"From Footsteps to Megawatts": Kinetic Energy Harvesting from Pedestrian and Vehicular Movement in Urban Environments

[1.]Ajene Adam AJENE & [2.]Joy Okache OMAGA

[1]*Department of Urban and Regional Planning, Moses Orshio Adasu University, Makurdi, Benue State*
[2]*Department of Science Mathematics Education, Moses Orshio Adasu University, Makurdi, Benue State*

Abstract
The combination of urban growth along with increasing energy requirements requires new approaches for supporting conventional renewable power generation. Kinetic energy harvesting (KEH) from pedestrian and vehicular movement has shown to provide great potential for sustainable urban energy, though this has been underexplored. This study examines cutting-edge KEH technology systems which include piezoelectric control, electromagnetic induction and triboelectric nanogenerators from a perspective of performance analysis, urban integration and policy implications. A systematic study of literature and case studies conducted between 2015 and 2024 revealed that the main hurdles blocking KEH progress were its low efficiency rates, instability of materials, high price and public resistance. Considerable levels of success in the implementation of KEH in cities like London and Tokyo have shown the potential of KEH in high-traffic zones, while hybrid systems (a combination of KEH and solar/wind technology) offer stability. This study recommends a multi-phase approach for testing new energy systems together with performance tracking methods and collaborative engagements between public and private entities to boost KEH implementation while focusing on Nigeria's framework for developing nations. KEH's evolution depends on the resolution of present-day challenges so it can achieve foundational status in smart city frameworks by utilising earth's untapped underground energy potential.

Keywords: Kinetic Energy Harvesting, Urban Renewable Energy, Piezoelectric Technology, Smart city infrastructure, Sustainable Mobility

1.0 INTRODUCTION

Cities across the world are undergoing rapid growth in the 21st century due to the steady increase in energy demands. The projected global urban growth to 70% will intensify the strain on current energy systems (Esfandi, 2024). The transition from fossil fuels to low-carbon systems necessitates significant innovations in renewable energy technologies and energy storage due to climate change mandates (Kabeyi & Olanrewaju, 2022).

While discussions about sustainable energy tends to focus on solar and wind power, these technologies face limitations when it comes to city implementation due to continuous land and occupation challenges. Interest in kinetic energy harvesting (KEH) is thus emerging because of its capabilities to convert human, mechanical and vehicular motion into electricity. The history of KEH as a technology covers two specific early applications through piezoelectric lighters and self-winding watches. Modern advancements in material technology together with energy storage systems and smart infrastructure technologies have given KEH a new potential as an implementation option for urban deployment across a large scale (Mohapatra, 2024; Kumar et al., 2024; Liang et al., 2023). Alternatively, KEH technology

operates by transforming surplus kinetic energy from footsteps and vehicular motion, together with road vibrations into electricity for practical use. The field of human-powered power generation consists of three core technologies that operate at the current time: these are:

1. Piezoelectric Systems that generate voltage when mechanically stressed using components such as embedded tiles (Sharma et al., 2022).
2. Electromagnetic induction which uses magnets in coils which can be applied in transportation systems such as in speed bumps (Wang et al., 2016)
3. Triboelectric Nanogenerators (TENGs) technology which transforms friction-driven static electrical charges into usable energy (Chen et al, 2023)

The total energy use of cities lies heavily in transportation and public settings where it consumes an average 30 percent of the energy (IEA, 2020). KEH offers unique advantages:

- The generated energy that is available at the point of use especially at points of high traffic flow patterns, significantly reduces the dependency on conventional grid energy thus encouraging decentralization (Jintanawan et al., 2020).
- High-activity areas with high footfall traffic such as busy sidewalks, metro stations and highways provide consistent energy output (Sandhya, 2021).
- Through synergy with the use of Smart Cities technology, KEH can monitor real-time energy use as part of IoT-based infrastructure integration for adaptive functionality

The Pavegen walkways in London and Tokyo's piezoelectric train stations are evidence of great potential in the use of KEH technology where foot traffic produces energy to operate lighting systems and sensors without requiring significant space area (Nia et al, 2017; Cuneo, 2023). The conversion rate of most KEH systems into electricity stays below 20% as deduced by Bai & Liu (2021), De lacovo et al (2025) and Chen et al (2023). There are other factors such as durability issues whereby urban environments demand weather-resistant and wear-proof materials. Economic viability needs to be addressed to encourage scalability and safety concerns also have to be further studied to gain widespread public approval.

The paper seeks to review frontline KEH technologies and their performance metrics, analyse urban integration challenges through case studies and propose policy and design strategies. It also explores how combining technical analysis and urban planning methods will speed up KEH implementation for future sustainable urban environments.

2.0 RESEARCH PROBLEM

Kinetic Energy Harvesting (KEH) from urban movement is often perceived as having great potential, yet highly underexplored in the field of renewable energy. After decades of research, it remains largely confined to pilot projects and niche applications. Four linked obstacles have increasingly widened the gap between KEH theoretical concepts and actual deployment because they become more pronounced during operations in urban environments. Firstly, KEH experiences poor energy conversion efficiency as its essential operational limitation (Bai & Liu., 2021; De lacovo et al., 2025; Chen et al., 2023). The problem intensifies as the area experiences low traffic flow. The fundamental question about KEH systems' competition potential for central power grids since they currently function as supplementary systems. In 2006, East Japan Railway Company implemented a trial of piezoelectric tiles at Tokyo Station's Yaesu North Exit to harvest energy from pedestrian foot traffic. The $6m^2$ installation generated approximately 10,000 watt-seconds (10kJ) of energy daily. This output equates to powering a 100W bulb for 100 seconds, demonstrating the direct relationship between pedestrian movement and energy yield.

Secondly, Cities rated as hostile sites create a challenge regarding material durability. The brittle nature of piezoelectric ceramics (tiles) causes them to deteriorate with time which eventually leads to replacement needs. The material choice together with environmental factors and usage patterns determine the product's operational period. Lead zirconate titanate (PZT) emerged to replace quartz in energy harvesting technology because it has become the principal choice among materials for power scavenging purposes (Ogbonna et al., 2022). The high operational efficiency of TENGs nonetheless makes them unfit for moist environments such as London or Tokyo because water exposure causes system failure according to Zhang (2024). The durability of TENGs was questioned during the second trial carried out at Tokyo Station. The energy generation capacity of these materials showed decreasing levels during three weeks of continuous pedestrian traffic due to wear and tear of the materials. The trial showed that stronger materials should be developed to face ongoing mechanical stress (Solbam & Mousa, 2019).

Thirdly, the major expense challenge emerges as the third issue. The implementation of piezoelectric systems in road infrastructure requires higher expenses than standard asphalt installation costs as reported by Mou et al (2025). According to Gaber (2023) KEH shows promising ROI potential which lasts more than 7 to10 years despite standard city development projections for 3 to 5 years. High prices caused by limited manufacturing means stop the government from securing bulk manufacture agreements. The research on using piezoelectric

tile systems in public transportation places like metro stations revealed substantial financial difficulties. The technologies faced challenges in their widespread adoption because of their high start-up expenditures and continued maintenance expenses. The researchers stressed that organisations must perform a detailed cost-benefit assessment before starting new projects (Moussa et al., 2021).

Fourthly, people shun walking pathways that show unevenness and experience vibrations when walking on them. SolaRoad sought to produce electricity through solar panels built into Netherlands bike path infrastructure. The project started with optimism but experienced severe degradation of the walking path surface which caused public apprehension about the functionality of modern power generation technologies. Researchers pulled out the path during 2020 because they feared its practical implementation (Bio journaal 2025; De Orkaan 2015). Making sustainable green infrastructure presents difficulties alongside meeting typical economic standards. Projects should be initiated first in selected strategic locations like train stations or solutions can be launched across the entire network. The successful improvement of KEH requires diverse expertise since research scientists need to enhance durability alongside urban planners who establish optimal locations and financial policy makers who minimise funding risks.

3.0 METHODOLOGY

The study employs a systematic literature review of peer-reviewed articles, technical reports and case studies from 2015 – 2024. Databases including IEEE Xplore, ScienceDirect and Scopus were queried using keywords: "Kinetic energy harvesting," "Piezoelectric sidewalks" and "smart city energy solutions." Inclusion criteria prioritised empirical data on energy output, efficiency and real-world deployments.

The scope of the study technologically is limited to piezoelectric, electromagnetic induction and Triboelectric nanogenerators (TENGS). Geographically it covered global case studies with emphasis on Sub-saharan Africa. While the metrics deal with efficiency (lab versus field), cost and scalability, the exclusion criteria include theoretical models without experimental validation and studies which predate 2015.

4.0 FINDINGS AND THEMATIC ANALYSIS

A substantial amount of research about kinetic energy harvesting from pedestrians and vehicles emerged during the last ten years because of technological materials developments as well as smart cities and renewable energy developments. Subsequently, a detailed and verified review on the major technology categories has been presented.

4.1 Performance Metrics of KEH Technologies

4.1.1 Piezoelectric

Piezoelectric energy harvesting systems are devices that convert mechanical energy, like vibrations or pressure into electrical energy, using piezoelectric materials. These materials can generate electric charge when subjected to mechanical stress. The harvested energy can then be used to power small electronic devices or store in batteries (Li & Lee, 2021). The mechanical stressing of lead zirconate titanate (PZT) and polyvinylidene fluoride (PVDF) materials produces electrical voltage output. Recent studies, along with laboratory trials indicate that:

i. PZT tiles can operate with much higher efficiency than the actual usage which produces significantly lower because of uneven loading stress (Covaci & Gontean., 2020; Bahmanziari & Zamani., 2024; Lee et al., 2023; Wang et al., 2021).
ii. PVDF films are more flexible and durable (~5 million cycles) but produce lower power density (0.5–2 W/m²) (Liu et al., 2022; Dallaev et al., 2022).



Fig 1: Electricity-generating floor tiles using Piezoelectric Technology
Source: Adapted from Refell (2025) Cannon (2017) TechJuice (2025)

These have been deployed by Pavegen in (London, UK) in shopping centres and schools and they generate 5 - 7w per step (Manthorpe, 2016). Tokyo Metro in Japan also has installed piezoelectric floors in Shibuya Station power LED signage with ~1.1 kWh/day (Bluesci, 2021; Li & Strezov, 2014).

4.1.2 Electromagnetic Induction systems

i. Vehicular Applications (Roads/Speed bumps) - Road and speed bump infrastructure uses vehicle kinetic energy to generate electricity through Faraday's law of induction in electromagnetic systems. The technology is suitable for installation on both roads and speed bumps.

- Each vehicle passing through speed bump generators produces electricity in the range of 10–30 W according to Farooq et al. (2020), Wang et al. (2020) and Sabri et al. (2018).
- Road-embedded coils (e.g., Energenix) claim 200 kWh/day per km but require high traffic density (>500 vehicles/hour) (ENRX, 2024; Sabri et al., 2018).

ii. Pedestrian Applications - Pavegen has made floor tiles from which pedestrians generate electricity through processes of electromagnetic induction. The downward tile compression generated by foot movement activates an internal electromagnetic generator that produces electrical energy. This energy can be used to power low-voltage applications such as LED lighting, sensors, and data transmission devices (Insights, 2025). Some of these have been installed in West Ham underground station, London in 2012, Dupont Circle, Washington DC in front of the White House, incorporating approximately 100 Pavegen tiles (Crandall, 2016) and Oxford Street, London. In 2013, 178 tiles were also installed near the finish line of the Paris Marathon. From the footfalls of 40,000 runners crossing the line, Pavegen fed energy back into the grid. In 2015, 100 tiles were installed on a football pitch in Lagos, Nigeria and the feet of the soccer players power the floodlights for the arena (Mandel, 2025).

4.1.3 Triboelectric Nanogenerators (TENGs)

Triboelectric nanogenerators (TENGs) work by converting mechanical energy into electrical energy through a combination of triboelectric effect and electrostatic induction (Wang, 2013).



Figure 2: TENG converts mechanical vibrations into electricity, which can be used for electrical powering or vibration sensing applications
Source: Haroun et al (2022)

Tests conducted in lab facilities show that TENGs achieve energy conversion efficiency rates between 50% and 85% although testing under natural conditions shows typical results between 5% and 8%. Real products used in the field produce lower efficiencies when compared to laboratory conditions where results range from 5% to 8%. The performance of TENGs declines because environmental elements have negative effects on their operation (Wang, 2023).

Outdoor application gets restricted because of the fact that materials show sensitivity to moisture. TENG materials face water molecule absorption on their surfaces because of excessive humidity conditions. The attachment of water molecules will increase the surface conductivity which results in decreased triboelectric effect that leads to efficiency loss. The output voltage output from a TENG made of nylon-11 experienced a 90% decrease when the relative humidity level rose from 15% to 95%. (Zhang, 2024)

Table 1: Comparative Analysis of KEH Technologies

Parameter	**Piezoelectric**	**Electromagnetic**	**Triboelectric Nanogenerators (TENGs)**
Operating Principle	Converts mechanical strain into electric charge via crystal lattice	Relative motion between a coil and magnetic field induces current	Contact electrification and electrostatic induction
Power Output	~0.1–0.3 mW/cm²	25W/vehicle; 2.1 kWh/day/100m	~0.01–0.1 mW/cm² (real-world)
Efficiency	20–30%	Up to 70% (lab)	Lab: 15–25%, Real: 5–8%
Durability	Brittle under high strain	Robust, long-life	Moisture-sensitive, lower durability
Cost	High (Installation materials)	Moderate	Low production, higher maintenance
Scalability	Moderate (sidewalks)	High (vehicular roads)	Low (urban), high (wearables)
Example	Tokyo station	California smart bumps, Israel	South Korea (wearables, sensors)

Source: Synthesised from Sun et al 2023, Zhang et al., 2024, Zhang et al., 2022, Muscat et al, 2022, Nguyen et al., 2015 and Chang et al., 2022.

The analysis of these three technological systems identifies three key research gaps. First, it reveals the lack of standardised testing. Most studies tend to report lab efficiencies and not necessarily field performance of these systems, thus not providing realistic outcomes on performance and efficiency. Secondly, only very few available projects tend to monitor durability of systems beyond 2 years which is inadequately conclusive for arguments. Third is the issue of economic feasibility. Despite the level of technological advancement, high costs of the systems are still persistent.

Based on the review and synthesis in assessing state of the art KEH technologies, it is evident that while piezoelectric systems tend to be more dominant in the market and current deployment, TENGs and electromagnetic solutions are showing some potential for future scalability.

4.2 Urban Planning Implications of Kinetic Energy Harvesting (KEH) in Smart Cities

Urban infrastructure integration of KEH systems offers transformative capabilities as well as complex challenges for the cities' planning sector and engineering departments as well as governmental policy development units. This will be discussed in detail.

4.2.1 Areas of Deployment of KEH for Spatial Optimization

High-Impact Zones: The energy potential of these floors reaches between 0.1 and 5kWh/day according to Worwavs (2025: Bluesci, 2021). KEH systems produce greatest power generation within areas featuring high vehicular traffic such as traffic signals as well as toll stations and speed bumps. Traditional energy harvesting technologies receive testing as part of pilot experiments which implement embedded piezoelectric systems within California road infrastructures. The project attempted to develop an electrical energy density configuration of 333 watts per square foot. Independent tests showed that this system can produce yearly energy outputs between 72,800 kilowatt-hours by installing it to one-mile of single-lane roadway. The annual energy output exceeds 907,873 kilowatt-hours per mile for heavy truck traffic which leads to carbon dioxide emission reductions amounting to 300 metric tonnes (Sun et al., 2023; Owano, 2011; CBS, 2009). Also, New Energy Technologies developed the MotionPower Express system, a "rumble strip" device designed to capture kinetic energy from vehicles as they slow down. The power generated from six hours of 580 cars passing the device at the Roanoke Civic Centre in Virginia served to energise a 150-square-foot electronic billboard for a complete day. The suitable application for this system occurs at locations where vehicles naturally decrease speed including toll booths rest areas and parking lots (Owano, 2011; CBS, 2009).

Low-Impact Zones: Sub-urban sidewalks and low-traffic roads may not justify costs due to insufficient energy yield.

4.2.2 Planning tools

- **GIS-based traffic modelling –** This can be used to identify optimal KEH sites such as heat maps of pedestrian/vehicle flow.
- **Public-private partnerships-** Such collaborations with malls and similar districts can drive down or offset installation costs.

4.2.3 Infrastructure Integration

Piezoelectric sensors need particular modifications in asphalt pavements sublayers to reach stability and operational functionality for energy harvesting objectives. Extra costs for construction together with delayed project schedules become direct consequences of these modifications. The implementation process and financial consequences tend to create additional costs and require longer construction time as well as modifications to the infrastructure (Enviko 2025). Using piezoelectric sensors in urban infrastructure needs the destruction of existing surfaces with subsequent changes made to roads and sidewalks. Public works leading to infrastructure changes produce notable disturbances within urban transportation networks which result in both traffic jams and transportation delays. The urban redevelopment plan in Rotterdam faced one year of delay because of unexpected events. The pandemic caused most of the delay but this incident demonstrates the hurdles which urban infrastructure projects frequently encounter (Ampler, 2022).

Urban planning obtains a forward-thinking direction through the integration of modular piezoelectric tiles during original pavement development. This implementation enhances both energy efficiency performance while supporting cities in their commitment to sustainability as well as innovation-led methods. Urban development requires such integrated solutions to establish resilient and environmentally friendly infrastructures according to Sharma et al. (2022). The municipal government of Amsterdam demonstrates solid environmental dedication through private information about financial support for KEH solutions in new transit hubs. Amsterdam has established 2030 as its timeline to transform every form of transportation into emission-free operations as part of its environmental sustainability drive (Willige, 2019). Similar incentives demonstrate how KEH systems support objectives that focus on sustainability which indicates KEH adoption may be part of extensive green initiatives.

4.2.4 Synergising Energy Grids and Microgrid Potential

Urban microgrids can benefit from Kinetic Energy Harvesting (KEH) systems because they assist other renewable sources like solar and wind in reducing peak demand. The 2012

London Olympics featured Pavegen's kinetic tiles as part of their installation. West Ham tube station received an installation of Pavegen tiles that transformed human activity-related energy into electric power to light the station's walkway with LED fixtures. During the event period the energy generation system produced 72 million joules of power which demonstrated KEH's potential for urban energy improvement (Wired, 2012).

Stable power supply requires the combination of energy storage systems with Kinetic Energy Harvesting (KEH) solutions for managing variable energy flow. Short-term applications of super capacitors function as effective buffers for the irregular output of KeH systems (Leem, 2020) and researchers are exploring saltwater batteries as long-term alternatives to lithium-ion batteries (Redway, 2024; Mims, 2024).

4.2.5 Policy and Governance Frameworks

Integrating KEH systems into urban infrastructure presents both opportunities and challenges. Based on the information available, subsidies, mandates and barriers will be highlighted: Through subsidy implementation the UK government works to advance energy-saving technologies by instituting various measures. With effect from February 1st 2024 retrofitted battery energy storage systems (BESS) were to receive VAT exemption as part of government policy to promote energy storage technology adoption (Lynas 2024). The VAT relief for energy-saving materials now includes buildings used exclusively for relevant charitable objectives like village halls. The government has added three new materials to its qualification list: water-source heat pumps, electrical battery storage and smart diverters (Tax Journal, 2024; Gov.Uk, 2024) In terms of mandates. the Singaporean organisation Land Transport Authority (LTA) performs feasibility analysis on upcoming rail infrastructure projects like Tengah and Seletar Lines to improve public rail connexions. Different factors are evaluated during these studies to determine integration options for efficient energy technologies (Land Transport Authority, 2025; Guang-Xi, 2025).

Standardised metrics are absent from the evaluation process. Different designs and technologies in energy harvesting systems lack a standard measurement system which prevents their effective comparison (Gawron et al., 2021; Liu et al., 2022). The implementation of KEH projects faces challenges due to the difficulty in coordinating funding along with implementation between transportation and energy agencies.

4.2.6 Social Inclusiveness and Public Acceptance

i) Community engagement - The process of involving people throughout the community development stages boosts adoption acceptance rates among the general public. The KEH plaza in Seoul implements a collaborative process

with residential stakeholders according to arguments presented by OIDP (2025), Seoul Metropolitan Government (2021) and Jeon (2023). Community perception about acceptance or opposition to certain projects strongly depends on their aesthetic attributes. "Invisible" installations such as subsurface piezoelectric installations face less resistance.

ii) Equity Risks **-** The first adoption of KEH will likely happen in wealthy territories thus creating more energy poverty across different demographics. The mitigation process should consider using transit hubs from low-income neighbourhoods as possible installation locations.

4.2.7 Economic viability and Mitigation

KEH technologies could get implemented faster in wealthier districts which would worsen current energy inequality between different socioeconomic groups. Studies show that low-income communities along with minority populations face higher exposure to both energy and transport poverty and thus face limitations in obtaining sustainable energy solutions (Del Rio et al., 2023).

KEH deployment at transit stations that serve disadvantaged communities should be made a top priority to ensure equal sustainable energy benefits reach everyone. The commitment to invest in public transit and infrastructure inside underserved communities improves energy security while minimising poverty gaps (C40 Knowledge, 2022). Activated through participatory design and aesthetic consideration with equal deployment processes, these KEH initiatives will enable social urban growth while sharing sustainable technology advantages throughout entire community networks.

5.0 RECOMMENDATIONS

Recommended guidelines are hereby provided for both urban planners and policy makers. City planners need to follow a three-part process which involves phased, data-driven and policy approach to achieve optimum Kinetic Energy Harvesting (KEH) results in urban applications. This text outlines four essential strategies which receive expanded implementation paths and practical examples.

1. ***Pilot tests*** – The implementation of KEH technology should begin with testing at busy low-risk zones because these pilots decrease the financial exposure during performance validation. The implementation of pilot KEH tests allows for the development of trust through the accomplishment of small and noticeable successes. The target locations can include bus Stops with high foot fall, pedestrian Crosswalks with consistent foot traffic and bike Lanes with moderate-speed kinetic energy

This can be done through partnerships with universities for independent performance monitoring and also, the use of modular designs such as removable piezoelectric tiles for easy upgrades.

2. ***System Hybridisation*** – The coupling of KEH with wind power or solar generates stabilised output systems. Regular power stability comes from hybrid systems even though KEH operates on an intermittent basis.
3. ***Legislation*** – KEH mandates are vital for new public infrastructure deployments because they allow new adopters to maximise scalability when implementing their KEH systems. The implementation of KEH at the construction phase helps eliminate unnecessary retrofit expenses.
4. ***Monitoring*** – Keeping track of and integrating Internet of Things (IoT) sensors within KEH projects remains vital because it builds performance capabilities while extending system durability and giving vital data useful for extra investments. KEH systems failed frequently due to lack of maintenance in their initial installations unless monitored. The implementation of IoT sensors provides real-time tracking for performance management which allows proactive maintenance operations and minimises unwanted system breakdowns. Operational efficiency advantages are ensured and energy generation stability is achieved through this method.

Policy Insights for Integrating Kinetic Energy Harvesting Technologies in Nigeria

i. Strategic Pilot Deployments in High-Traffic Urban Zones **-** High pedestrian and vehicular volumes found in Nigeria's dense urban centres including Lagos and Abuja and Port Harcourt make them suitable locations for KEH deployment. The success of KEH deployment starts with implementing pilot projects at Balogun Market walkways in Lagos alongside Murtala Mohammed airport walkalators and Eagle Square pedestrian paths in Abuja. The deployment strategy receives backing through analysis of comparable international projects. The adoption of energy-efficient piezoelectric tiles by Delhi Metro demonstrates how India invests in alternative power generation schemes for lighting infrastructure. (Bhatt et al., 2015). Building partnerships between NSIA and other bodies could mobilise funds to initiate such projects by using infrastructure development capital provided by NSIA. The Nigeria Sovereign Investment Authority (NSIA) and similar bodies can collaborate to finance such projects using their available infrastructure development funds.

ii. Policy Amendments for Renewable Energy Integration **-** KEH needs to become an essential part of Nigeria's energy transition by modifying the National Renewable Energy and Energy Efficiency Policy (NREEEP) along with updating the 2022 National Renewable Energy

Plan to recognise KEH as an alternative power source. The energy policy of Lagos State supports renewable solutions so it should set an example by ordering KEH installations throughout its upcoming public walkway projects including the Lekki-Ikoyi Link Bridge expansion. The 2021 Green Building Code of Rwanda requires sustainable integration in public infrastructure similar to this approach (Republic of Rwanda, 2019).

iii. Mobilising Investment through Public-Private Partnerships (PPPs) **–** The planning, design, construction and operation of KEH have a number of pros and cons that can be enlisted to be attractive to private investors. One of the points that come up is the concession agreement method were companies such as Pavegen or Energy Floors could still be responsible for the installation and maintenance of KEH tiles if they were given the rights to display their advertising (A model successfully used on London's Oxford Street). Thus, in case of the said concession, the Companies Income Tax Act of Section 23 of Nigeria clearly allows for tax holidays which renewable technology producers can benefit from. South Africa adopted a similar PPP structure that supported piezoelectric walkway installations at the Durban International Convention Centre in 2023 (Durban ICC Sustainability Report, 2023)

iii. Enhancing Local Manufacturing and Employment - Given the current scenario, KEH systems serve as not only a source of energy but also as an economic multiplier. Rejuvenation of Ajaokuta Steel for sensor housing and assembly parts can provide capacity for local manufacturing of KEH components. In addition, the National Directorate of Employment (NDE) can pursue personalised training courses directed towards KEH system installation and maintenance. The data available tells us that building a kilometre of KEH-enabled sidewalk can give about 120 jobs to the local population, not only to production but also to maintenance (UNIDO, 2020).

v. Enabling Frameworks and Monitoring Systems – In order to promote further research and innovation, agencies such as the Nigerian Electricity Regulatory Commission (NERC) can establish a regulatory framework for KEH systems in order to allow for initial deployments. The inclusion of academic institutions like University of Lagos (UNILAG), Federal University of Technology, Akure (FUTA), and Ahmadu Bello University, Zaria (ABU) could pioneer KEH research by accessing TETFUND sponsorship. This has to be followed up with monitoring and evaluation as a key part of the implementation process. KEH performance can be monitored in real-time using IoT and AI-driven solutions, similar to the systems installed at the Shinjuku Station in Tokyo (East Japan Railway Technical Review, 2022). Mobile network operators such as MTN and Airtel can also key in by providing

support to the infrastructure. Tax exemptions on KEH imports under ECOWAS renewable energy protocols public awareness campaigns can enable public acceptance and sustainability.

A combination of these policy actions will propel Nigeria to the top of the smart infrastructure innovation ranking in Sub-Saharan Africa, and at the same time, will provide the country with the capacity to measure social, economic and environmental development in addition to positive public feedback.

CONCLUSION

Kinetic Energy Harvesting is not the ultimate solution, but it could be a starting point for cities to develop their smart urban ecosystems. To seize the whole potential, the city can take direction in several ways:

1. ***Starting small and Growing Smartly:*** Through pilot projects, the city can turn the risk of implementing a new technology into uncertainty about the income (ROI).
2. ***Using Hybridisation to Enable:*** KEH in combination with solar, wind, and storage is more effective as against KEH as a lone system.
3. ***Legalize with openness to change:*** Strategies should be changing along with technology and thus leaving much flexible space for adaptation at the same time allowing for in-depth regular checks of the law
4. ***Condition-Based Repetition:*** First-hand information can't be compared with laboratory experiments so it's better to be results-oriented in reality than in theory.

Tokyo and Singapore illustrate a wider range of KEH's values, from generating public engagement in sustainability to creating environmental job opportunities that secure the infrastructure behind urban development. It will witness further change towards partnerships with engineers who enhance resilience, planners who optimise placement, and policymakers who ensure risk in investment is minimised. Urban energy of the future resides not only in solar above us or wind beside us. The future could very well be beneath our feet.

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