solar and wind power could help cities achieve their sustainability goals. By supporting the transition to renewable energy, WET can contribute to the reduction of greenhouse gas emissions, helping to mitigate climate change while enhancing energy security. While economic barriers such as high infrastructure costs and uncertain returns on investment pose challenges to WET adoption, a range of economic strategies can help facilitate its integration into smart cities. Public-private partnerships, dynamic pricing models, and financial incentives are key to overcoming these barriers, offering both immediate and long-term benefits that make WET a viable and transformative energy solution (Voorwinden, 2021).

2.3. Interplay of Behavioral and Economic Factors in WET Adoption

The integration of Wireless Energy Transmission (WET) in smart cities requires a comprehensive approach that addresses both behavioural and economic factors (Mahmood *et al.*, 2021). Understanding how human behaviour interacts with financial incentives is critical for the widespread adoption of WET technologies. This section explores the synergies between behavioural and economic strategies, proposes an integrated framework for WET adoption, and suggests patentable solutions for accelerating the technology's uptake. Economic strategies such as subsidies, tax incentives, and dynamic pricing models are effective in promoting technology adoption, but their impact can be significantly enhanced by behavioural interventions. For instance, studies show that when economic incentives are paired with targeted awareness campaigns, adoption rates can increase dramatically. A case in point is the adoption of renewable energy systems. According to the International Energy Agency (IEA), countries that implemented public education initiatives alongside economic incentives for solar panels saw a 30% higher adoption rate compared to those that relied on financial incentives alone. Similarly, for WET, public education campaigns can increase the perceived value of WET technology, encouraging more users to invest in the infrastructure and devices required for wireless energy (Dyantyi and Njenga, 2022). Additionally, leveraging social proof—showcasing how others are benefiting from WET can reduce psychological barriers and enhance the effectiveness of economic incentives. For example, research on electric vehicle (EV) adoption found that visible charging stations in urban areas serve as a form of social proof, making individuals more likely to purchase EVs. In the context of WET, the more people see others using wireless charging stations or wireless energy-enabled devices, the more they are likely to embrace the technology, particularly when coupled with economic incentives like rebates or dynamic pricing. Social norms play a pivotal role in shaping collective behaviour, especially when new technologies are involved. Economic incentives can drive individual decisions, but widespread adoption of WET requires a shift in collective behaviour. Social norms—unwritten rules that govern behaviour can either hinder or promote the uptake of WET systems, depending on how they are shaped. In situations where WET is perceived as environmentally friendly or cutting-edge, social norms can encourage its use. To foster positive social norms, policymakers can implement pilot projects that highlight the economic and environmental benefits of WET. For example, a 2019 study on the adoption of renewable energy sources in Denmark demonstrated that communities exposed to small-scale, successful renewable energy projects were more likely to support large-scale deployments. Similarly, early WET adopters, such as public transportation systems or smart buildings, can serve as role models for the wider community, illustrating the economic and societal benefits of the technology (Schwartz and Krarti, 2022). The combination of social norms and economic incentives creates a reinforcing cycle that can drive widespread WET adoption.

An integrated framework for WET adoption must address the psychological, social, and economic dimensions of technology adoption (Sunny *et al.*, 2022). One potential model involves three interconnected pillars: behavioural nudges, economic incentives, and social engagement. These are small interventions designed to influence decision-making without restricting choices. For WET, nudges might include default settings that encourage the use of wireless energy systems, such as wireless charging stations installed in public spaces. Subsidies, grants, and dynamic pricing models can encourage early adopters and lower the perceived cost barriers to WET adoption. Community-driven projects and public demonstrations of WET technologies can create social proof and foster new social norms that encourage widespread usage (Fadairo *et al.*, 2020). By combining these elements, cities can create a holistic approach to WET adoption that addresses the psychological reluctance, economic concerns, and social hesitations that may otherwise impede progress. Scaling WET adoption across urban populations requires adaptive strategies that take into account the diverse economic backgrounds, technological literacy, and energy needs of different communities. For example, low-income neighbourhoods may require additional subsidies or targeted outreach efforts to encourage the use of WET-enabled devices, while tech-savvy populations might respond more to gamification techniques that reward frequent use of wireless energy systems. Data from smart grid implementations show that engagement strategies need to be tailored to specific population groups. In one study conducted in the U.K., dynamic pricing and awareness campaigns led to a 17% reduction in energy use in affluent areas but had less impact in low-income neighbourhoods, where upfront costs and distrust of new technologies were higher. Thus, an adaptive strategy for WET should involve flexible economic models such as tiered pricing or sliding-scale subsidies combined with tailored behavioural interventions, such as community-led education initiatives or incentive programs (Cox and Henderson, 2022). A key objective of this research is to identify patentable solutions that combine behavioural and economic strategies for WET adoption. One potential innovation is a patentable "smart incentive platform" that dynamically adjusts economic rewards based on user behaviour. For example, the platform could track the energy usage patterns of wireless energy users and provide tailored economic incentives (such as discounted energy rates or loyalty rewards) based on their engagement with WET systems. By leveraging real-time data, this platform could provide both individual and collective rewards, encouraging not only individual adoption but also broader community engagement. Another potential patentable solution is a wireless energy device with embedded social features. For instance, users could earn points for every kilowatt-hour of wireless energy they consume, which they can share or compare with friends via a mobile app, fostering competition and collective action. This system could integrate gamification elements with economic incentives, driving behavioural change through competition and social engagement. Finally, adaptive infrastructure designs that combine both economic and psychological incentives such as wireless charging stations that offer real-time pricing discounts during low-demand periods could be another patentable avenue. By embedding dynamic pricing features into the physical infrastructure, cities could encourage more widespread use of WET systems while balancing the load on the energy grid (Sharda *et al*., 2021).

The interplay of behavioural and economic factors is essential for the successful integration of WET in smart cities (Baklanov *et al*., 2020). By combining economic incentives with behavioural interventions and leveraging social norms, cities can create a comprehensive strategy for widespread WET adoption. An integrated framework that addresses psychological, social, and economic dimensions will not only accelerate adoption but also foster the development of patentable solutions that further enhance the effectiveness of WET systems.

2.4. Legal and Regulatory Considerations in Wireless Energy Transmission

The successful integration of Wireless Energy Transmission (WET) in smart cities hinges not only on technological advancements and public adoption but also on the establishment of robust legal and regulatory frameworks (Ijemaru *et al*., 2022). The regulatory landscape for WET is still in its formative stages, with different regions adopting varying approaches based on their existing energy policies and technological ecosystems. In many countries, WET is regulated under broader energy policies that govern wireless communication and electromagnetic spectrum use. For instance, in the United States, the Federal Communications Commission (FCC) oversees the use of radio frequencies essential for wireless power transfer, while the Federal Energy Regulatory Commission (FERC) regulates the broader energy infrastructure. Similarly, the European Union (EU) has begun incorporating WET into its regulatory framework through directives on energy efficiency and electromagnetic compatibility. However, these regulations are often piecemeal and not specifically tailored to the unique requirements of WET. This can lead to gaps in safety standards, inconsistencies in implementation, and uncertainties in compliance, particularly when it comes to large-scale urban deployments. The regulatory challenges for WET vary significantly across regions due to differences in legal systems, technological infrastructure, and economic priorities (King *et al*., 2021). In developed regions like North America and Europe, the primary challenge lies in integrating WET into existing energy and communications infrastructures without disrupting services or creating new safety hazards. Regulatory bodies must address concerns about electromagnetic interference, energy efficiency, and public safety while ensuring that WET technologies comply with existing environmental and health standards. In contrast, developing regions face different challenges. In many parts of Asia and Africa, the lack of a comprehensive regulatory framework for emerging technologies like WET can slow down adoption and innovation. These regions often have less stringent regulations, which can lead to safety risks, but also present an opportunity to develop new frameworks that encourage innovation while ensuring public safety. Additionally, the disparity in infrastructure development between urban and rural areas in these regions poses a significant challenge to the widespread deployment of WET technologies.

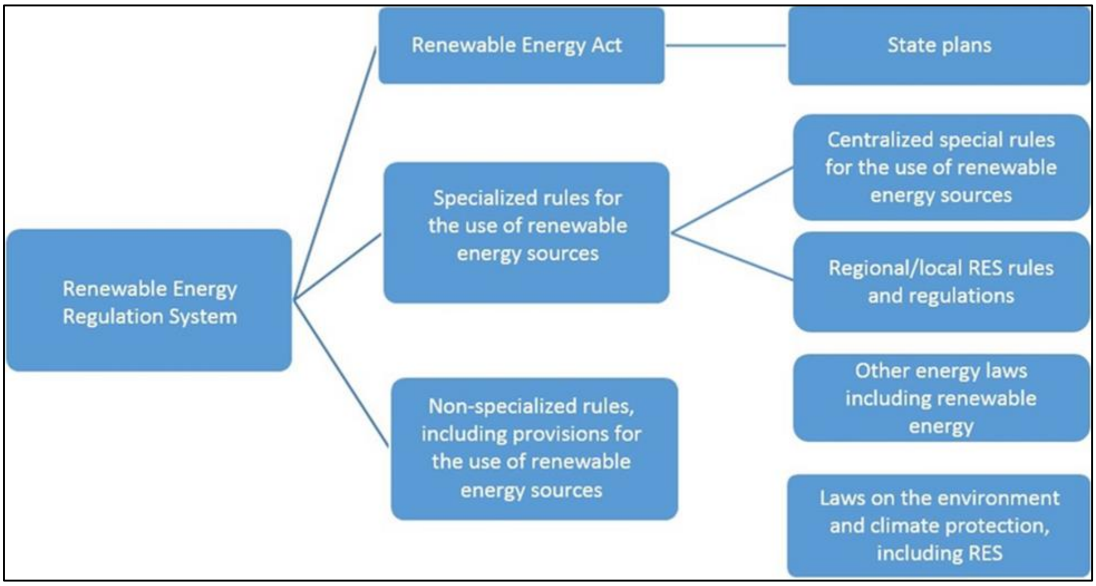

Figure 3 Proposed system of legal regulation of renewable energy (Sabyrzhan *et al*., 2021)

To foster innovation in WET, governments and regulatory bodies need to adopt proactive policies that encourage research, development, and deployment of these technologies as explained in figure 3 (Vushe, 2021; Sabyrzhan *et al.*, 2021). One recommendation is to establish clear and consistent regulatory standards that address the unique characteristics of WET, such as electromagnetic field exposure limits and energy efficiency requirements. Governments should also consider creating regulatory sandboxes-controlled environments where companies can test WET technologies without the full burden of regulation (Lin and Chen, 2020). This approach allows regulators to observe the technology in action and refine policies based on real-world data. Another critical policy recommendation is to harmonize regulations across regions to facilitate global deployment and integration of WET technologies. This could involve international cooperation to develop common standards for WET, similar to how the International Telecommunication Union (ITU) coordinates global telecommunications standards (Frieden, 2020). Streamlining the approval process for WET technologies is essential for accelerating their adoption in smart cities. One strategy is to create specialized regulatory bodies or task forces focused solely on emerging technologies like WET. These bodies could provide faster review times and more tailored guidance to companies developing WET solutions. Additionally, adopting a risk-based approach to regulation where the stringency of regulations is proportional to the potential risks can help balance safety with innovation. Another strategy involves implementing a tiered approval process, where small-scale or pilot WET projects receive expedited approval, while larger deployments undergo more rigorous review. This approach encourages incremental innovation and allows regulators to gather data and refine policies as the technology evolves. As WET technologies advance, intellectual property (IP) considerations become increasingly important. Companies developing novel methods for integrating WET into smart cities must navigate complex patent landscapes to protect their innovations (Ghorbani *et al.*, 2022). Patent laws vary widely between regions, which can create challenges for companies seeking global IP protection. Innovators must conduct thorough patent searches and consider filing for patents in multiple jurisdictions to secure comprehensive protection. Additionally, policymakers should consider updating patent laws to better accommodate emerging technologies like WET. This could include extending the scope of patentable subject matter to cover new types of WET-related inventions or creating expedited patent examination processes for technologies deemed critical for smart city development. The legal and regulatory landscape for WET in smart cities is still developing, with significant challenges and opportunities ahead. By creating supportive legal frameworks, streamlining approval processes, and addressing IP considerations, governments and regulatory bodies can foster innovation and facilitate the widespread adoption of WET technologies. These efforts will be essential for ensuring that WET becomes an integral part of the smart cities of the future, enabling more efficient and sustainable urban environments (Mishra *et al.*, 2022).

2.5. Case Studies of Wireless Energy Transmission (WET) Integration in Smart Cities

Wireless Energy Transmission (WET) is emerging as a pivotal technology for the energy infrastructure of smart cities (Sah *et al.*, 2022). Around the globe, select cities have begun adopting WET to power various devices, enhance urban mobility, and integrate renewable energy. This section provides an analysis of global case studies where WET systems have been implemented, exploring the behavioural and economic strategies employed. It also identifies key success factors and lessons learned to guide future smart city development.

Oulu, a city in northern Finland, has been at the forefront of smart city innovation and WET integration (Meyer, 2022). The city began a pilot project in 2019, incorporating resonant inductive coupling technology to wirelessly charge electric buses. Charging pads were installed at bus stops, enabling buses to recharge wirelessly during regular operations. This initiative significantly reduced downtime, improving fleet efficiency. The city secured funding through public-private partnerships and utilized European Union (EU) grants aimed at fostering green energy solutions. By collaborating with energy companies and research institutions, Oulu reduced the financial burden on the city and accelerated the project timeline. Public information campaigns were critical for reducing scepticism surrounding wireless charging. Community workshops and demonstrations were organized to raise awareness and ensure the public's trust in the safety and benefits of WET (Loury *et al.*, 2021).

In 2020, Oslo implemented a large-scale WET project focusing on inductive wireless charging for electric taxis. The city partnered with wireless energy companies like Momentum Dynamics to install charging pads at taxi stands. The system enabled taxis to charge wirelessly while waiting for passengers, thus removing the need for extensive physical charging infrastructure (Oliveira *et al.*, 2020). Oslo's initiative was driven by Norway's government-backed incentives for electrification. The city utilized tax rebates and subsidies to encourage taxi operators to adopt electric vehicles (EVs), further facilitated by the convenience of wireless charging. The economic benefits were underscored by a reduced reliance on fossil fuels, long-term savings from efficient energy usage, and lower maintenance costs associated with wireless systems. A major focus in Oslo was to reduce the perceived complexity of WET. The city deployed user-friendly interfaces for taxi drivers, simplifying the transition from conventional charging to wireless systems. Awareness campaigns emphasized the environmental and cost benefits, fostering a positive attitude toward the technology. According to data from Oslo's municipal reports, the initiative led to a 30% increase in EV taxi adoption by 2022.

Shanghai, known for its progressive stance on smart city technologies, piloted a WET project focused on powering Internet of Things (IoT) devices across urban infrastructure (Zaręba *et al*., 2021). Wireless charging technology was integrated into streetlights, traffic signals, and public Wi-Fi hotspots to minimize the need for wired connections and enhance urban efficiency. Shanghai's pilot was funded through a combination of municipal investment and private partnerships with leading Chinese tech companies. The city also took advantage of government policies promoting smart city development and innovation, helping offset the high initial costs of WET infrastructure. Shanghai launched extensive educational campaigns aimed at both the public and key stakeholders, explaining the utility of wireless power systems in maintaining urban infrastructure. Public exhibitions and tech showcases were utilized to familiarize the population with the benefits of WET (McGenity *et al*., 2020). As a result, the city saw a 15% reduction in operational costs associated with maintaining wired infrastructure within three years of implementation.

Across these case studies, several commonalities have emerged. Firstly, public-private partnerships were essential in reducing the financial burden on cities and accelerating the adoption of WET technologies. Leveraging government subsidies, tax incentives, and private investments enabled cities like Oulu, Oslo, and Shanghai to overcome high initial costs. Secondly, widespread public education and awareness campaigns played a crucial role in addressing psychological barriers. By openly communicating the safety, reliability, and benefits of WET systems, these cities fostered public trust and encouraged behavioural adoption (Bellezoni *et al*., 2022). Public acceptance, in turn, facilitated quicker scaling of WET technologies across different urban sectors. The key success factors identified from these global examples can guide future smart cities in adopting WET technologies. Ensuring a well-coordinated mix of economic incentives and behavioural strategies is critical. Governments must proactively design subsidies and grants to ease the financial challenges, while private companies can provide technological expertise. Additionally, public engagement is paramount. Smart cities can learn from the educational campaigns in Oslo and Shanghai, where community involvement and transparent communication helped overcome scepticism and foster acceptance. As future WET technologies evolve, cities must remain agile in addressing both technical and societal challenges. The integration of WET systems in smart cities hinges on a combination of economic and behavioural strategies. The case studies of Oulu, Oslo, and Shanghai reveal that strong public-private partnerships, robust economic incentives, and proactive public engagement are essential for widespread adoption. These lessons provide a blueprint for future smart cities, helping them navigate the complexities of WET integration while maximizing the technology's benefits.

2.6. Future Trends and Opportunities in Wireless Energy Transmission (WET)

Wireless Energy Transmission (WET) is poised to become an integral component of smart cities as technological advancements and urbanization accelerate (Choudhary *et al*., 2021). As cities evolve to accommodate growing populations and increasing energy demands, WET offers a sustainable and efficient energy solution. This explores emerging innovations in WET technologies, integration with other smart city systems, and opportunities for developing patentable solutions, particularly in the realms of behaviour-driven systems and economic models.

Technological progress in WET continues to expand the boundaries of what is possible in energy transmission, particularly through the integration of artificial intelligence (AI). AI-enhanced energy management systems are becoming a crucial advancement, optimizing energy distribution and consumption in real-time. For instance, AI can monitor energy needs across different city sectors—transportation, buildings, and IoT devices and automatically adjust the energy supply to maximize efficiency. These intelligent systems can learn from usage patterns, predict demand fluctuations, and allocate wireless power accordingly. Additionally, breakthroughs in long-range wireless power transfer using resonance-based power and microwave transmission are reshaping WET applications. New developments in magnetically coupled resonators have increased transmission range and efficiency, making WET more feasible for urban-scale deployment (Toro *et al*., 2022). This allows smart city infrastructures to power devices such as drones, electric vehicles, and other mobile technologies without the need for frequent recharging at physical stations. The convergence of WET with other smart city technologies, such as 5G networks, the Internet of Things (IoT), and autonomous systems, presents new opportunities for enhancing urban life. 5G's ultra-low latency and high-speed connectivity are pivotal for supporting the massive data transfer required for real-time energy management. WET systems can be integrated into 5G networks to ensure seamless communication between power transmitters and receivers in a smart city environment (Muratkar *et al*., 2022). This will enable continuous power delivery to IoT devices like smart sensors, traffic lights, and public Wi-Fi stations, enhancing their reliability and operational efficiency. Moreover, WET plays a crucial role in the deployment of autonomous systems, such as electric vehicles and drones. As these technologies become more prevalent in smart cities, WET solutions that wirelessly charge autonomous vehicles during operation will reduce downtime, eliminate the need for large-scale charging stations, and increase the sustainability of urban mobility systems. This could be particularly impactful for electric public transportation systems, where continuous wireless charging at bus stops or taxi stands can maintain operational efficiency.

One of the most exciting areas for patentable innovation lies in the development of behavior-driven WET systems. By leveraging behavioural data from users, WET technologies can be designed to adapt dynamically to individual or collective energy consumption patterns (Piano and Smith, 2022). For instance, AI-powered platforms could predict a user's energy needs based on their daily habits such as commuting times, building usage, or device charging patterns and automatically adjust wireless power supply accordingly. Such personalized energy delivery systems present a fertile ground for patenting unique algorithms and interfaces that make WET systems user-centric. Moreover, gamification and incentive-driven energy systems present another area for innovation. By designing WET interfaces that reward users for efficient energy use, cities could promote sustainable energy consumption while increasing public engagement. For example, integrating real-time feedback systems that show users how much energy they save when using WET, compared to traditional methods, could drive adoption rates. These behaviour-driven systems could become patentable innovations by combining unique methods of data collection, user interaction, and energy management algorithms. Economic strategies for monetizing WET technologies also present a wealth of patentable opportunities. Dynamic pricing models, where users are charged different rates based on peak demand periods or energy efficiency, could be embedded into smart city infrastructures (Saharan *et al*., 2020). Such models can leverage AI-driven analytics to optimize wireless energy pricing, ensuring equitable access while maintaining profitability for energy providers. Patenting these dynamic pricing systems, particularly those that adapt to user behaviour in real-time, would offer a competitive edge to innovators in the WET market. Furthermore, public-private partnerships for financing WET infrastructure open opportunities for creating new economic models that can be patented. For instance, models that allow energy providers, governments, and private companies to share infrastructure costs and profits, while dynamically adjusting prices based on demand, offer a scalable and financially sustainable framework for deploying WET technologies. Patents could be filed for specific methods of structuring these partnerships, including contractual agreements, profit-sharing mechanisms, and incentive structures that encourage investment in WET.

The future of Wireless Energy Transmission in smart cities is marked by tremendous technological advancements and innovation opportunities. With AI-enhanced energy management systems, long-range wireless power transfer, and integration with 5G and IoT, WET will transform how energy is distributed and consumed in urban environments. Opportunities for patenting new technologies abound, particularly in behaviour-driven WET systems and innovative economic models. As these technologies continue to evolve, WET will play an increasingly critical role in powering the cities of the future, offering both environmental sustainability and economic viability.

3. Conclusion

The integration of Wireless Energy Transmission (WET) into smart cities represents a transformative advancement in urban energy systems. This essay has explored the multifaceted strategies necessary for the successful adoption of WET, emphasizing both behavioural and economic dimensions.

Behavioural strategies for widespread WET adoption involve addressing psychological barriers such as public scepticism and resistance to change. Educational campaigns, user-friendly designs, and gamification have proven effective in overcoming these hurdles and fostering acceptance. Economically, high initial infrastructure costs and concerns about return on investment pose significant challenges. Strategies such as public-private partnerships, dynamic pricing models, and subsidies are crucial for mitigating these economic barriers and facilitating widespread implementation. Addressing these psychological and economic barriers is vital to ensure a smooth transition to WET systems, maximizing their potential benefits in urban environments.

Looking ahead, further research is needed to refine WET technologies and optimize their integration into smart cities. Studies should focus on improving energy efficiency, extending the range of wireless power transfer, and enhancing the adaptability of WET systems to diverse urban contexts. Additionally, exploring innovative economic models and behavioural incentives will be essential for fostering adoption and scalability.

A call for multi-disciplinary collaboration is crucial for advancing WET deployment. Combining expertise from fields such as engineering, psychology, economics, and urban planning will facilitate the development of comprehensive strategies that address both technological and socio-economic aspects. Collaborative efforts can drive innovation, streamline regulatory processes, and ensure that WET systems are seamlessly integrated into the infrastructure of future smart cities.

In summary, advancing WET technology and its adoption requires a concerted effort across various domains. By addressing both behavioural and economic challenges and encouraging collaborative research, we can unlock the full potential of WET in creating more efficient, sustainable, and connected urban environments.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

References

[1] Agupugo, C.P., Ajayi, A.O., Nwanevu, C. and Oladipo, S.S., 2022. Advancements in Technology for Renewable Energy Microgrids.

[2] Agupugo, C.P., Kehinde, H.M. and Manuel, H.N.N., 2024. Optimization of microgrid operations using renewable energy sources. *Engineering Science & Technology Journal*, *5*(7), pp.2379-2401.

[3] Ahmad, T. and Zhang, D., 2021. Using the Internet of Things in smart energy systems and networks. *Sustainable Cities and Society*, *68*, p.102783.

[4] Alnahari, M.S. and Ariaratnam, S.T., 2022. The application of blockchain technology to smart city infrastructure. *Smart Cities*, *5*(3), pp.979-993.

[5] Baklanov, A., Cárdenas, B., Lee, T.C., Leroyer, S., Masson, V., Molina, L.T., Müller, T., Ren, C., Vogel, F.R. and Voogt, J.A., 2020. Integrated urban services: Experience from four cities on different continents. *Urban Climate*, *32*, p.100610.

[6] Beard, T.R., Ford, G.S., Spiwak, L.J. and Stern, M., 2020. The law and economics of municipal broadband. *Fed. Comm. LJ*, *73*, p.1.

[7] Bellezoni, R.A., Seto, K.C. and Puppim de Oliveira, J.A., 2022. What can cities do to enhance the water-energy-food nexus as a sustainable development strategy? In *Water-energy-food nexus and climate change in cities* (pp. 39-57). Cham: Springer International Publishing.

[8] Belli, L., Cilfone, A., Davoli, L., Ferrari, G., Adorni, P., Di Nocera, F., Dall'Olio, A., Pellegrini, C., Mordacci, M. and Bertolotti, E., 2020. IoT-enabled smart sustainable cities: Challenges and approaches. *Smart Cities*, *3*(3), pp.1039-1071.

[9] Bibri, S.E., 2019. On the sustainability of smart and smarter cities in the era of big data: an interdisciplinary and transdisciplinary literature review. *Journal of Big Data*, *6*(1), p.25.

[10] Choudhary, P., Bhargava, L., Suhag, A.K., Choudhary, M. and Singh, S., 2021. An era of the Internet of Things leads to smart city initiatives towards urbanization. *Digital Cities Roadmap: IoT-Based Architecture and Sustainable Buildings*, pp.319-350.

[11] Considine, T., Cox, W. and Cazalet, E.G., 2021. Understanding microgrids as the essential architecture of smart energy. In *Automated Diagnostics and Analytics for Buildings* (pp. 345-357). River Publishers.

[12] Cox, S.J. and Henderson, D.M., 2022. State of Utah. *Bull elk*, *211*, p.26.

[13] Dyantyi, O. and Njenga, J., 2022, May. Awareness and Perceptions of Smart Irrigation Technologies by Small Scale Farmers in Rural South Africa. In *2022 IST-Africa Conference (IST-Africa)* (pp. 1-10). IEEE.

[14] Fadairo, O., Alabi-Adelakun, O. and Adetunji, A., 2020. Promoting community-led water, sanitation and hygiene interventions in rural settlements in Oyo state, Nigeria: Lessons from Agile and Mogba communities of Ibarapa-East Local Government Area. *Rural-Urban Link Sustain Dev*, *163*, pp.176-201.

[15] Fartash, K., Azizi, A. and Khayatian Yazdi, M., 2021. Tehran in the path of transition to a smart city: Initiatives, implementation, and governance. *Handbook of smart cities*, pp.361-390.

[16] Filip, R., Gheorghita Puscaselu, R., Anchidin-Norocel, L., Dimian, M. and Savage, W.K., 2022. Global challenges to public health care systems during the COVID-19 pandemic: a review of pandemic measures and problems. *Journal of personalized medicine*, *12*(8), p.1295.

[17] Freed, A. and Zimmerman, R., 2022. Urban systems and services: vulnerabilities and impact. *Climate change and US cities: Urban systems, sectors, and prospects for action*, p.79.

[18] Frieden, R., 2020. The evolving 5G case study in United States unilateral spectrum planning and policy. *Telecommunications Policy*, *44*(9), p.102011.

[19] Ghorbani, Y., Zhang, S.E., Nwaila, G.T. and Bourdeau, J.E., 2022. Framework components for data-centric dry laboratories in the minerals industry: A path to science-and-technology-led innovation. *The Extractive Industries and Society*, *10*, p.101089.

[20] Golding, S.A., 2021. *Electric Mountains: Climate, Power, and Justice in an Energy Transition*. Rutgers University Press.

[21] Guan, P., Zhu, R., Hu, G., Patterson, R., Chen, F., Liu, C., Zhang, S., Feng, Z., Jiang, Y., Wan, T. and Hu, L., 2022. Recent Development of Moisture-Enabled-Electric Nanogenerators. *Small*, *18*(46), p.2204603.

[22] Gupta, K., Zhang, W. and Hall, R.P., 2021. Risk priorities and their co-occurrences in smart city project implementation: Evidence from India's Smart Cities Mission (SCM). *Environment and Planning B: Urban Analytics and City Science*, *48*(4), pp.880-894.

[23] Hoang, A.T. and Nguyen, X.P., 2021. Integrating renewable sources into energy systems for the smart city is a sagacious strategy towards a clean and sustainable process. *Journal of Cleaner Production*, *305*, p.127161.

[24] Hobbie, S.E. and Grimm, N.B., 2020. Nature-based approaches to managing climate change impacts in cities. *Philosophical Transactions of the Royal Society B*, *375*(1794), p.20190124.

[25] Ijemaru, G.K., Ang, L.M. and Seng, K.P., 2022. Transformation from IoT to IoV for waste management in smart cities. *Journal of Network and Computer Applications*, *204*, p.103393.

[26] Jiang, C., Li, X., Lian, S.W.M., Ying, Y., Ho, J.S. and Ping, J., 2021. Wireless technologies for energy harvesting and transmission for ambient self-powered systems. *ACS nano*, *15*(6), pp.9328-9354.

[27] Karki, A., Phuyal, S., Tuladhar, D., Basnet, S. and Shrestha, B.P., 2020. Status of pure electric vehicle power train technology and prospects. *Applied System Innovation*, *3*(3), p.35.

[28] Khan, S.R., Pavuluri, S.K., Cummins, G. and Desmulliez, M.P., 2020. Wireless power transfer techniques for implantable medical devices: A review. *Sensors*, *20*(12), p.3487.

[29] King, S.L., Laubhan, M.K., Tashjian, P., Vradenburg, J. and Fredrickson, L., 2021. Wetland conservation: challenges related to water law and farm policy. *Wetlands*, *41*(5), p.54.

[30] Kumar, H., Singh, M.K., Gupta, M.P. and Madaan, J., 2020. Moving towards smart cities: Solutions that lead to the Smart City Transformation Framework. *Technological forecasting and social change*, *153*, p.119281.

[31] Lee, H. and Baek, K., 2021. Developing a smart multifunctional outdoor jacket with wearable sensing technology for user health and safety. *Multimedia Tools and Applications*, *80*(21), pp.32273-32310.

[32] Lerner, J. and Nanda, R., 2020. Venture capital's role in financing innovation: What we know and how much we still need to learn. *Journal of Economic Perspectives*, *34*(3), pp.237-261.

[33] Li, B., 2022. Effective energy utilization through economic development for sustainable management in smart cities. *Energy Reports*, *8*, pp.4975-4987.

[34] Li, L., Collins, A.M., Cheshmehzangi, A. and Chan, F.K.S., 2020. Identifying enablers and barriers to the implementation of the Green Infrastructure for urban flood management: A comparative analysis of the UK and China. *Urban forestry & urban greening*, *54*, p.126770.

[35] Lin, L. and Chen, C., 2020. The promise and perils of InsurTech. *Singapore Journal of Legal Studies*, (Mar 2020), pp.115-142.

[36] Loury, E.K., Eschenroeder, J.C., Seat, L., Chea, S., Chhut, C., Kritsanavarin, S., Lovgren, S., Ramsay, E.G., Thao, D. and Hogan, Z.S., 2021. Communicating for aquatic conservation in Cambodia and beyond lessons learned from in-person and media-based environmental education and outreach strategies. *Water*, *13*(13), p.1853.

[37] Mahmood, D., Javaid, N., Ahmed, G., Khan, S. and Monteiro, V., 2021. A review on optimization strategies integrating renewable energy sources focusing uncertainty factor–Paving path to eco-friendly smart cities. *Sustainable Computing: Informatics and Systems*, *30*, p.100559.

[38] Maloberti, F. and Davies, A.C., 2022. The Golden Epoch. In *A Short History of Circuits and Systems* (pp. 23-58). River Publishers.

[39] McGenity, T.J., Gessesse, A., Hallsworth, J.E., Garcia Cela, E., Verheecke-Vaessen, C., Wang, F., Chavarría, M., Haggblom, M.M., Molin, S., Danchin, A. and Smid, E.J., 2020. Visualizing the invisible: class excursions to ignite children's enthusiasm for microbes. *Microbial Biotechnology*, *13*(4), pp.844-887.

[40] Meyer, J.E., 2022. Communities Lead the Way. In *The Post-Pandemic World: Sustainable Living on a Wounded Planet* (pp. 233-273). Cham: Springer International Publishing.

[41] Mishra, R.K., Kumari, C.L., Janaki Krishna, P.S. and Dubey, A., 2022. Smart cities for sustainable development: an overview. *Smart cities for sustainable development*, pp.1-12.

[42] Muratkar, T.S., Bhurane, A., Kothari, A. and Bhadoria, R.S., 2022. Ambient Backscatter Communication: A Solution for Energy-Efficient 5G-Enabled IoT. In *5G and Beyond* (pp. 109-131). Chapman and Hall/CRC.

[43] Mutule, A., Domingues, M., Ulloa-Vásquez, F., Carrizo, D., García-Santander, L., Dumitrescu, A.M., Issicaba, D. and Melo, L., 2021. Implementing smart city technologies to inspire change in consumer energy behaviour. *Energies*, *14*(14), p.4310.

[44] O'Dwyer, E., Pan, I., Acha, S. and Shah, N., 2019. Smart energy systems for sustainable smart cities: Current developments, trends and future directions. *Applied Energy*, *237*, pp.581-597.

[45] Ofosu-Ampong, K., Boateng, R., Anning-Dorson, T. and Kolog, E.A., 2020. Are we ready for Gamification? An exploratory analysis in a developing country. *Education and Information Technologies*, *25*(3), pp.1723-1742.

[46] Oliveira, L., Ulahannan, A., Knight, M. and Birrell, S., 2020. Wireless charging of electric taxis: Understanding the facilitators and barriers to its introduction. *Sustainability*, *12*(21), p.8798.

[47] Paiva, S., Ahad, M.A., Tripathi, G., Feroz, N. and Casalino, G., 2021. Enabling technologies for urban smart mobility: Recent trends, opportunities and challenges. *Sensors*, *21*(6), p.2143.

[48] Perera, T.D.P., Jayakody, D.N.K., Sharma, S.K., Chatzinotas, S. and Li, J., 2017. Simultaneous wireless information and power transfer (SWIPT): Recent advances and future challenges. *IEEE Communications Surveys & Tutorials*, *20*(1), pp.264-302.

[49] Piano, S.L. and Smith, S.T., 2022. Energy demand and its temporal flexibility: Approaches, criticalities and ways forward. *Renewable and Sustainable Energy Reviews*, *160*, p.112249.

[50] Pouryazdan, M., Kantarci, B., Soyata, T. and Song, H., 2016. Anchor-assisted and vote-based trustworthiness assurance in smart city crowdsensing. *IEEE Access*, *4*, pp.529-541.

[51] Radini, S., Marinelli, E., Akyol, Ç., Eusebi, A.L., Vasilaki, V., Mancini, A., Frontoni, E., Bischetti, G.B., Gandolfi, C., Katsou, E. and Fatone, F., 2021. Urban water-energy-food-climate nexus in integrated wastewater and reuse systems: Cyber-physical framework and innovations. *Applied Energy*, *298*, p.117268.

[52] Raj, E.F.I., Appadurai, M., Darwin, S. and Rani, E.F.I., 2022. Internet of Things (IoT) for sustainable smart cities. In *Internet of Things* (pp. 163-188). CRC Press.

[53] Ramalingam, S.P. and Shanmugam, P.K., 2022. A comprehensive review of wired and wireless communication technologies and challenges in smart residential buildings. *Recent Advances in Computer Science and Communications (Formerly: Recent Patents on Computer Science)*, *15*(9), pp.1140-1167.

[54] Rasul, G. and Neupane, N., 2021. Improving policy coordination across the water, energy, and food, sectors in South Asia: a framework. *Frontiers in Sustainable Food Systems*, *5*, p.602475.

[55] Sabyrzhan, A., Balgimbekova, G. and Shestak, V., 2021. RETRACTED ARTICLE: Economic and legal regulation of the use and development of renewable energy sources. *International Environmental Agreements: Politics, Law and Economics*, *21*(4), pp.595-610.

[56] Sah, D.K., Poongodi, M., Donta, P.K., Hamdi, M., Cengiz, K., Kamruzzaman, M.M. and Rauf, H.T., 2022. Secured wireless energy transfer for the Internet of Everything in ambient intelligent environments. *IEEE Internet of Things Magazine*, *5*(1), pp.62-66.

[57] Saharan, S., Bawa, S. and Kumar, N., 2020. Dynamic pricing techniques for Intelligent Transportation System in smart cities: A systematic review. *Computer Communications*, *150*, pp.603-625.

[58] Schwartz, E.K. and Krarti, M., 2022. Review of adoption status of sustainable energy technologies in the US residential building sector. *Energies*, *15*(6), p.2027.

[59] Sharda, S., Singh, M. and Sharma, K., 2021. Demand side management through load shifting in IoT based HEMS: Overview, challenges and opportunities. *Sustainable Cities and Society*, *65*, p.102517.

[60] Sunny, F.A., Karimanzira, T.T.P., Peng, W., Rahman, M.S. and Zuhui, H., 2022. Understanding the determinants and impact of the adoption of technologies for sustainable farming systems in water-scarce areas of Bangladesh. *Frontiers in Sustainable Food Systems*, *6*, p.961034.

[61] Tabassum, S., Rahman, T., Islam, A.U., Rahman, S., Dipta, D.R., Roy, S., Mohammad, N., Nawar, N. and Hossain, E., 2021. Solar Energy in the United States: Development, Challenges, and Future Prospects. Energies 2021, 14, 8142.

[62] Temby, H. and Ransan-Cooper, H., 2021. 'We want it to work': understanding household experiences with new energy technologies in Australia. *Final report of the VOICES project (Victorian Energy and Water Ombudsman's Investigation of Consumer Experiences)*.

[63] Toro, U.S., ElHalawany, B.M., Wong, A.B., Wang, L. and Wu, K., 2022. Backscatter communication-based wireless sensing (BBWS): Performance enhancement and future applications. *Journal of Network and Computer Applications*, *208*, p.103518.

[64] Ureta, J., Motallebi, M., Scaroni, A.E., Lovelace, S. and Ureta, J.C., 2021. Understanding the public's behaviour in adopting green stormwater infrastructure. *Sustainable Cities and Society*, *69*, p.102815.

[65] Verbeek, J., Oftedal, G., Feychting, M., van Rongen, E., Scarfì, M.R., Mann, S., Wong, R. and van Deventer, E., 2021. Prioritizing health outcomes when assessing the effects of exposure to radiofrequency electromagnetic fields: A survey among experts. *Environment International*, *146*, p.106300.

[66] Voorwinden, A., 2021. The privatised city: Technology and public-private partnerships in the smart city. *Law, Innovation and Technology*, *13*(2), pp.439-463.

[67] Vushe, A., 2021. Proposed research, science, technology, and innovation to address current and future challenges of climate change and water resource management in Africa. *Climate Change and Water Resources in Africa: Perspectives and Solutions Towards an Imminent Water Crisis*, pp.489-518.

[68] Wang, Y., Chen, C.F., Kong, P.Y., Li, H. and Wen, Q., 2022. A cyber-physical–social perspective on future smart distribution systems. *Proceedings of the IEEE*, *111*(7), pp.694-724.

[69] Zaręba, A., Krzemińska, A. and Kozik, R., 2021. Urban vertical farming is an example of nature-based solutions supporting a healthy society living in the urban environment. *Resources*, *10*(11), p.109.

[70] Zeb, H., Gohar, M., Ali, M., Rahman, A.U., Ahmad, W., Ghani, A., Choi, J.G. and Koh, S.J., 2022. Zero energy IoT devices in smart cities using RF energy harvesting. *Electronics*, *12*(1), p.148.