International Journal of
Electro-Mechanics and Material Behavior

Volume 3, Issue 2, 2025
July–December
DOI Journal: 10.37591/IJEMB

https://journals.stmjournals.com/ijemb

Research IJEMB

# Piezoelectricity: For Power Generation

Rohit Kushwaha[1,]*, Rachit Srivastava[2]

***Abstract***

*Undeniably, piezoelectric materials are an exciting possibility for serving as a workable energy source; the question is whether technologies at this point in their development are ready for wide-scale application. This requires considering their value in the real context of modern urban environments and ecological conditions. A critical literature review has been carried out in this paper for the identification of the most successful piezoelectric generation techniques that have been utilized to date. Comparing these various methods in respect of their energy output and socioeconomic impact provides a clearer understanding of the specific hurdles and advantages involved. The overall findings indicate the practical, positive role that the implementation of piezoelectric systems could continue to play in the support of global power generation. A promising family of energy-harvesting devices that can transform ambient mechanical energy into usable electrical power is represented by piezoelectric nanogenerators (PENGs). These systems provide a sustainable substitute for traditional batteries by taking advantage of the piezoelectric effect at the micro and nanoscale, especially for distributed and low-power electronic applications. The development of piezoelectric materials and device architectures that have greatly increased mechanical flexibility, long-term durability, and energy conversion efficiency is examined in this article. The focus is on nanostructured materials that have shown improved electromechanical coupling and scalability, such as zinc oxide nanowires, lead zirconate titanate, and newly developed lead-free piezoelectric composites. Additionally covered is the integration of PENGs with power management circuits and energy storage devices, emphasizing methods for output stabilization and continuous operation. Optimized piezoelectric nanogenerators can capture energy from human motion, vibrations, and ambient sources to power portable electronics and sensors, according to recent experimental demonstrations. Notwithstanding these developments, problems with material toxicity, manufacturing costs, and system dependability still exist. In order to move piezoelectric power generation from laboratory research to broad commercial and industrial applications, it will be essential to address these challenges through creative material design and large-scale manufacturing procedures.*

**Keywords:** Power generation, piezoelectricity, energy collector, piezoelectric slates, piezoelectric breakwater

***Author for Correspondence**
Rohit Kushwaha
E-mail: rohitkush199@gmail.com

[1]Student, Department of Electrical Engineering, Bansal Institute of Engineering and Technology Lucknow, Uttar Pradesh, India.
[2]Assistant Professor, Department of Electrical Engineering, Bansal Institute of Engineering and Technology Lucknow, Uttar Pradesh, India.

Received- December 11, 2025
Accepted- December 13, 2025
Published- December 22, 2025

**Citation:** Rohit Kushwaha, Rachit Srivastava. Piezoelectricity: For Power Generation. International Journal of Electro-

## INTRODUCTION

With increasing densification and the continued rise in energy usage, we must look to a future where upgrading our current infrastructure is standard practice to create intelligent, self-sustaining urban environments. One potential path toward this objective is "energy harvesting, " as discussed by Priya and Inman. Essentially, it means capturing clean, free residual energy from our environment to supplement our power needs [1–5]. Unfortunately, turning this into a practical reality is easier said than done; the expected rise in energy demands calls for heavy research and development into newer forms of generating power. Which leads to the intriguing question: is it possible that daily commutes, afternoon strolls through the park, or even the waves within our oceans will someday be able to power our cities?

This idea is based on the principle of piezoelectricity, which was discovered by the Curie brothers as far back as 1880. Although the technology is ancient, its applications have changed considerably. In simple terms, piezoelectricity refers to the capability of certain materials to produce an electric voltage when mechanical pressure is applied on them. Modern research is currently finding a wide range of uses for this principle, from pressure-sensitive bricks on pedestrian sidewalks to sensors embedded in railways and roads and further to specialized breakwaters in littoral areas. Current literature indicates that piezoelectric materials may have an important role to play in the future of the generation of sustainable power [6–10].

In this context, the present paper intends to analyse those energy harvesting methodologies and their socio-economic implications. We want to see how piezoelectric solutions can contribute to the rising energy matrix without moving the physical structure of the urban environment. For this reason, the study contains the comparison between the different methodologies regarding energy production and an evaluation of the practicality of production with respect to different energy parameters. This paper is organized to present, in its first section, a reference framework for piezoelectric energy collection, followed by the results of our review. Conclusions and broader implications are discussed, hoping that this may constitute a stimulus for stakeholders of the productive sector to invest in emerging technologies compatible with urban development and citizens' needs.

## FRAMEWORK AND PROPOSAL FOR PIEZOELECTRICITY

The next section describes the major techniques utilized in harnessing piezoelectric materials for energy support, giving equal attention to specific strengths and weaknesses. In addition to the typical techniques, we examine unique case studies and innovative proposals currently on the table. This is followed immediately by a critical assessment of the broader picture: consideration of the environmental footprint and economic viability of the technologies considered. The paper closes by integrating these findings into a specific proposition regarding the future of piezoelectric power generation.

## PIEZOELECTRIC SLATES

Reflect the idea of a "smart" floor tile that acts as a small power plant, captivating in the simple gestures of walking and turning them into usable electricity. Such a system enables micro-power generation due to the kinetic energy of passersby being converted into electrical energy using piezoelectric materials. In most research, scientists divide the mechanics in two ways: "hitting" and "vibrating." While the "hitting" method involves modules receiving direct impact loads, the "vibration" method is considered more practical for implementation on a larger scale. Since it can bear superficial loads better, the vibration method offers better durability and, when distributed over larger surface areas, provides significant power.

Taking into consideration that human mobility is a constant, high-traffic environments like crosswalks, office lobbies, shopping malls, and even nightclubs are ideal settings to capture this energy. This provides a uniquely reliable path to clean energy, for as long as people go from one place to another, the "raw material" of this power source is virtually guaranteed.

## PIEZOELECTRIC ROADWAY AS ENERGY COLLECTOR BY ROAD TRAFFIC

The most promising application is the "piezoelectric pathway" where harvesting devices are embedded directly beneath the asphalt. These systems capture the pressure and vibrations exerted by moving vehicles and convert that mechanical stress to electric power. Due to the nature of this energy production, coming in irregular pulses, system-specific circuitry is needed for rectification and transformation to make it into stable, storable electricity.

This technology fully corresponds to the global need to extend the road network, since the car fleets continue to grow. As the former Assemblyman Mike Gatto mentioned in regard to California, it makes sense to capture the renewable energy "right beneath our tires" rather than wasting it. The idea has not stayed in the realm of theory, and special sections of roads have already begun testing this technology in countries like Israel, Japan, the United States, and Colombia.

The application is particularly compelling because of its dual utility. Beyond generating significant power-especially when triggered by heavy trucks-the piezoelectric layer acts as a smart sensor, collecting valuable data on vehicle speed, weight, and traffic frequency. Research indicates that even short stretches, such as one kilometres of road, possess high generation capacity. On routes dominated by heavy freight, the energy potential is high enough that the system could theoretically achieve grid independence and eventually recover its own installation costs. Thus, this brings us to our second proposition: future road design, particularly for heavy-traffic corridors, should prioritize the integration of piezoelectric pavement in order to maximize power generation.

## RAILWAYS MODIFIED WITH PIEZOELECTRIC DEVICES

Using train tracks to generate electricity is essentially an extension of the idea of piezoelectric pavements used on roads. The benefit of applying this technology to railways is that the pressure from trains is consistently applied at the same points, making energy capture more reliable. Piezoelectric devices placed in the joints of the rails can convert this mechanical stress into usable electricity, which can then be directed to power trains, operate railway signals, or even feed into the main electrical grid. Studies suggest that the movement of trains could produce around 120 kWh of clean energy, while also providing valuable data such as train speed, weight, and wheel count. Since trains naturally create vibrations and pressure along the tracks, this system could support self-sustaining railway signals and, in the case of electric trains, reduce their dependence on the grid. In this way, adapting piezoelectric devices for railways offers a promising method of harvesting energy to support power generation Figure 1.

## PIEZOELECTRIC BREAKWATER

Wave energy signifies a huge and clean basis of power that can be appointed using piezoelectric plans. Yoking the immense power of the ocean waves presents an huge opportunity for power generation, seeing the seas cover nearly 70% of our planet's surface. A key technology for this involves placing devices on offshore buoys or floating platforms. For these systems to be cost-real, they must be developed and applied on a large, profitable scale. A major benefit of these systems is that they cause very little disruption to marine life. In fact, the constructions themselves can serve additional drives, such as holding direction-finding sensors. This massive, unused energy source gifts a significant chance for coastal areas that now struggle with power reliability, offering a chance to reduce the cost of building substructure while supplying renewable and environmentally friendly electricity.

## RESEARCH METHODOLOGY

To meet the objectives of this study, a complete review of existing literature was carried out, following the framework suggested by earlier investigators. The focus was on analyzing publications related to piezoelectricity as a means of supporting power generation, while placing the discussion within a global context.

For this study's data collection, we first focused on primary sources retrieved from respected academic databases like ScienceDirect, JSTOR, and EBSCO. We also utilized secondary sources such as Google Scholar, ResearchGate, and Academia, and in some limited cases, we reached out to authors directly for information. Our literature review covered publications spanning 1994 to 2019, with a special emphasis on research directly concerning energy harvesting using piezoelectric devices. The paper year and language, primarily concentrating on works in English and Spanish.

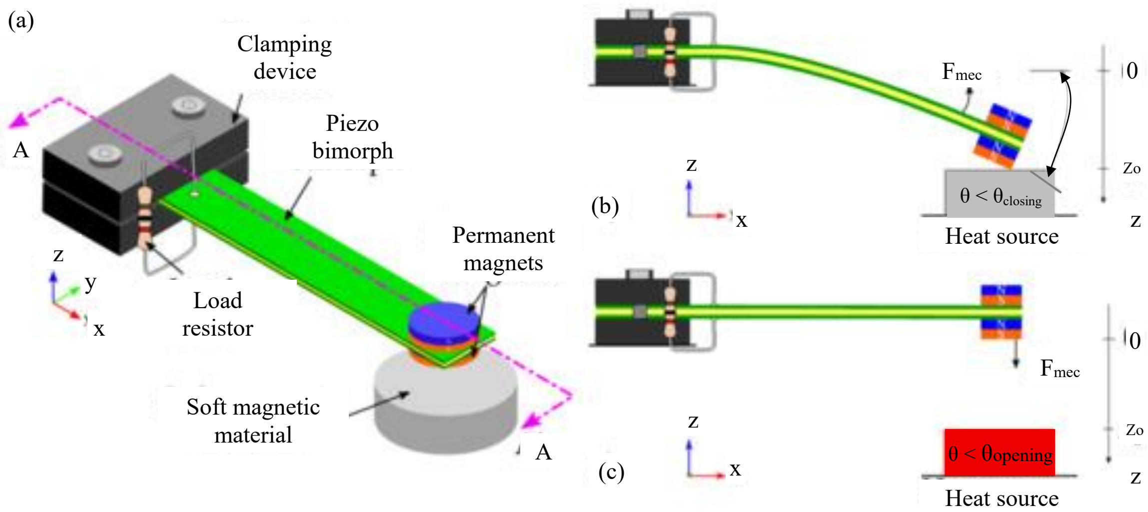


**Figure 1.** Schematic view.

**Table 1.** Comparative Generation Capacity.

| Generation Method | Energy Production | Place of Harvest | Source |
|---|---|---|---|
| Piezoelectric tiles | 27 kWh/day | Macquarie University, Sydney, Australia | [1] |
| Piezoelectric pavement | 840 kWh/day | Avenida Boyacá & Calle 17, Bogotá, Colombia | [2] |
| Piezoelectric railways | 2880 kWh/day | Israel | [3] |
| Piezoelectric breakwaters | 4 kWh/day | Cantabria, Santander, Spain | [4] |

This initial sweep brought up 51 documents, which included journal articles, theses, and books. We then excluded 14 of these based on a lack of relevance. In the second stage, we closely examined the abstracts of the papers that remained, which led to the removal of 7 more papers. This meticulous process produced a final pool of 34 highly relevant studies that were combined into our review. Our search strategy was guided by specific keywords, such as piezoelectricity, power generation, and energy harvesting. To ensure the information was as current as possible, we gave preference to documents published within the last five years of the search period, as they offered the most up-to-date insights available in the field (Table 1).

## RESULTS

In the early stage of the appraisal, a total of 51 papers were composed. After applying selection criteria, this number was reduced to 34 documents for deeper analysis. The useful sources included studies on general piezoelectricity, piezoelectric tiles, piezoelectric pavements, wave-based-applications, environmental aspects, economic considerations, and solar support systems. On the other hand, several documents were excluded, such as those focusing on specific material types, operating frequencies, microcircuits, crystal structures, wind generation, and micro-generation.

After examining the content of the 30 most relevant documents from stage two, the study was able to identify key insights into the strengths and limitations of different piezoelectric energy harvesting methods.

Among the methods reviewed, railways stand out as having the highest potential. Their energy generation capacity is about 343% greater than that of piezoelectric pavements. To put this into perspective, the electricity produced by piezoelectric railways could power around 2, 400 sodium lamps for 12 hours a day over an entire month. This highlights the strong potential of piezoelectricity as a supplemental energy source in areas where these systems can be applied.

 

Each method has its own strengths depending on the environment. For example, piezoelectric pavements can generate more than enough electricity to cover street lighting needs—125% of the demand for sodium lamps and 287% for LED lamps.

## DISCUSSIONS AND CONCLUSIONS

Schemes based on piezoelectric tiles are growing fast. The concept of producing electricity from eccentric sources is clearly expanding. Roads joining piezoelectric resources can generate energy simply from vehicle movement, and this potential has been validated by several pilot projects globally.

Following its success, plans are underway to expand this technology to more roads in the country.

Railways offer the highest energy generation capacity among the studied methods. Data shows that piezoelectric railways outperform pavements and tiles significantly. According to research, the structural nature of rail transport makes it ideal for piezoelectric applications. With countries having wide rail networks—some averaging 40, 000 km—this method holds huge promise for future energy reaping.

Climate alteration and environmental concerns make it vital to adopt energy solutions that are clean and sustainable. Piezoelectric skill fits this need well because it can be combined into current constructions without causing damage or creating harmful emissions. Since it relies on motorized stress slightly than burning, it offers an eco-friendly way to generate electricity. This makes piezoelectric systems a valued option for secondary sustainable development, as they align with global efforts to reduce pollution and defend biodiversity.

One of the main challenges for piezoelectric energy reaping is its economic positioning in the market. For the technology to prosper, strong support from governments and private investors is required. See-through policies, monetary inducements, and long-term funding are crucial to inspire innovation and make schemes viable. While renewable energy acceptance has grown significantly universal, piezoelectric schemes still face hurdles in terms of profitability and large-scale application. With better asset frameworks and helpful public policies, however, these methods could become more modest and generally adopted in the future.

## REFERENCES

1. F. Laumann, M. M. Sørensen, R. F. Jul Lindemann, T. M. Hansen, and T. Tambo, “Energy harvesting through piezoelectricity - Technology foresight, ” Energy Procedia, vol. 142, pp. 3062–3068, 2017
2. X. Li and V. Strezov, “Modelling piezoelectric energy harvesting potential in an educational building,” Energy Convers. Manag., vol. 85, pp. 435–442, 2014.
3. D. Armando and T. Zapata, “Como Proyecto Piloto En Un Perfil Vial De Bogotá.”
4. M. González Díaz, “Facultad Ciencias Obtención de energía de las olas empleando materiales piezoeléctricos (Ocean wave power generation using piezoelectric devices),” 2017
5. Sun, Xiao-ming, et al. "An overview on piezoelectric power generation system for electricity generation." Electrical Engineering and Automation: Proceedings of the International Conference on Electrical Engineering and Automation (EEA2016). 2017.
6. Sun, X. M., Peng, W. F., Zhang, L., & Zhang, M. Q. (2017). An overview on piezoelectric power generation system for electricity generation. In Electrical Engineering and Automation: Proceedings of the International Conference on Electrical Engineering and Automation (EEA2016) (pp. 340–347).
7. Sun, Xiao-ming, Wei-feng Peng, Li Zhang, and Ming-qian Zhang. "An overview on piezoelectric power generation system for electricity generation." In Electrical Engineering and Automation: Proceedings of the International Conference on Electrical Engineering and Automation (EEA2016), pp. 340–347. 2017.

8. Sun, X.M., Peng, W.F., Zhang, L. and Zhang, M.Q., 2017. An overview on piezoelectric power generation system for electricity generation. In Electrical Engineering and Automation: Proceedings of the International Conference on Electrical Engineering and Automation (EEA2016) (pp. 340–347).
9. Sun XM, Peng WF, Zhang L, Zhang MQ. An overview on piezoelectric power generation system for electricity generation. In Electrical Engineering and Automation: Proceedings of the International Conference on Electrical Engineering and Automation (EEA2016) 2017 (pp. 340–347).
10. Howells, Christopher A. "Piezoelectric energy harvesting." Energy Conversion and Management 50.7 (2009): 1847–1850.