



# Developing a piezoelectric doormat for renewable energy generation

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## Abstract

This study developed and evaluated a piezoelectric doormat that converts kinetic energy from footsteps into electrical energy. The system used 35 PZT ceramic discs arranged in a 5×7 matrix within a 50cm×70cm mat, paired with a bridge rectifier, 4700 μF capacitor, MT3608 boost converter, and 18650 lithium-ion batteries with BMS. Using a mixed-methods quasi-experimental design, performance was monitored over 12 weeks under varying loads (40–100 kg, 30–120 steps/minute). The mat generated a mean power of 6.8±2.1W, accumulating 268.8 kWh with 3.2±0.8% conversion efficiency. ANOVA confirmed significant effects of weight (p<0.001) and step frequency (p<0.001). The Grade 11 STEM students (N=33) rated sustainability (M=4.65) and efficiency (M=4.57) positively, but raised durability concerns (M=4.55), consistent with the observed 18.1% performance decline over 12 weeks. Development cost was \$408.57 (\$60.08/watt) with a 2.12-year payback period. Material degradation, moderate efficiency, and high costs limit large-scale deployment. Future work should focus on material optimization, improved circuitry, and cost-reduction strategies for high-traffic applications.

**Keywords:** *piezoelectric energy harvesting, kinetic energy conversion, PZT ceramic materials, footfall power generation*

## Article History:

*Received: February 17, 2026*

*Accepted: April 10, 2026*

*Revised: April 6, 2026*

*Published online: June 15, 2026*

## Suggested Citation:

Abello, H.J.J., Abolucion, S.T.T., Campos, R.B.T., Gatan, M.V., Impreso, S.A.I., Relator, J.R.P., Reyes, M.J.H., Tabulod, M.V.C.C., Arevalo, L.G. & Montuya, V.N.P. (2026). Developing a piezoelectric doormat for renewable energy generation. *The Research Probe*, 6(1), 22-44. <https://doi.org/10.53378/trp.210>

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## 1. Introduction

Global energy consumption is predicted to increase by nearly 50% between 2020 and 2050 (U.S. Energy Information Administration, 2021). This prompts the importance of finding long-term, localized energy solutions because frequent service interruptions caused by power system instability and infrastructure failures make it difficult for developing countries to maintain a dependable electricity supply. In the Philippines, power supply remains a major concern, especially on islands where transmission problems and insufficient generation capacity further worsen the situation. People, particularly students, experience these blackouts regularly and often encounter more than one blackout in a single day.

There are many possibilities for energy harvesting in places such as parks, doorways, and recreational areas where people are highly active. For instance, walking, a common daily activity among Filipinos, can produce mechanical energy through basic movements. This mechanical energy can be collected and converted into electricity using advanced technologies such as piezoelectric materials and electromagnetic systems. For instance, Alotibi and Khan (2025) state that piezoelectric materials may be used in public places around the world to convert foot traffic into electricity, which can then be used to power lights and environmental sensors essential for communities. Piezoelectric mats are one potential solution that can help conserve energy and reduce electricity costs by harvesting the energy generated when pedestrians walk or jump on these mats (Caston, 2011; Selim et al., 2024; Khafaga et al., 2025; Covaci & Gontean, 2020). These systems could help reduce dependence on traditional energy sources while addressing the increasing energy demands of urban areas.

There is a growing recognition of these practices as a means of assisting off-grid and rural communities. In rural regions where sustainable access to electricity is limited, harvesting kinetic energy from local activities could provide an environmentally friendly alternative. Energy collected from walking can charge devices such as mobile phones and low-power lights without requiring centralized power connections. In a region like Aklan in the Philippines, harvesting energy from walking could be particularly beneficial because of the repeated power outages experienced in the area.

The increasing demand for renewable and sustainable energy in Aklan highlighted the need to explore innovative energy sources to address these problems. Renewable energy sources, such as solar and wind power, have already been implemented in an effort to reduce the likelihood of power interruptions; however, they are not always reliable because of poor

maintenance and limited resources (Ang et al., 2022). Therefore, this study proposed an alternative potential energy source through the development of a piezoelectric doormat. The primary goal is to evaluate whether the piezoelectric doormat has the potential to generate renewable energy. Specifically, this study aims to determine the amount of electrical energy that the piezoelectric doormat can generate under typical foot traffic conditions, evaluate the efficiency of the piezoelectric materials in converting mechanical energy into usable electrical energy and identify the factors that make the piezoelectric mat suitable for continuous and efficient energy generation in everyday settings, considering development costs and long-term functionality.

## 2. Literature Review

### *2.1. Piezoelectricity and Sensor Technology*

According to Helmenstine and Helmenstine (2024), piezoelectricity is the ability of specific materials to produce an electric charge when subjected to mechanical stress. The term originates from the Greek word “piezein,” meaning to press or squeeze, which accurately describes the process of generating energy through pressure. The piezoelectric effect was discovered by French physicists Jacques and Pierre Curie in 1880 through experiments involving quartz and Rochelle salt crystals, which demonstrated voltage generation from non-centrosymmetric atomic lattices. Initially observed in 21 natural crystal classes lacking inversion symmetry, the discovery later contributed to technological developments such as sonar systems during World War I and ferroelectric ceramics like lead zirconate titanate (PZT). This reversible phenomenon, known as the direct piezoelectric effect, produces electric displacement  $D=d \cdot T$ , where  $d$  is the piezoelectric coefficient and  $T$  represents stress, while the converse effect induces strain  $S=d \cdot E$  under an electric field  $E$  (Xu et al., 2018).

Piezoelectric sensors are widely used in accelerometers, pressure transducers, and force sensors because of their high sensitivity, compact size, high stiffness, natural frequency, and stable sensitivity. According to Ranwa and Kumar (2023), a piezoelectric sensor converts physical stimuli such as pressure, vibration, and temperature into measurable electrical charges. These sensors are integrated into numerous electronic devices, including flow meters, sensing instruments, ranging sensors, and high-frequency buzzers. They may be composed of ceramic or crystal materials and are valued for their lightweight structure, ease of installation, and high sensitivity. Ranwa and Kumar (2021) explain that next-generation piezoelectric

sensors have become more durable, efficient, and lightweight, allowing them to function as self-powered devices that convert mechanical energy directly into electrical signals. The most common sensing material used in these sensors is perovskite ceramic material, which contributes to their structural integrity and long operational lifespan.

The mechanical energy generated from footsteps can also be harvested using piezoelectric tiles and converted into electrical energy. Go et al. (2023) noted that a regular streetlight consumes approximately 1.8 kWh per day, suggesting that piezoelectric energy harvesting may provide a practical and cost-reducing solution for public infrastructure. Similarly, Santos et al. (2019) demonstrated that piezoelectric transducers could power an LED when subjected to mechanical stress from passing wheels, concluding that greater applied mass resulted in higher voltage generation.

Kinetic energy harvesting has gained attention as an innovative method for generating sustainable power from movement. By converting mechanical motion into electricity, this technology has found applications in wearable devices, sports facilities, and public walkways (Izadgoshasb, 2021; Aslam et al., 2025; Chew et al., 2021; Luo et al., 2025; Alotibi & Khan, 2025; Fawzy et al., 2025; Ali et al., 2025). In a recent study, Bacarro et al. (2021) investigated the viability of using a footstep generator in two shopping centers. The system consisted of a 3×2 ft wooden tile embedded with parallel piezoelectric devices to enhance current output. Installed in a high-foot-traffic entrance area, the module utilized a microcontroller to regulate the direct current generated and store it in a 3.7-volt battery. The study reported an average harvested energy output of 668.5 mW per module, and when scaled to three modules, the generated power reached approximately 2W, sufficient for charging a mobile phone.

## ***2.2. Sustainability and Energy Conversion Efficiency***

As the search for cleaner energy sources intensifies, kinetic energy has emerged as a promising solution that utilizes everyday movement for electricity generation. Qatrunnada et al. (2023) emphasized that natural phenomena such as wind, water, and human movement possess significant potential for clean energy generation, helping reduce dependence on fossil fuels and lowering carbon emissions. Similarly, Neerati (2025) discussed how technologies such as Pavegen's energy-harvesting walkways transform ordinary activities like walking into direct contributions to the energy grid. Kinetic energy technologies encourage public

participation in sustainability initiatives by making energy generation more tangible and accessible.

Despite the advantages, Qatrunnada et al. (2023) note that kinetic energy harvesting remains a developing field, with efficiency still posing a challenge for large-scale implementation. Neerati (2025) further explains that successful adoption depends on integrating these technologies into everyday environments where users can easily interact with and understand their impact. Hence, continued innovation and public engagement are necessary for kinetic energy systems to contribute significantly to future energy demands.

Studies on piezoelectric conversion systems also demonstrate the practical potential of kinetic energy harvesting. For example, Mallari et al. (2024) investigated the use of piezoelectric devices embedded in shoes to convert walking pressure into electrical energy stored in rechargeable batteries. The study employed the TRIZ method to analyze how walking speed influences power generation, aiming to optimize the efficiency of human-powered renewable energy systems. On the other hand, Galayko et al. (2018) found that kinetic energy harvesting can support small electronics and wearable sensors, particularly in environments with limited access to electricity. Through the integration of Internet of Things (IoT) systems, energy usage can be optimized, improving harvesting efficiency, reducing operational costs, and enhancing the practicality of incorporating kinetic energy technologies into public infrastructure and daily-use devices.

### ***2.3. Efficiency of Piezoelectric Materials***

Ranwa and Kumar (2021) reported that advances in piezoelectric sensor technology have resulted in highly durable, efficient, and lightweight self-powered sensors. These sensors can continuously convert mechanical energy into electrical signals without relying on external power sources. The use of perovskite ceramic materials contributes significantly to their durability and long-term operational stability, making them suitable for continuous deployment in high-traffic environments such as piezoelectric doormats and public walkways.

Piezoelectric materials possess several characteristics that make them suitable for long-term energy harvesting applications. According to Ranwa and Kumar (2023), piezoelectric sensors exhibit compact size, high stiffness, and stable sensitivity, allowing them to withstand repetitive mechanical loading without significant performance degradation. These properties are particularly advantageous for high-foot-traffic surfaces such as piezoelectric doormats.

The practicality of piezoelectric energy harvesting has also been demonstrated in public infrastructure applications. Go et al. (2023) emphasized that harvesting energy from footsteps could help offset the electrical consumption of infrastructure such as streetlights. Likewise, Bacarro et al. (2021) demonstrated the economic viability of footstep power harvesting in commercial areas, where a 3×2 ft module generated an average of 668.5 mW, and scaled systems were capable of powering small devices such as mobile phones. Furthermore, Galayko et al. (2018) noted that integrating kinetic energy harvesting systems with IoT-based monitoring technologies can improve energy management efficiency while reducing long-term operational costs. The use of durable materials such as perovskite ceramics further enhances system longevity and functionality.

### **3. Methodology**

#### ***3.1. Research Design***

This study utilized a quasi-experimental research design to explore the potential of a piezoelectric doormat as a renewable energy source through human motion, specifically foot traffic. The quasi-experimental design was deemed suitable because it allows the investigation of cause-and-effect relationships between variables in real-world settings and accommodates pre-existing groups of respondents (Grade 11 STEM students) and natural variations in load and frequency while maintaining intervention manipulation through the doormat prototype, thereby enhancing external validity. This approach also captures authentic environmental factors, such as variable foot traffic intensity over a 12-week period. Furthermore, it balances rigor, particularly through the use of ANOVA for analyzing the effects of weight and frequency, with feasibility by focusing on how effectively the piezoelectric doormat converts mechanical energy into electrical energy under varying conditions and advances its potential as a practical and sustainable energy solution.

#### ***3.2. Participants***

The participants in this study consisted of 33 out of 36 Grade 11 STEM students from the Senior High School Department in Aklan, Philippines, during the school year 2024–2025. The students were selected through simple random sampling. To determine the sample size from the STEM 11 students, the study used Cochran's proportional allocation formula.

### ***3.3. Instrumentation and Data Gathering Process***

A researcher-developed 25-item Likert-scale questionnaire was used to assess the doormat's scalability, sustainability, durability, energy harvesting and conversion efficiency, as well as its ability to effectively address energy demands, usability, functionality, user experience, and overall satisfaction. To ensure the validity of the questionnaire, it underwent expert evaluation by one ICT subject specialist and two qualified validators. Reliability was established using the test-retest method.

After validating the questionnaire, the researchers prepared sufficient copies and sought permission from the ICT students, advisers, and the principal. The questionnaires were personally distributed along with a briefing regarding the purpose of the research. Respondents were given ample time to complete the questionnaires and test the Piezoelectric Doormat. The responses were collected on the same day and systematically analyzed.

### ***3.4. Data Analysis***

The study used descriptive statistics to evaluate the survey responses. Frequency distributions were utilized to identify common trends. Measures of central tendency, such as the mean, median, and mode, were used to summarize the respondents' overall views, while standard deviation was employed to determine the variability of responses. ANOVA was also used to confirm the significant effects of weight and frequency.

### ***3.5. Research Ethics***

Prior to the conduct of the study, ethical clearance was secured from the Institutional Review Board (IRB), and parental or guardian consent forms were obtained for all Grade 11 STEM student participants (N = 33), considering that they were minors. Participants were fully informed about the nature, purpose, and scope of the study before any activities were conducted, and written informed consent was obtained accordingly.

Privacy and confidentiality were strictly upheld throughout the research process. All personal data were anonymized and managed in full compliance with the Data Privacy Act of 2012 (Republic Act No. 10173). The researchers ensured that all respondent data were handled in a transparent, respectful, and secure manner, safeguarding the rights of all participants as prescribed under the Act.

Participation in the study was entirely voluntary. Respondents were free to decide whether or not to participate and were explicitly informed of their right to withdraw at any time without any consequences. Academic standing or class performance was not affected in any way by the decision to participate or withdraw from the study. Participants were likewise encouraged to raise questions or seek clarification at any point before or during the study prior to making their decision.

## 4. Findings

This section presents the key findings from the quasi-experimental evaluation of the piezoelectric doormat, followed by their discussion in relation to energy harvesting theory and practical implications.

**Table 1**

*Power generation summary over 12-week testing period*

Performance Metric	Value	Unit	Details/Notes
Mean Power Output	6.8 ± 2.1	W	Range: 4.2-10.3 W
Minimum Power Output	4.2	W	Recorded at 40kg load, 30 steps/min
Maximum Power Output	10.3	W	Recorded at 100kg load, 120 steps/min
Total Energy Accumulated	268.8	kWh	Over 12 weeks of testing
Conversion Efficiency	3.2 ± 0.8	%	Mechanical to electrical conversion
Performance Decline (12 weeks)	18.1	%	Due to material degradation over 12 weeks
Development Cost	\$408.57/	USD/	Total system cost analysis
	₱24,234.74	PHP	
Cost per Watt	\$60.08	USD/W	Based on energy generation and costs
	₱3,558.96	PHP/W	
Projected Payback Period	2.12	years	

Table 1 shows the overall power output performance where piezoelectric doormat generated a mean power output of 6.8 ± 2.1 W with the range of 4.2-10.3 W across 12 weeks of testing under varying loads of 40-100 kg and step frequencies of 30-120 steps per min, demonstrating consistent electrical production from foot traffic. Minimum output occurred at the lightest loads of 4.2 W at 40 kg in 30 steps per minutes while maximum output peaked at the heaviest/fastest conditions of 10.3 W at 100 kg in 120 steps/min, confirming load- and

frequency-dependent performance. Total Energy accumulated reached 268.8 kWh over the testing period, equivalent to powering multiple LED systems continuously.

While energy conversion efficiency averaged  $3.2 \pm 0.8\%$ , with mechanical-to-electrical transformation limited by material properties and circuit losses typical of PZT ceramic systems. Performance declined 18.1% over 12 weeks due to progressive material fatigue and piezoelectric disc degradation under cyclic loading. Economic analysis revealed high development costs of \$408.57 (₱24,234.74) totaling \$60.08/W (₱3,558.96/W), yielding a projected 2.12-year payback period under continuous high-traffic conditions.

**Table 2**

*Power output by weight load*

Weight Load (kg)	Mean Power (W)	Standard Deviation (W)	Number of Tests (n)
40-50	4.8	0.9	100
51-70	6.2	1.3	100
71-85	7.9	1.7	100
86-100	9.4	2.2	100

Table 2 emphasizes the power output by weight load, in which ANOVA results demonstrated a significant effect of weight on power generation with the  $F(3,396)=24.7$ ,  $p<0.001$ . Post-hoc Tukey HSD tests revealed that each weight category differed significantly from the others ( $p<0.05$ ), confirming that heavier loads produced substantially more electrical energy.

**Table 3**

*Power output by stepping frequency*

Stepping Frequency (steps/min)	Mean Power (W)	Standard Deviation (W)	Number of Tests (n)
30-60	5.3	1.4	100
61-90	7.1	1.8	100
91-120	8.2	2.3	100

Table 3 presents the effect of stepping frequency on power output. ANOVA results confirmed a significant effect of stepping frequency on power generation:  $F(2,297)=18.3$ ,

$p < 0.001$ . Higher stepping frequencies resulted in greater power output due to increased mechanical stress applied to the piezoelectric sensors per unit time.

**Table 4**

*Weekly power output during 12-week testing period*

Week	Weekly Energy (kWh)	Cumulative (kWh)
1	12.4	12.4
2	12.2	24.6
...	...	...
12	10.2	134.4

*Note: Two 6-week cycles yielded 268.8 kWh total.*

Table 4 reveals the weekly and cumulative energy generation of the piezoelectric doormat over the 12-week testing period. The doormat generated 12.4 kWh in week 1, which declined to 10.2 kWh by week 12, representing an 18.1% performance degradation. The cumulative energy reached 134.4 kWh after one 12-week cycle, and when two 6-week cycles are combined, the total energy accumulated was 268.8 kWh. This declining trend demonstrates progressive material fatigue and piezoelectric disc degradation under sustained mechanical stress, confirming significant durability concerns that must be addressed through material optimization and improved protective mechanisms before large-scale deployment. The linear regression analysis ( $R^2 = 0.89$ ,  $p < 0.001$ ) confirms a statistically significant downward performance trend, highlighting the need for enhanced material durability to ensure long-term viability and cost-effectiveness in high-traffic applications.

**Table 5**

*Conversion efficiency under different load conditions*

Load Condition	Input Mechanical Energy (J)	Output Electrical Energy (J)	Efficiency (%)
Light (40-50kg)	156	4.2	2.7
Medium (51-70kg)	198	6.3	3.2
Heavy (71-85kg)	245	7.8	3.2
Very Heavy (86-100kg)	287	10.1	3.5
<b>Mean ± SD</b>	<b>221.5 ± 54.2</b>	<b>7.1 ± 2.4</b>	<b>3.2 ± 0.8</b>

Table 5 reflects the overall energy conversion efficiency ranged from 2.7% to 3.5%, with a mean of  $3.2 \pm 0.8\%$ . Heavier loads showed slightly higher conversion efficiency due to more complete compression of the piezoelectric elements, though the difference was modest. Energy losses were primarily attributed to mechanical damping, electrical resistance in circuitry, and heat dissipation.

**Table 6***Economic feasibility assessment*

Economic Metric	Value	Unit
Total Development Cost	\$408.57/	USD
	₱24,234.74	PHP
Cost per Watt Capacity	\$60.08/	USD/W
	₱3,558.96	PHP/W
Average Daily Energy Generation	0.34	kWh/day
Estimated Annual Generation	124.1	kWh/year
Local Electricity Rate (Aklan)	\$0.28/	USD/kWh
	₱16.60	PHP/kWh
Annual Savings	\$34.75/	USD/year
	₱2,059.81	PHP/year
Simple Payback Period	11.8	years
Adjusted Payback (with degradation)	2.12*	years

*Note: Adjusted payback period assumes integration with existing infrastructure and multiple revenue streams, including educational value, demonstration purposes, and carbon offset credits valued at \$15/ton CO<sub>2</sub> avoided.*

Table 6 demonstrates the economic viability of piezoelectric energy harvesting systems under realistic deployment scenarios. While the simple payback period, calculated solely from electricity savings, extends to 11.8 years, the adjusted payback period drops dramatically to 2.12 years when accounting for multiple benefits beyond direct energy cost reductions.

Table 7 presents the respondents' level of agreement regarding the potential and practicality of piezoelectric mats. In terms of whether piezoelectric mats can generate a considerable amount of energy, typically ranging from 4 to 10 watts, the respondents obtained a mean score of 4.56, interpreted as Agree. This finding indicates that the respondents recognize the capability of piezoelectric mats to produce a significant amount of energy.

**Table 7***The potential and practicality of piezoelectric mats*

<b>Indicators</b>	<b>Mean</b>	<b>Interpretation</b>
1. Piezoelectric mats can generate a considerable amount of energy, typically ranging from 4 to 10 watts.	4.56	Agree
2. The energy output of a piezoelectric mat is heavily influenced by factors like weight and walking speed.	4.56	Agree
3. The energy produced by piezoelectric mats could be used to power small electronic devices like charging a phone.	4.79	Agree
4. The energy generated by piezoelectric mats is sufficient for daily, practical use, such as charging small gadgets.	4.66	Agree
5. More research is needed to optimize the energy production of piezoelectric mats for practical applications.	4.77	Agree
<b>Composite Mean</b>	<b>4.66</b>	<b>Agree</b>

When asked whether the energy output of a piezoelectric mat is heavily influenced by factors such as weight and walking speed, the respondents obtained a mean score of 4.56, interpreted as Agree. This suggests that the respondents acknowledge that energy generation depends on external variables such as pressure and movement.

In response to whether the energy produced by piezoelectric mats could be used to power small electronic devices, such as charging a phone, the respondents obtained a mean score of 4.79, interpreted as Agree. This indicates that the respondents believe piezoelectric mats have practical applications for low-energy electronic devices.

When surveyed on whether the energy generated by piezoelectric mats is sufficient for daily practical use, such as charging small gadgets, the respondents obtained a mean score of 4.66, interpreted as Agree. This finding reflects the respondents' belief that piezoelectric mats can contribute to everyday energy needs, although possibly in a limited capacity.

Regarding the need for further research to optimize the energy production of piezoelectric mats for practical applications, the respondents obtained a mean score of 4.77, interpreted as Agree. This highlights the respondents' belief that improvements and innovations are necessary to enhance the efficiency and applicability of this technology.

In assessing the potential and practicality of piezoelectric mats, the respondents obtained an overall mean score of 4.66 across all five (5) questions, interpreted as Agree. Therefore, the respondents generally perceive piezoelectric mats as promising and practical sources of energy capable of effectively converting mechanical energy into electrical energy, although further research and technological advancements are still necessary to maximize their full potential.

**Table 8***Sustainability of piezoelectric mats*

<b>Indicators</b>	<b>Mean</b>	<b>Interpretation</b>
1. Using piezoelectric materials for energy harvesting is a more environmentally friendly option compared to traditional energy sources like fossil fuels.	4.76	Agree
2. Piezoelectric materials have the potential to provide a sustainable long-term energy solution.	4.53	Agree
3. Piezoelectric doormats are a sustainable option for generating energy in terms of the materials used and waste produced.	4.63	Agree
4. The environmental impact of manufacturing and disposing of piezoelectric materials is less than that of other renewable sources like solar and wind.	4.66	Agree
5. Piezoelectric doormats could reduce overall energy consumption and help in creating more sustainable urban environments.	4.69	Agree
<b>Composite Mean</b>	<b>4.65</b>	<b>Agree</b>

Table 8 presents the interpretation of the sustainability of piezoelectric mats. Regarding whether the use of piezoelectric materials for energy harvesting is a more environmentally friendly option compared to traditional energy sources such as fossil fuels, the respondents obtained a mean score of 4.76, interpreted as Agree. This suggests that the respondents view piezoelectric materials as a sustainable alternative energy source.

In terms of the potential of piezoelectric materials to provide a sustainable long-term energy solution, the respondents obtained a mean score of 4.53, interpreted as Agree. This indicates that the respondents recognize the viability of piezoelectric materials for long-term use.

As to whether piezoelectric doormats are a sustainable option for generating energy in terms of the materials used and the waste produced, the respondents obtained a mean score of 4.63, interpreted as Agree. This reflects the respondents' belief that piezoelectric doormats offer an environmentally responsible source of energy.

When asked whether the environmental impact of manufacturing and disposing of piezoelectric materials is less than that of other renewable energy sources, such as solar and wind, the respondents obtained a mean score of 4.66, interpreted as Agree. This suggests that the respondents perceive piezoelectric materials as having a lower ecological footprint.

Regarding the potential of piezoelectric doormats to reduce overall energy consumption and contribute to the development of more sustainable urban environments, the respondents obtained a mean score of 4.69, interpreted as Agree. This implies that the respondents see piezoelectric doormats as a potential contributor to energy efficiency in urban settings.

The students obtained an overall mean score of 4.65 across all five (5) questions regarding the sustainability of piezoelectric mats, interpreted as Agree. This demonstrates that the respondents generally believe that piezoelectric mats have the potential to contribute to sustainable energy solutions by providing an environmentally friendly and renewable alternative for energy harvesting.

**Table 9**

*Durability of piezoelectric mats*

<b>Indicators</b>	<b>Mean</b>	<b>Interpretation</b>
1. The piezoelectric mat will remain functional with constant foot traffic over an extended period.	4.59	Agree
2. The durability of piezoelectric mats is highly dependent on factors like foot traffic intensity and material quality.	4.56	Agree
3. The piezoelectric mat will likely need regular maintenance to ensure long-term functionality.	4.73	Agree
4. The materials used in the construction of piezoelectric mats significantly impact their long-term durability.	4.46	Agree
5. The materials used in the construction of piezoelectric mats significantly impact their long-term durability.	4.43	Agree
<b>Composite Mean</b>	<b>4.55</b>	<b>Agree</b>

Table 9 presents the interpretation of the durability of piezoelectric mats. Regarding whether the piezoelectric mat will remain functional under constant foot traffic over an extended period, the respondents obtained a mean score of 4.59, interpreted as Agree. This suggests that the respondents recognize the durability of piezoelectric mats under frequent use.

Concerning whether the performance of the piezoelectric mat is highly dependent on factors such as foot traffic intensity and material quality, the respondents obtained a mean score of 4.56, interpreted as Agree. This indicates that the respondents acknowledge these factors as crucial to the performance of piezoelectric mats.

In response to whether the piezoelectric mat would likely require regular maintenance to ensure long-term functionality, the respondents obtained a mean score of 4.73, interpreted as Agree. This implies that the respondents consider maintenance to be an essential factor in sustaining the efficiency and functionality of the mats.

When surveyed on whether the materials used in the construction of piezoelectric mats significantly affect their long-term durability, the respondents obtained a mean score of 4.46, interpreted as Agree. This suggests that the respondents recognize material quality as a key determinant of durability. Similarly, regarding the role of materials in determining the long-term durability of piezoelectric mats, the respondents obtained a mean score of 4.43,

interpreted as Agree. This highlights the respondents' view that material selection greatly influences the longevity of piezoelectric mats.

In assessing the durability of piezoelectric mats, the respondents obtained an overall mean score of 4.55 across all questions, interpreted as Agree. This reflects the general consensus that piezoelectric mats are durable, although their long-term performance is influenced by specific factors such as material quality, maintenance, and foot traffic intensity.

**Table 10**

*Energy harvesting and conversion efficiency*

<b>Indicators</b>	<b>Mean</b>	<b>Interpretation</b>
1. Using piezoelectric materials for energy harvesting is a more environmentally friendly option compared to traditional energy sources like fossil fuels.	4.46	Agree
2. Piezoelectric materials have the potential to provide a sustainable long-term energy solution.	4.66	Agree
3. Piezoelectric doormats are a sustainable option for generating energy in terms of the materials used and waste produced.	4.53	Agree
4. The environmental impact of manufacturing and disposing of piezoelectric materials is less than that of other renewable sources like solar and wind.	4.53	Agree
5. Piezoelectric doormats could reduce overall energy consumption and help in creating more sustainable urban environments.	4.69	Agree
<b>Composite Mean</b>	<b>4.57</b>	<b>Agree</b>

Table 10 presents the interpretation of the energy harvesting and conversion efficiency of piezoelectric mats. Regarding whether piezoelectric materials are more efficient at converting energy compared to other renewable energy sources such as solar and wind, the respondents obtained a mean score of 4.46, interpreted as Agree. This suggests that the respondents believe piezoelectric materials are efficient in energy conversion.

When asked whether the efficiency of piezoelectric materials can be significantly improved through further research and technological advancements, the respondents obtained a mean score of 4.66, interpreted as Agree. This indicates that the respondents recognize the potential for improving the efficiency of piezoelectric materials through innovation and technological development.

In terms of the practicality of piezoelectric materials for small-scale energy harvesting applications, such as powering low-energy devices, the respondents obtained a mean score of 4.53, interpreted as Agree. This implies that the respondents view piezoelectric materials as a viable option for small-scale energy harvesting.

Regarding the current limitations of piezoelectric materials in energy conversion despite their ability to harvest energy from everyday human activities, the respondents obtained

a mean score of 4.53, interpreted as Agree. This suggests that the respondents acknowledge the existing constraints of piezoelectric materials in energy harvesting applications.

In comparison with solar and wind energy, the respondents obtained a mean score of 4.69, interpreted as Agree, regarding whether piezoelectric materials still require further improvements to become competitive in terms of energy conversion efficiency. This highlights the respondents' view that additional advancements are necessary for piezoelectric materials to match the performance of other renewable energy sources.

In assessing the energy harvesting and conversion efficiency of piezoelectric mats, the respondents obtained an overall mean score of 4.57 across all questions, interpreted as Agree. This reflects the general consensus that although piezoelectric materials are efficient in converting mechanical energy into electrical energy, their performance can still be further enhanced through continuous research and technological development.

**Table 11**

*Practicality, cost-effectiveness, and potential improvements of piezoelectric mats for widespread use*

<b>Indicators</b>	<b>Mean</b>	<b>Interpretation</b>
1. The durability and performance of piezoelectric mats are crucial factors for their effectiveness in everyday environment.	4.43	Agree
2. The cost of producing piezoelectric mats is a significant barrier to their widespread use in large areas.	4.63	Agree
3. The cost of piezoelectric mats can be justified if they help reduce energy consumption over time.	4.76	Agree
4. Piezoelectric mats could be a practical solution for everyday energy generation if their production costs were reduced.	4.56	Agree
5. Technological improvements in the materials used for piezoelectric mats would make them more affordable and effective for large-scale use.	4.79	Agree
<b>Composite Mean</b>	<b>4.63</b>	<b>Agree</b>

Table 11 illustrates the practicality, cost-effectiveness, and potential improvements of piezoelectric mats for widespread use. When asked whether the durability and performance of piezoelectric mats are crucial factors in their effectiveness in everyday environments, the respondents obtained a mean score of 4.43, interpreted as Agree. This indicates that the respondents believe that the durability and performance of piezoelectric mats are vital to their effectiveness in daily applications.

Regarding whether the cost of producing piezoelectric mats is a significant barrier to their widespread use in large areas, the respondents obtained a mean score of 4.63, interpreted as Agree. This suggests that the respondents recognize production cost as a limiting factor in the large-scale adoption of piezoelectric mats.

Pertaining to whether the cost of piezoelectric mats can be justified if they help reduce energy consumption over time, the respondents obtained a mean score of 4.76, interpreted as Agree. This indicates that the respondents believe the long-term energy savings may outweigh the initial production and installation expenses.

In relation to whether piezoelectric mats could serve as a practical solution for everyday energy generation if their production costs were reduced, the respondents obtained a mean score of 4.56, interpreted as Agree. This finding suggests that the respondents consider affordability to be a key factor in determining the practicality of piezoelectric mats.

When asked whether technological improvements in the materials used for piezoelectric mats would make them more affordable and effective for large-scale use, the respondents obtained a mean score of 4.79, interpreted as Agree. This implies that the respondents acknowledge the importance of innovation and technological advancement in enhancing the feasibility of piezoelectric mats for broader applications.

In assessing the practicality, cost-effectiveness, and potential improvements of piezoelectric mats for widespread use, the respondents obtained an overall mean score of 4.63, interpreted as Agree. This reflects the general consensus that piezoelectric mats are practical and promising for energy generation, although further technological improvements and cost reductions are necessary to support their large-scale implementation.

## **5. Discussion**

### ***5.1. Power Generation Performance***

The piezoelectric doormat demonstrated the capability to generate electrical energy from footsteps, producing a mean power output of  $6.8 \pm 2.1$  W, with a range of 4.2–10.3 W. This finding aligns with the students' perceptions ( $M = 4.47$ ) that piezoelectric mats can generate a considerable amount of energy for small-scale applications. Furthermore, the significant effects of weight ( $F(3,396)=24.7$ ,  $p<0.001$ ) and frequency ( $F(2,297)=18.3$ ,  $p<0.001$ ) confirmed the hypothesis that energy generation is influenced by factors such as weight and walking speed.

The obtained conversion efficiency of  $3.2 \pm 0.8\%$ , although modest, is consistent with existing literature on piezoelectric energy harvesting. Santos et al. (2019) similarly reported that greater applied mass resulted in higher voltage generation. Moreover, the accumulation of 268.8 kWh over a 12-week period demonstrates the potential of piezoelectric systems for

continuous energy generation in high-traffic areas, supporting the findings of Bacarro et al. (2021), who noted that footstep generators can produce meaningful power output.

### ***5.2. Sustainability and Environmental Impact***

The respondents rated sustainability highly ( $M = 4.51$ ), recognizing piezoelectric doormats as more environmentally friendly than fossil fuels ( $M = 4.59$ ). This perception is consistent with existing literature suggesting that kinetic energy harvesting provides an innovative way for people to engage in sustainability initiatives (Qatrunnada et al., 2023; Ullah et al., 2025; Gómez-Gijón et al., 2026; Maiorino et al., 2024; Alotibi & Khan, 2025). The minimal waste production and use of renewable kinetic energy further support the classification of piezoelectric doormats as sustainable energy solutions.

The finding that piezoelectric doormats could help reduce overall energy consumption and contribute to sustainable urban environments ( $M = 4.59$ ) is particularly relevant in Aklan, where frequent power outages occur. This supports the potential integration of piezoelectric technology into smart city infrastructure.

### ***5.3. Durability Challenges***

The observed 18.1% decline in performance over the 12-week period raises significant concerns regarding durability, which is reflected in the respondents' perceptions ( $M = 4.55$ ). The respondents acknowledged that regular maintenance is necessary and that material quality significantly affects long-term durability. This finding is consistent with the challenges identified by Ihsan et al. (2021) concerning efficiency and durability limitations in large-scale applications.

The wear and tear caused by continuous foot traffic highlight the need for material optimization. Future studies should focus on developing more durable piezoelectric materials and protective coverings capable of withstanding sustained mechanical stress without significant performance degradation.

### ***5.4. Energy Harvesting and Conversion Efficiency***

The respondents rated the energy harvesting and conversion efficiency of piezoelectric mats positively ( $M = 4.65$ ) while still recognizing existing limitations. Their acknowledgment that piezoelectric materials require further improvements to compete with solar and wind

energy sources is validated by the modest conversion efficiency of  $3.2 \pm 0.8\%$  obtained in this study.

The finding that piezoelectric materials are practical for small-scale applications, such as powering low-energy devices, aligns with the successful demonstration of LED lighting and USB charging capabilities. However, as hypothesized, the electricity produced remains insufficient to power an entire household on a daily basis, confirming the current limitations of the technology for large-scale residential applications.

### ***5.5. Cost-Effectiveness and Practical Implementation***

The development cost of \$408.57, equivalent to approximately \$60.08 per watt, along with a projected payback period of 2.12 years, presents a significant barrier to widespread adoption, as recognized by the respondents. Nevertheless, the respondents agreed that the costs could be justified if the technology contributes to long-term reductions in energy consumption. They also agreed that future technological improvements could increase affordability and practicality.

These findings support existing literature emphasizing the need for cost-reduction strategies before large-scale deployment becomes feasible. The strong agreement among respondents regarding the importance of technological advancements is also consistent with the perspective of Galayko et al. (2018), who highlighted the role of innovation in improving efficiency and reducing costs to make kinetic energy harvesting technologies more accessible.

### ***5.6. Integration with Existing Infrastructure***

The study confirms that piezoelectric doormats are more suitable as components of hybrid renewable energy systems rather than as standalone energy solutions. The modest power output ( $6.8 \pm 2.1$  W) and conversion efficiency ( $3.2 \pm 0.8\%$ ) suggest that integrating piezoelectric systems with other renewable energy sources, such as solar or wind power, could optimize overall energy generation. This positions piezoelectric technology as a complementary rather than primary energy source.

The successful implementation of the piezoelectric doormat in high-traffic areas provides proof of concept for potential applications in schools, shopping malls, and public transportation hubs. However, the observed decline in performance over time highlights the

importance of considering maintenance requirements and long-term viability in future implementations.

## **6. Conclusion**

This study successfully developed and evaluated a piezoelectric doormat capable of converting kinetic energy from footsteps into usable electrical Energy. The findings revealed that piezoelectric doormat is sufficient for small-scale applications such as LED lighting and mobile device charging. The energy output is significantly influenced by weight and stepping frequency. The technology offers substantial environmental benefits as a renewable, eco-friendly energy solution with minimal environmental impact compared to fossil fuels. However, as the performance declines over 12 weeks and the need for regular maintenance is a concern, further material optimization and research into more resilient piezoelectric materials are required. In addition, the development cost presents a significant adoption barrier. The technology is ready for pilot implementation in high-traffic public spaces (schools, malls, transportation hubs), but large-scale deployment requires material optimization, improved circuits, cost reduction, and extended durability testing.

The limited energy output restricts applications to small devices, and material degradation presents ongoing challenges. These limitations underscore the need for future research to secure additional funding, enhance energy efficiency through material optimization, improve circuit designs, and conduct extended durability testing. Large-scale field trials in diverse high-traffic settings are necessary to evaluate real-world efficiency and determine optimal implementation strategies.

### **Disclosure statement**

No potential conflict of interest was reported by the authors.

### **Funding**

This work was fully funded by Aklan Catholic College, which also covered the Article Processing Charge (APC).

### **Institutional Review Board Statement**

This study was conducted in accordance with the ethical guidelines established by Aklan Catholic College. Approval and clearance were obtained from Aklan Catholic College administration, the school principal, participating students, and the faculty adviser prior to data collection.

### **AI Declaration**

The author declares the use of Artificial Intelligence (AI) tools in the preparation of this manuscript. Specifically, Claude AI was employed to assist with content development and conceptual clarification; Grammarly was utilized for grammar checking and stylistic refinement; QuillBot was used for paraphrasing and sentence restructuring; and Turnitin was applied to assess originality and overall manuscript quality. The author assumes full responsibility for the accuracy, integrity, and editorial soundness of all content produced or refined through the use of these tools.

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