A REVIEW ON ECO: POWER PIEZO TILE FOR SUSTAINABLE ENERGY HARVESTING

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ABSTRACT
This Term Paper explores collection of journals explores intersection. The process of obtaining and transforming environmental energy into electrical power that can power a variety of electronic devices is known as energy harvesting. The particular application and the environment in which the device is used determine which energy harvesting source is most effective. The strengths and challenges of various sources vary, and depending on the situation, some may be more appropriate than others. This project analyses the idea of energy harvesting with piezo tiles, an inventive and sustainable method of generating electricity. By transforming the mechanical energy of footsteps into electrical energy, piezoelectric tiles offer a clean and environmentally friendly power source. A piezo tile-based energy harvesting system that can power small devices, lighting systems, or even contribute to the grid is being designed, developed, and examined as part of this project. The abstract presents the main features of the project, such as the energy harvesting circuit, the piezoelectricity principles, the piezo tile design, and potential applications of the technology. This project contributes to a more environmentally friendly future by emphasising the potential of piezo tiles as a feasible renewable energy source.
Keywords: Energy harvesting, Piezo tiles, Piezoelectricity, Renewable energy, Sustainable power.

I. Introduction
The world is moving toward sustainable solutions because of the rising demand for energy and the negative effects of fossil fuels. Traditional power generation methods, such as coal and petroleum, are limited in supply and harmful to the environment. To overcome these problems, researchers are exploring renewable energy sources that are clean, reliable, and efficient. One such innovative approach is the use of piezoelectric tiles for energy harvesting. Piezoelectric tiles work on the principle of the piezoelectric effect, where certain materials generate electric charge when subjected to pressure, stress, or vibration. These tiles are designed in such a way that when a person walks over them, or when vehicles move across, the pressure applied is converted into electrical energy. This process transforms the everyday movement of people into a source of power. The electricity produced by piezo tiles can be stored in batteries or directly used for small applications, such as powering LED lights, charging mobile devices, or running sensors. The idea is simple but powerful: convert wasted mechanical energy from footsteps and vibrations into useful energy. By implementing these tiles in high-footfall areas such as railway stations, airports, shopping malls, schools, or busy roads, significant amounts of energy can be generated.

II. Literature
[1] Mouna Ben Zohra et al., This study builds on prior research integrating piezoelectric materials and shape memory alloys (SMAs) for energy harvesting. Earlier works explored piezoelectric ceramics, cantilever beams, and SMA dampers to enhance efficiency and durability. The literature highlights fatigue issues and stress instability, which this paper addresses by proposing a hybrid SMA-piezoelectric system that improves energy output, stabilizes stress, and extends lifespan—advancing smart infrastructure applications. [2] Muhammad Ikbal et al., build on prior research into piezoelectric energy harvesting from vehicle tires. Earlier studies explored PZT and PVDF materials, highlighting issues with brittleness and heat sensitivity. Recent advancements introduced flexible

PVDF films and protective layers. This paper refines the approach by integrating a TPU end-cap system, enhancing durability, thermal resistance, and output—addressing limitations in previous designs and improving wireless sensor support**.** [3] Luciano Mendes dos Santos et al. build on prior studies of piezoelectric energy harvesting, focusing on PZT tablet configurations and rectification techniques. Earlier research explored series and parallel setups, but lacked analysis under high-vibration conditions. This study introduces hybrid arrangements and diode bridge rectification, showing enhanced power output. It advances sustainable energy harvesting for agricultural machinery, addressing limitations in efficiency, vibration response, and practical deployment. [4] Filiz Mizrak et al., reviews piezoelectric energy harvesting materials for smart urban infrastructure, emphasizing their efficiency, scalability, and environmental impact. Materials like $BaTiO_3$ and ZnO are highlighted for sustainability, while PZT offers high energy output but raises ecological concerns. The study integrates advanced decision-making models to evaluate material suitability, contributing a strategic framework for sustainable urban development and smart city planning. [5] Xinxin Ma et al., developed a compact broadband piezoelectric energy harvester (CBPEH) featuring dual resonant frequencies for enhanced vibration energy capture. Their design integrates a self-powered SDCS-SECE interface circuit to optimize phase control and reduce energy loss. Experimental validation confirms high power density and stable performance, making the system a promising candidate for powering wireless sensor networks in Internet of Things applications. [6] Wenbin Kang et al. review mechanical energy harvesting, comparing traditional piezoelectric methods with advanced ferroelectric/ferroelastic switching. They highlight limitations in power density and frequency adaptability of conventional systems, and propose switching-based strategies for enhanced energy output. The study explores material innovations, structural designs, and metamaterials, offering insights into future directions for sustainable, high-efficiency energy harvesters in wearable electronics and IoT applications. [7] Abdulla Alsaad et al. present a wearable hybrid energy harvester (WH-EH) integrating piezoelectric and electromagnetic mechanisms to capture human motion energy. Designed for shoe integration, the device features a cantilever beam with magnets and micro planar coils. Experimental results show a peak power output of 577 µW, outperforming similar devices. The study highlights WH-EH's potential for powering sustainable wearable gadgets and advancing self-sufficient electronics. [8] Weijia Xiu et al. present a piezoelectric-electromagnetic vibration energy harvester with real-time adjustable resonant frequency using magnetic spacing. The device integrates bending piezoelectric transducers to enhance magnetic potential energy utilization. Experimental results show peak power of 9.1 mW at 2g acceleration and tunable resonance from 12.4 Hz to 18 Hz. This design improves energy harvesting efficiency and adaptability for dynamic environments. [9] Muhammad Akbar Asis et al. investigate sloshing mitigation and energy harvesting using flexible piezoelectric nanogenerators (PENG). Through SPH simulations and experiments, they demonstrate that perforated flexible baffles reduce kinetic energy by up to 76.42% and generate power up to 145.2 mW/m^3. The dual-function design enhances structural stability and energy efficiency, offering a sustainable solution for maritime environments under dynamic fluid-structure interactions. [10] Omar Hussein et al. propose a hybrid energy harvesting system combining solar tracking panels and piezoelectric footsteps to address urban and rural power needs. The solar tracker, optimized for Baghdad's solar angles, achieves up to 99% efficiency. Footsteps embedded with 48 piezoelectric sensors generate 0.12–0.42 kWh daily. The system ensures 100% DC power transmission efficiency, offering a cost-effective, sustainable solution for off-grid applications. [11] Amal Megdich et al. developed a bio-inspired 3D-printed piezoelectric energy harvester using PVDF/BT nanocomposites. The optimized BT-30 composition achieved a high β-phase fraction and piezoelectric coefficient. Innovative 3D structures enhanced stress distribution and voltage output, reaching 30.8 V. The device powered a smart wireless mouse, demonstrating practical self-powered applications. Numerical and experimental analyses confirmed superior performance and durability of the proposed design. [12] Tao Yang et al. developed a high-output piezoelectric nanogenerator using textured $CsPbI_3$ nanorods embedded in

PVDF fibers. Through texture engineering and self-polarization, the device achieved a record 81 V output without electric poling. The composite demonstrated excellent thermal and water stability, enabling reliable energy harvesting in diverse environments. This work highlights the potential of halide perovskite-polymer hybrids for powering low-energy electronics like LEDs and smart wearables. [13] Bankole I. Oladapo et al. review advancements in piezoelectric materials for biomedical implants, emphasizing self-healing, stretchability, and hybrid energy harvesting. They explore integration with thermoelectrics for continuous power generation and highlight biodegradable, adaptive designs aligned with UN Sustainable Development Goals. The study underscores the potential of nano-fillers and structural engineering to enhance resilience, efficiency, and sustainability in next-generation implantable energy harvesting systems. [14] Meryiem Derraza et al. present a mathematical model to predict electrical energy harvested from $BaTiO_3$/PLA piezoelectric composites under mechanical strain. By analyzing material properties and strain frequencies, the model identifies optimal ceramic-polymer ratios for energy efficiency. Experimental validation confirms peak power output of 4.5 μW at 1% strain with 60% $BaTiO_3$. This approach advances smart system applications and sustainable energy harvesting technologies. [15] J.R. Leppe-Nerey et al. explore energy harvesting from car tires using PVDF/PMMA polymer films enriched with multi-walled carbon nanotubes (MWCNT). Their study identifies 0.05 wt% MWCNT as optimal for maximizing piezoelectric output. Simulated tire stress tests show enhanced voltage generation, with potential energy recovery up to 4.3 kWh over a 100 km trip. The research supports sustainable energy solutions through advanced nanocomposite materials. [16] Dongfang Yang et al. review advancements in piezoelectric nanogenerators (PENGs) for mechanical energy harvesting. They explore materials like ZnO, PZT ceramics, and PVDF polymers, emphasizing innovations in structure and lead-free options. The study highlights PENGs' efficiency, flexibility, and sustainability for powering wearable electronics, biomedical devices, and sensors. Challenges include material optimization and integration, but PENGs show strong promise for future self-powered systems. [17] Ge Shi et al., developed a dual piezoelectric-electromagnetic energy harvester (DHEH) using up-conversion technology to capture ultra-low-frequency human motion. The device integrates arc-shaped magnets and coils to enhance energy output. Simulations and experiments show a 23-fold increase in piezoelectric efficiency and a power density of 86.3 $\mu W/cm^3$. The DHEH demonstrates strong potential for powering wearable electronics through biomechanical energy harvesting. [18] Ahsan Ali et al., review recent advances in piezoelectric wearable energy harvesting from human motion, emphasizing material selection, structural design, and operational modes. They categorize biomechanical energy sources into joint rotation, foot strike, and center-of-mass motion. The study highlights flexible polymers, ceramics, and nanocomposites, discussing integration challenges and future opportunities. Applications span healthcare, fitness, and smart textiles, promoting sustainable, battery-free wearable technologies. [19] Giacomo Selleri et al., developed an external self-powered supercapacitor (eSPSC) integrating a stack of 15 PZT ceramic disks with an ionic liquid-based micro-supercapacitor. Under 2 Hz compressive loading, the system achieved 3.1 V and stored 110 mJ in 2 hours. This configuration outperforms prior designs by enabling independent sizing of harvesting and storage units, offering a scalable solution for powering low-energy wearable electronics. [20] Guansong Shan et al., developed a robust piezoelectric stack energy harvester for railway applications, integrating a frequency up-conversion mechanism and mechanical transformer to enhance power output. Operating in d33 compression mode, the device achieved 511 mW peak and 24.5 mW average power under 21 Hz excitation. Pre-compression and plate springs improved durability. The system successfully powered wireless sensors, demonstrating its viability for smart railway infrastructure monitoring. [21] Yaonan Yu et al., developed a carbon fiber-reinforced polymer-enhanced piezoelectric nanocomposite (C-PVEH) for energy harvesting and wireless communication. Using KNN nanoparticles in epoxy resin and CFRP electrodes, the device achieved high conductivity (7190 S/m) and stable output (89.61 $\mu W/cm^3$). It powered LEDs and wireless IoT sensors without batteries. Finite element simulations validated performance, highlighting C-PVEH's potential for durable, self-powered smart systems in harsh environments. [22] Mohamadreza Khalili et al. developed a piezoelectric energy harvester (PEH) using four PZT stacks to power a weigh-in-motion (WIM) system for road vehicles. The system integrates a SECE circuit with flyback and step-down converters, achieving over 200 mW output under realistic traffic loads. Laboratory tests and modeling confirm sufficient power generation from heavy truck tires, enabling autonomous WIM operation without grid dependency. [23] Shehab Salem et al., investigate acoustic energy harvesting using a cylindrical PZT-5A piezoelectric transducer. The study maps impedance characteristics across 40 Hz to 50 kHz, revealing strong capacitive behavior in the audible range. Using impedance analysis, the authors propose matched load circuit design to optimize energy conversion. The work highlights potential for powering ultra-low-power electronics and MEMS devices from ambient acoustic sources. [24] Saleh Gareh et al., evaluate piezoelectric energy harvesting in road traffic using a 2DOF electromechanical model and Cellular Automata traffic simulation. Using APC 855 ceramic and Piezoelectric Cymbal Transducers (PCTs), they demonstrate power outputs of 35 mW and 51 mW for single and two-lane roads. Their model suggests potential generation of 170 kW/km, highlighting piezoelectric systems' viability for sustainable roadway energy solutions. [25] Neetu Kumari et al. propose a hybrid piezo-pyro transducer for energy harvesting in automotive sensors, combining $LiNbO_3$ and PVDF cantilevers on a thermally conductive GaN-metal block. Using thermal network modeling, they analyze heat flow and resistance across materials to optimize power output. The design leverages vibrational and thermal energy, aiming to enhance efficiency and support self-powered sensor applications in vehicles. [26] Nirmal Prashanth Maria Joseph Raj et al. developed a flexible yarn-based piezoelectric nanogenerator (FY-PNG) using $Bi_4Ti_3O_{12}$ nanoparticles and PVDF via brush-coating. The device achieved 60 V and 400 nA under 1 N force, powering LEDs and sensors. It also functioned as a self-powered breath sensor, detecting inhalation/exhalation with 0.2–0.4 V output. The eco-friendly fabrication method supports scalable applications in wearable electronics and biomedical monitoring. [27] Mingyi Liu et al. designed a high-efficiency energy harvesting paver using a DC generator, rack-pinion system, and flywheel to convert footstep energy into electricity. Their dynamic model incorporates Coulomb and viscous damping, optimizing load resistance and flywheel inertia. Experiments show 1.8 J electrical output per step and peak power of 12 W, achieving 75% mechanical energy capture. The system suits smart infrastructure and pedestrian-heavy environments. [28] G. Acciari et al. investigate rainfall energy harvesting using piezoelectric transducers and an Arduino-based measurement system. The study evaluates energy output from raindrop impacts on cantilevered PVDF and PZT sensors, highlighting challenges like splashing and variable drop dynamics. Experimental field tests and modeling confirm low but measurable power generation, suggesting potential for self-powered environmental sensors. Efficiency improvements via advanced rectifiers and cantilever design are discussed. [29] A. Rami Reddy et al., (2015) present a piezoelectric energy harvester integrating a shape memory alloy (SMA) actuator powered by solar energy. The system excites a cantilever beam using SMA's thermal response, converting mechanical vibrations into electrical output. Analytical modeling and experiments confirm higher voltage generation at elevated water temperatures and flow rates. The design demonstrates a hybrid energy harvesting approach, offering sustainable, low-frequency power generation for self-powered devices. [30] Mohammad Adnan Ilyas et al. investigate piezoelectric energy harvesting from raindrop impacts using PVDF-based sensors. Their experiments reveal two distinct output stages: logarithmic voltage growth during droplet interaction and exponential decay post-impact. Peak power output reaches 2.5 μW with efficiency below 0.12%. A kinetic model and harvester array simulation demonstrate scalability, highlighting potential for powering low-energy devices in remote, rainy environments through improved surface design and impact mechanics. [31] X.D. Xie et al. developed a piezoelectric energy harvester that captures longitudinal sea wave motion using a cantilever beam with PZT patches and a proof mass. Their mathematical model, based on Airy wave theory and beam dynamics, predicts power output up to 55 W under realistic wave conditions. Simulations show increased efficiency with greater wave height, sea depth, and cantilever dimensions, offering scalable solutions for coastal energy harvesting. [32] Junrui Liang et al. present a comprehensive impedance modeling framework for piezoelectric energy harvesting systems, analyzing standard, parallel, and series synchronized switch harvesting interfaces. They clarify impedance definitions, constraints, and energy flow dynamics, proposing equivalent mechanical and electrical models. Their findings reveal that harvested power optimization differs from conventional impedance matching, offering improved predictive accuracy and experimental validation for real-world vibration energy harvesting applications. [33] Junrui Liang et al. present a comprehensive impedance modeling framework for piezoelectric energy harvesting systems, analyzing standard, parallel, and series synchronized switch harvesting interfaces. They clarify impedance definitions, constraints, and energy flow dynamics, proposing equivalent mechanical and electrical models. Their findings reveal that harvested power optimization differs from conventional impedance matching, offering improved predictive accuracy and experimental validation for real-world vibration energy harvesting applications. [34] Yogesh K. Ramadass et al. present a bias-flip rectifier circuit that significantly enhances power extraction from piezoelectric energy harvesters, outperforming conventional full-bridge rectifiers by over 4×. Implemented in 0.35 µm CMOS, the design shares an inductor across multiple DC-DC converters, reducing component count and improving efficiency. Experimental results show up to 32.5 µW output with 85% buck converter efficiency, enabling compact, battery-less microsensor systems. [35] Chris Howells et al. developed a heel-mounted piezoelectric energy harvester using four PZT-5A bimorph stacks to convert walking motion into electrical power. The system produced 0.09 W per step at 1 Hz, with a regulated 12 V DC output via a buck converter. Mechanical inefficiencies due to stack stiffness and force imbalance limited performance. Future improvements include material optimization and enhanced stack alignment for increased power output. [36] Meiling Zhu et al. developed a coupled piezoelectric-circuit finite element model (CPC-FEM) to analyze power output from piezoelectric energy harvesters directly connected to resistive loads. Their model reveals that vibration amplitude, tip displacement, and resonant frequency shift significantly depend on load resistance—contrary to prior assumptions. CPC-FEM enables accurate prediction of electrical output and mechanical response, aiding optimal design of energy harvesters for wireless sensor applications. [37] Elie Lefeuvre et al. review piezoelectric energy harvesting systems, focusing on materials, mechanical structures, and power interfaces. They compare one-, two-, and three-stage circuits for optimizing energy transfer, highlighting the Parallel-SSHI and Ericsson cycle techniques. Experimental results show Ericsson-based processing yields superior power output. The study emphasizes low-loss, low-consumption electronics for efficient vibration-powered generators in autonomous low-power applications. [38] Elie Lefeuvre et al. present a sensorless buck-boost converter for optimizing piezoelectric energy harvesting. Their model analyzes generator power dependence on acceleration and frequency, enabling load resistance tuning for maximum output. Operating in discontinuous mode, the converter achieves over 84% efficiency across 1.6–5.5 V input and 200 µW–1.5 mW output. Experimental results validate its effectiveness for charging batteries and powering low-energy devices without complex control systems. [39] Hyeoungwoo Kim et al. investigate impedance matching techniques to enhance piezoelectric energy harvesting using cymbal transducers. By integrating high-g PZT ceramics and multilayer structures, they achieve a 100% increase in output power and 10× higher current. A DC-DC buck converter optimized for low power consumption (<5 mW) enables efficient energy transfer to low-impedance loads. Applications include LED lighting and battery charging from ambient vibrations. [40] Geffrey K. Ottman et al. developed an adaptive piezoelectric energy harvesting circuit using a rectifier, battery, and switch-mode DC-DC converter. Their model identifies optimal power transfer conditions, maintaining rectifier voltage at half the open-circuit level. Experimental results show a 400% increase in harvested power compared to direct charging. The converter dynamically adjusts duty cycle via feedback, enabling efficient wireless power supply from mechanical vibrations.

III. Conclusion

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Piezo tiles offer a smart and eco-friendly way to turn everyday movement into electricity. These tiles use piezoelectric materials that generate power when stepped on or pressed, making them ideal for crowded places like sidewalks, train stations, and shopping malls. They help capture energy that would otherwise be wasted, supporting clean and renewable energy goals. Compared to traditional sources, piezo tiles are low-maintenance, durable, and can work in places where solar or wind energy isn't practical. While the energy output from each tile is small, large-scale use can make a meaningful impact. With ongoing improvements in material design and efficiency, piezo tiles could become a key part of smart cities and sustainable buildings. This technology shows great promise for powering small devices and sensors, reducing our reliance on fossil fuels. Overall, piezo tiles are a step forward in building a greener, more energy-efficient future.

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