Research article

Hari Anand and Binod Kumar Singh*

Piezoelectric energy generation in India: an empirical investigation

https://doi.org/10.1515/ehs-2020-0002
Received November 15, 2020; accepted December 24, 2020; published online January 15, 2021

Abstract: The consumption of energy has always been in exponential growth and also there is always an increasing demand in the requirement of energy in some way or the other. So, there is a need to search for energy availability from alternate sources of energy. The utilization of waste energy of foot power with human locomotion is relevant and important for highly populated countries like India where the railway station, temples, etc., are overcrowded all round the clock. When the flooring is engineered with piezoelectric technology, the electrical energy produced by the pressure is captured by floor sensors and converted to an electrical charge by piezo transducers, then stored and used as a power source. This paper deals with the generation of alternate sources of energy through piezoelectric materials. This research describes the use of piezoelectric materials to harvest energy from people walking vibration for generating and accumulating energy. This study also studies the perceptions and adaptability of piezoelectricity. The adaptability of piezoelectric technology in a real-time environment has been studied by comparing the overall cost of generating electricity with solar energy. This study also suggests a footstep of the piezoelectric energy harvesting model which is cost-effective and easy to implement.

Keywords: clean energy; electrical energy; piezoelectric energy; waste energy.

Introduction

In India energy constitutes 52% of the commercial and industrial respondents. With the yearly rise in the demand for electricity throughout the country it is high time that we think about generating cleaner sources of electricity. For this already the Indian power sector has taken various initiatives to promote renewable sources of power like solar, wind, hydro, etc. through policies and schemes that overall benefit the entire stakeholders. But still, there need many more ways through which electricity can be generated.

For an alternate method to generate electricity, there are a number of methods by which electricity can be produced, out of such methods footstep energy generation can be an effective method to generate electricity.

Considering the daily emerging demand for power and the global climatic changes there is a heavy requirement of cleaner sources of power before it is too late. Also, India has set targets of achieving 175 GW of power by 2022 only through renewable forms of energy. Keeping in mind the above ambitious targets that countries are putting forth regarding the cleaner sources of fuel, there is an urgent requirement of alternate sources of power that not only satisfies the requirement but also meets the financial, adoption, and implementation into the real-time scenarios as well. Below, the shares of energy generation in India are shown (Table 1 and Figure 1).

The piezoelectric effect

The piezoelectric effect was discovered in 1880, by two French physicists brothers Pierre and Paul. A piezoelectric sensor is a device that uses the piezoelectric effect to measure pressure, acceleration, and force by converting them to an electrical signal (Figure 2). When pressure is applied to piezoelectric crystals electricity is developed over the crystal lattice.

Characteristics of piezo electricity

These days most of the research in the energy field is to develop sources of energy for the future. It is time to find renewable sources of energy for the future. Piezoelectric

***Corresponding author: Binod Kumar Singh,** University of Petroleum and Energy Studies, Dehradun, India,
E-mail: bksingh_ism@yahoo.co.in. https://orcid.org/0000-0002-2215-8568
Hari Anand, University of Petroleum and Energy Studies, Dehradun, India

Table 1: Total power production in India (as on 31.01.2020).

Fuel	MW	% of total
Total thermal	2,30,189.57	63.2%
Coal	1,97,964.5	54.2%
Lignite	6,760	1.7%
Gas	24,955.36	6.9%
Diesel	509.71	0.1%
Hydro (renewable)	45,399.22	12.6%
Nuclear	6,780	1.9%
Renewables	86,321.03	22.7%
Total	368,689.82	

(Source: CERC 2020)

materials are being more and more studied as they turn out to be very unusual materials with very specific and interesting properties.

Energy can never be created nor destroyed; it can only be transferred from one form to another. In fact, their materials could produce electrical energy from mechanical energy and may convert mechanical behavior like vibrations into electricity. While recent experiments have shown that these materials could be used as power generators (Figure 3).

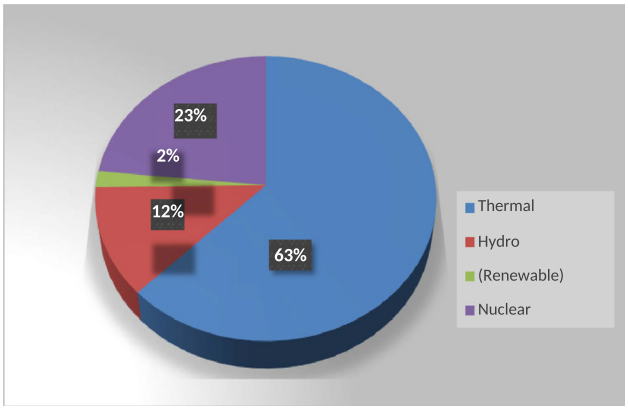

Figure 1: Power capacity in India till Jan'2020. (**Source:** CERC 2020).

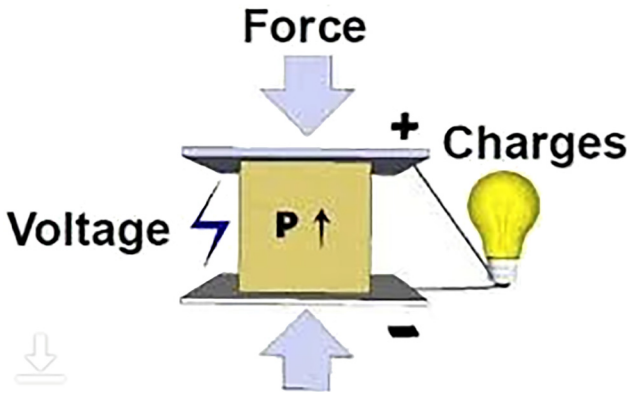

Figure 2: Piezo power with force direction. **(Source:** kinetictiles.wordpress.com).

Factors leading to requirement of piezo electricity

Below, Figure 4 shows the basic factors that lead to the requirement of the piezoelectricity.

Important components of piezoelectric tile

Piezoelectric sensor

A sensor that utilizes the piezoelectric effect, to measure changes in acceleration, strain, pressure, and force by converting them into electrical charge is called a piezoelectric sensor. This generated piezoelectricity is proportional to the pressure applied to the solid piezoelectric crystal materials.

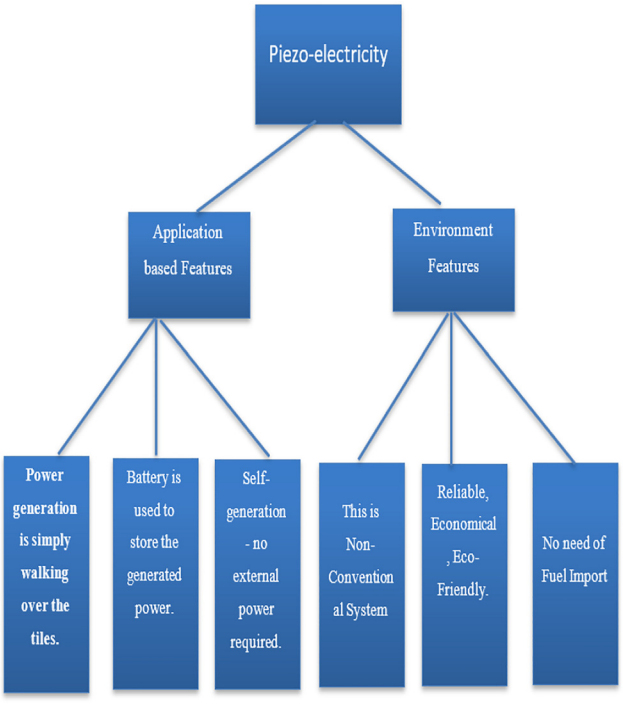

Figure 3: Piezoelectricity properties layout. **(Source:** Compiled by the author).

Battery

A Battery is an array of electrochemical cells for electricity storage, either individually linked or individually linked and housed in a single unit. An electrical battery is a combination of one or more electrochemical cells, used to convert stored chemical energy into electrical energy. An electricity is used to be generated and consumed at the same time, hence batteries are used as a storage device for storing electricity.

Primary battery

Primary batteries can produce current immediately on assembly. Disposable batteries are intended to be used once and discarded. These are mostly used in portable devices such as in alarm and communication circuits where other electric power is only intermittently available.

Secondary battery

Secondary batteries must be charged before use; they are usually assembled with active materials in the discharged state. Rechargeable batteries or secondary cells can be recharged by applying electrical current, which reverses the chemical reactions that occur during its use. Devices to supply the appropriate current are called chargers or rechargers.

Figure 4: Factors of piezoelectricity. **(Source:** Compiled by the author).

Piezoelectric tiles

Piezoelectric floors (Figure 5) are designed to capture the wasted energy and resources and store or redistribute them where they are needed. Energy is generated when a person steps on tiles that feature piezoelectric attributes. This kinetic energy is converted into electricity (Figure 6).

Literature review

Electricity from footsteps, SS Taliyan, BB Biswas, RK Patil, GP Srivastava, TK Basu, 2010. This paper discusses the basic engineering and operational mechanism of piezo crystal, engineering analysis of the model, working of piezo crystal and energy generation through footsteps.

Potentials of piezoelectric and thermoelectric technologies for harvesting energy from pavements, Lukai Guo, Quing Lu, 2017. This paper discusses the cost-effectiveness analysis of energy harvesting pavement technologies. It estimates electrical energy generation from a pavement network by two technologies cost calculation and estimating needs. Cost analysis and estimation of energy production based on piezoelectric technology.

Floor tile energy harvester for self-powered wireless occupancy sensing, Nathan Sharpes, Dušan Vučković and Shashank Priya, 2016. This paper presents details about designing and optimum structure of the piezoelectric product. Also proposed a suitable structure for product design for commercialization and design of outer shell circuit design and structure.

Green sidewalk makes electricity – one footstep at a time, George Webster, 2011. This paper studies the power generation method. Reviews of the public and studies introduction of an alternate source of energy in the market.

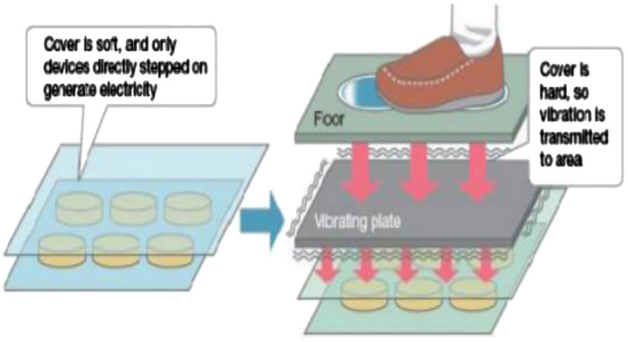

Figure 5: Piezoelectric tile layout. (**Source:** Shreeshayana et al. 2017).

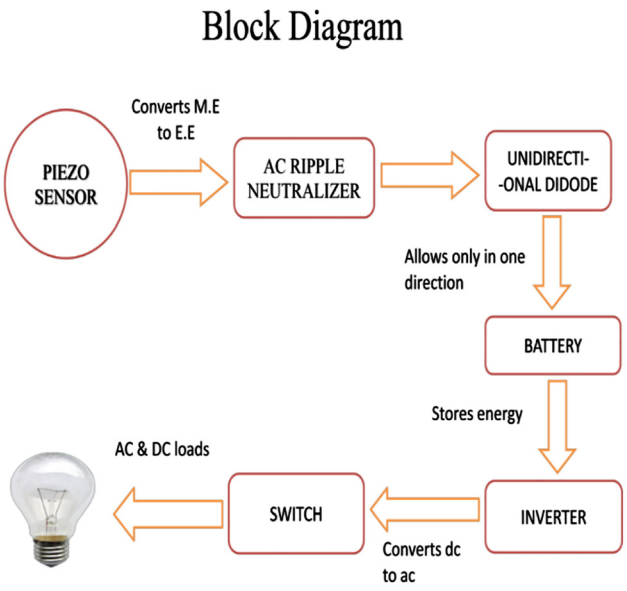

Figure 6: Block diagram of piezoelectric tile. (**Source:** Naresh et al. 2018).

An Investigation into energy generating tiles – Pavegen, Zhen Liang Seow, Song Tao Chen, and Nor Bainin Khairudin, 2011. This paper provides an idea of commercialization of the piezoelectric based energy production in a live scenario.

Future uses of the piezoelectric effect for energy production, Zack Mester and Guilherme Tamassia, 2012. This paper discusses the economic aspects of piezoelectricity, drawbacks of piezo electricity and other innovative techniques of piezoelectric generation. Also studied how to minimize the potential drawbacks of piezoelectricity and improve the efficiency of energy generated.

Feasibility study for using piezoelectric energy harvesting floor in buildings' interior spaces, Adnan Mohamad Mahmoud Yousif, 2017. In this paper, the feasibility of piezo electric tiles in the interior of buildings is studied. Analysis of energy transformation with the help of piezo electric tiles is done. Also studied the feasibility of energy-generating tiles in the interior of buildings and also at low pedestrian spaces like apartment case by using harvesting floor tiles in a different way to generate and save energy.

Application of piezoelectric transducer in energy harvesting in the pavement, Xiaochen Xu, Dongwei Cao, 2017. This paper states that utilizing piezoelectric technology in road energy harvesting is feasible and has a bright future. It defines the working mechanism in detail and the use of piezoelectric in energy harvesting.

Electricity from footsteps, S.S. Taliyan, B.B. Biswas, R.K. Patil, and G.P. Srivastava, 2013. This paper presents the possibility of the generation of electricity from footsteps. Working model of the footstep-based energy generator. The article has given a detailed working model and functioning of the footstep-based electricity generating system. This is an energy-efficient way of producing electricity as walking is one of the most common things, we do in the day to day life.

A review of power harvesting from vibrations using piezoelectric materials, Henry A. Sadano, Daniel J. Inman, and Gyuhae Park, 2004. This paper analyzes harvesting power from vibration using a piezoelectric material. Various aspects of energy harvesting based on mechanical and electric components are investigated. With the advancements in technology harvesting, electricity with the help of piezoelectric materials will be more efficient.

Energy harvesting through the piezoelectric effect at sports venues, Julius Evans, 2015. This paper studies the various parameters related to consumer behaviour and adaptability of the tiles.

Footsteps: Renewed tiles, Fatima Zahra Bouzidy, 2017. This paper carries out a detailed STEEPLE analysis of piezoelectric energy.

Background of the study

The recent study has revealed that an alternate source of energy is desperately required to meet the emerging future energy demands. Hence to meet the requirements a financially stable and viable source of power is required that will be environment friendly and possess a very easy methodology of producing energy. Hence the piezoelectric model justifies the study for an alternate source of power generation. Through the literature study, various parameters for considering the piezoelectric tile to be used as an alternate source of energy were identified like power availability, usage pattern in an area, cost of a unit of power, and overall electricity bill of a consumer. Few parameters identified were awareness about piezoelectricity, the willingness of producing standalone power. The above parameters have been studied in detail for meeting the core objectives of the research.

Purpose of the study

This study is undertaken to study the various parameters of piezoelectric tile to be used as an alternate source of energy, study consumer perceptions, response, adaptability

of piezoelectricity, and also analyze the unit cost of electricity under piezoelectric.

Methodology

This study is a mixed study. In this study, primary data is collected using non-probability sampling method, where the respondents from different sections especially those who are having the basic ideas about the trending technologies in the market were selected. The futuristic ideas that are prevailing in the current technological market especially in the sector of engineering and power. This was required as many factors were felt necessary to come up with a conclusion based upon the output received by the samples. Not only based upon the behavior of the consumer but also the market requirements were focused upon while analyzing or studying the samples. For collecting data questionnaire is prepared based on variables and also three-point likert scale is used. In this study, 143 respondents were selected. The survey was done using Google sheets. For collecting qualitative data personal interview using face to face Skype mode is used. Further, the Delphi method is also used by selecting two industry experts.

Data analysis

Data analysis is done as per objectives. To achieve the first objective the following questions are used for collecting data and then these data are being analyzed.

Question 1. Do you have frequent power cuts in your house/area?

Question 2. Do you save electricity by switching off the appliances whenever they are not required?

Question 3. What is the cost per unit you pay for your electricity bill a month?

Question 4. How much do you pay for your overall electricity consumption in a month?

To achieve the second objective the following questions are used for collecting data and then these data are being analyzed.

Question 1. Will you opt for generating electricity by walking?

Question 2. Are you interested in producing power on your own?

Question 3. Have you heard about piezo electricity?

Question 4. How did you come to know about this technology?

Question 5. Do you wish to have new electronic flooring tiles installed in your home?

Question 6. How often do u walk a day?

Question 7. Which exercise do you prefer doing regularly?

Question 8. How much will you prefer in investing in gadgets that can generate electricity for households?

To achieve the third objective cost analysis is prepared and compared with solar energy. A layout of cost analysis is as given below (Table 2):

Also, further the piezoelectric power produced is compared with solar energy that stands currently as an emerging alternate renewable source of power which is also highly commercialized (Table 3).

Table 2: Total cost of piezoelectric tile and output in India.

Parameters	Unit	Value
Overall cost (one piezoelectric tile)	(Rs)	₹ 12,511
Average steps per day	Nos.	7000
Total hits (assuming 3 hits per person in a house)	Nos.	21,000
Energy per step	Joules	5 J × 4 nos of piezo crystals = 20 J
Total energy per day (J)	Joules	420,000 J
Total energy per day (kWh)	kWh	0.11664 kWh
Total energy per year	kWh	42.573 kWh
Durability	Years	15 years

Table 3: Comparison of solar power with piezoelectric power.

Solar power		Piezo based power	
Cost of installation of 1 kW	Rs 75,000	Cost of one tile	Rs 12,511
Number of units produced in one year (considering CUF-20%)	1752 Units	Number of units produced by one tile in one year (considering 21,000 footsteps)	42.573 Units

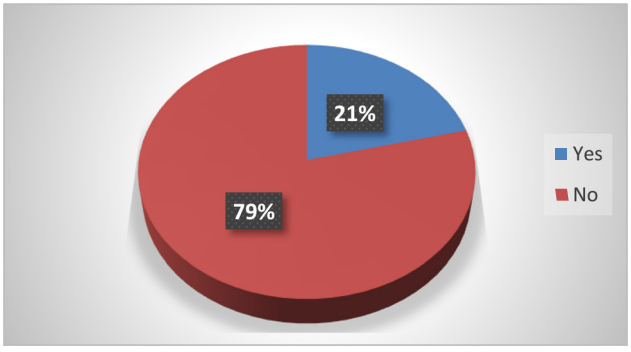

Figure 7: Power availability in area.

Result and discussion

It is clear from Figure 7 that 21% of respondents have the opinion that there are frequent power cuts in the area. 96% of respondents do have the habit of switching off the appliances when not required, while still, 4% of the respondents do lack in the same habit (Figure 8). Nearly 40% of respondents pay the electricity bills in a range of Rs 3–5 and above Rs 5 per unit of electricity consumption a month (Figure 9). 77% of respondents get above Rs 1000 as their overall electricity consumption a month, 18% pay above Rs 500 per month and the remaining get their electricity bill below Rs 500 (Figure 10).

This clearly gives an idea that 83% of the people do have power readily available for them in their respective areas but still the other 17% do lack in the same and 81% of the people do pay a lot for their electricity consumption in a month. Hence the requirement of the piezoelectric based power system can be easily anticipated and will be successful if commercialized and implemented in the market that can be helpful in generating power to the consumers

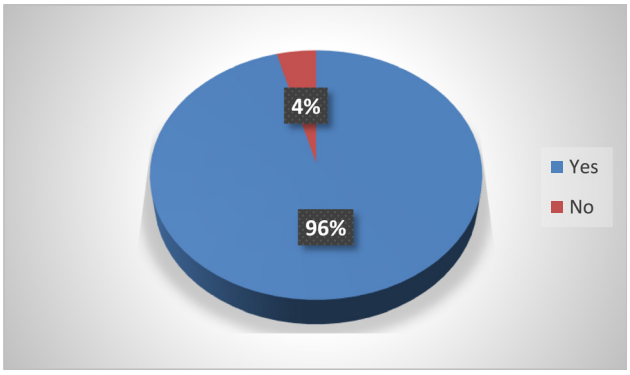

Figure 8: Usage pattern of electricity.

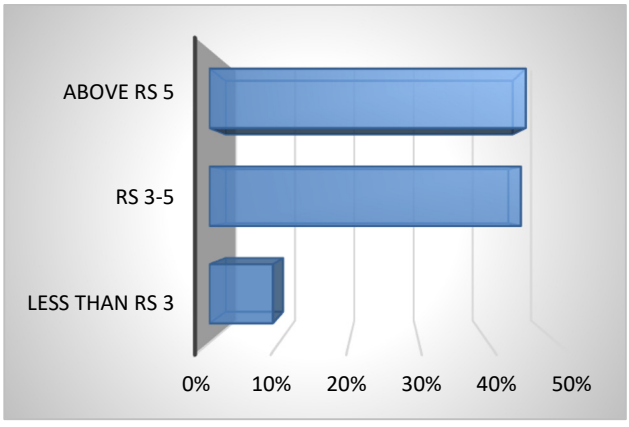

Figure 9: Cost of per unit electricity.

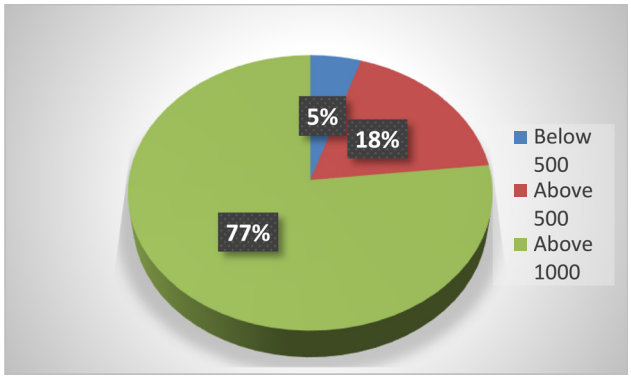

Figure 10: Monthly electricity bill (in Rs).

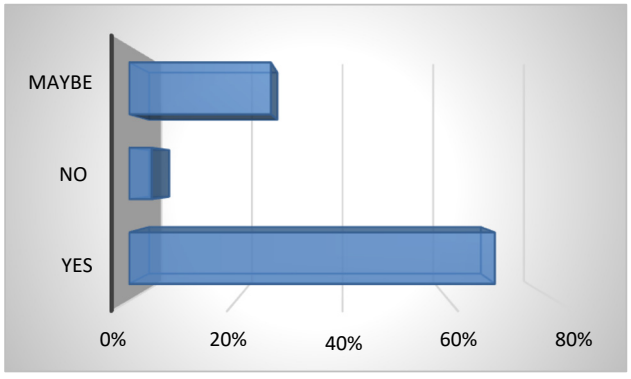

Figure 11: Willingness of producing electricity by walking.

on their own using this standalone based power for their daily menial jobs.

It is clear from Figure 11 that around 80% of customers are having the willingness to produce their own electricity by walking. 86% of the consumers are interested in producing power of their own that can be consumed by them as per their own requirements (Figure 12). 60% of the consumers have already heard about the energy generation through piezoelectricity and hence less promotion will be required among the customers to marketize the product

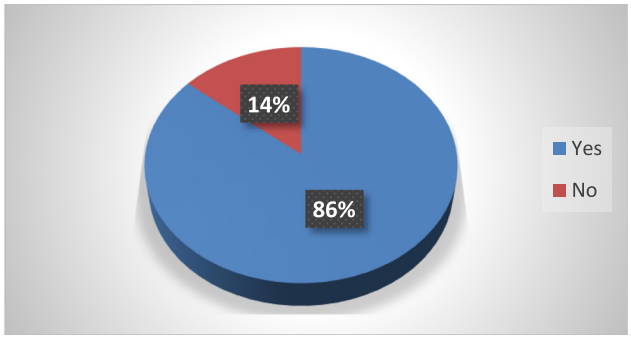

Figure 12: Willingness of producing by own.

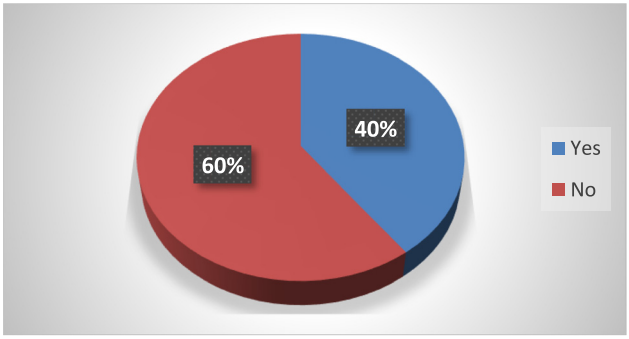

Figure 13: Awareness about piezo electricity.

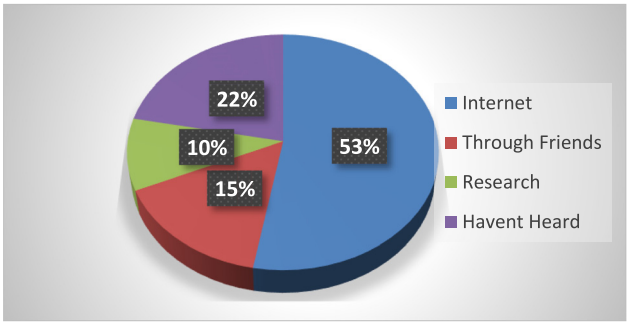

Figure 14: Source of information of piezoelectric.

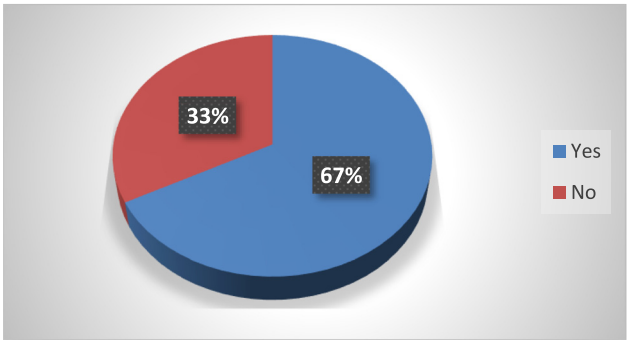

Figure 15: Willingness to avail piezoelectric tiles.

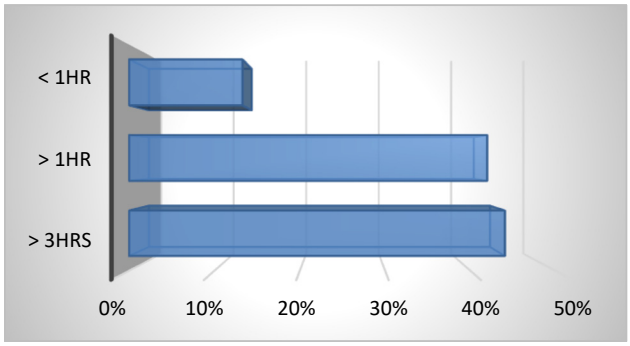

Figure 16: Time spent in walking in a day.

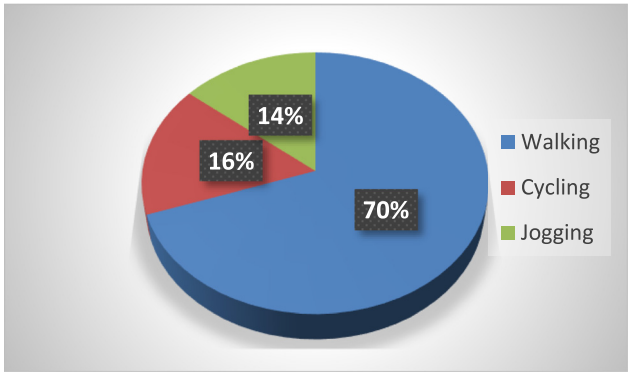

Figure 17: Preference of exercise method.

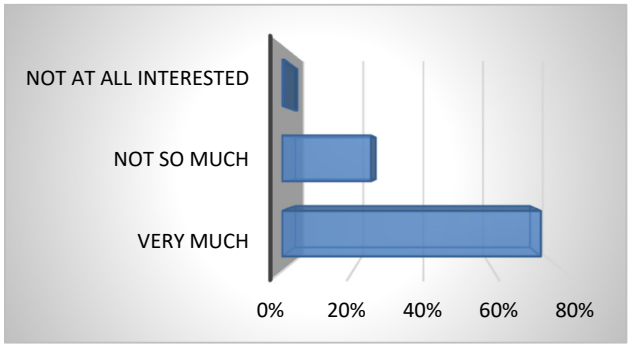

Figure 18: Willingness to invest on tiles to install at locations.

(Figure 13). 53% of customers came to know about the technology through the Internet as the medium, 15% have got the idea through their friends and 10% of the consumers have come across the same thorough research as the medium (Figure 14). Hence a little bit of awareness and promotion will be required for launching the product into the market. 67% of the consumers wish to upgrade and have electronic flooring tiles installed at their homes while 33% of the consumers are still lacking the same, this might be due to the unawareness among the consumers for the same (Figure 15). Nearly 40% of customers walk more than 3 h and up to 3 h a day (Figure 16). 70% of customers prefer doing walking as regular exercise and want to keep them physically fit. 16 and 14% of the consumers prefer Cycling and Jogging as their primary exercise source, respectively (Figure 17).

Nearly 70% of customers are willing to invest their money in generating power of their own through the piezoelectricity tiles and wish to own the same (Figure 18).

This clearly demonstrates that 74% of the people are interested in upgrading and installing piezoelectric tiles in their homes and areas. 84% of the consumers daily perform

walking and this energy can be easily tapped for generating power and can be utilized efficiently for regular use. 73% of the customers are willing to invest in producing power of their own through the piezo electric tiles and wish to invest in the same and get a home gadget for their same. This clearly provides a glimpse of the customer responses, perceptions, and willingness to adopt the piezoelectric tiles in the market.

For the same cost of solar panel, six numbers of piezoelectric tiles can be installed, thus producing 255.438 units per year. The above units generated are for tentative numbers of household footsteps of 21,000. If the tiles are installed in areas with heavy footfall like commercial buildings, the footfall might be 20× the household footsteps i.e. 4, 20,000 steps thus making power generation of 851 units generated per year per tile. This is approximately 3× more power generated in a year by investing in the same cost as of 1 kW solar.

Conclusion and recommendation

The survey responses and analysis clearly support the adaptability of piezoelectricity in the market. Tech-talks with expertise also favour's the product to be launched into the market. With India expected to produce 175 GW power only from renewal energy by 2022, piezo-based energy generation will be a booming factor in the market. As, it meets all the necessary requirements of the respondent, gradually increasing the efficiency & durability of the piezoelectric tiles, the piezoelectric system will surely be a reliable option.

Acquired advice from industrial expertise to know about the project feasibility and sale recommendations in the market. So, there is a need to broadening the idea with respect to service for the product. With an increase in smart gadgets in the market, the product will have a high positive response in the market. Also recommended to work over increasing the efficiency level of electricity production, as footsteps may fall at areas with less load defined fields resulting in less power generation so that the system is more reliable and available throughout for electricity generation.

Scope for further research

This study is based on a limited geographical location and also an adequate sample is taken.

Researchers may also propose a framework related to piezoelectric energy.

Author contribution: All the authors have accepted responsibility for the entire content of this submitted manuscript and approved submission.

Research funding: None declared.

Conflict of interest statement: The authors declare no conflicts of interest regarding this article.

References

Americanpiezo.com/knowledge-center/piezo-theory/piezoelectricity (accessed April 10, 2020).

Bouzidy, F. Z. 2017. *Footsteps: Renewed Tiles*. Ifrane, Middle Atlas region of Morocco: Al Akhawayn University.

Central Electricity Regulatory Commission. 2020 (accessed June 27, 2020).

Evans, J. 2015. *Energy Harvesting Through the Piezoelectric Effect at Sports Venues*. Arcata, California, USA: The Faculty of Humboldt State University, Humboldt State University.

Guo, L., and Q. Lu. 2017. "Potentials of Piezoelectric and Thermoelectric Technologies for Harvesting Energy from Pavements." *Renewable and Sustainable Energy Reviews* 72: 761–73.

Kinetictiles.wordpress.com/tag/piezoelectric-floor-tiles (accessed April 10, 2020).

Mester, Z., and G. Tamassia. 2012. "Future Uses of the Piezoelectric Effect for Energy Production." In *Documentation at Twelfth Annual Freshman Conference*.

Mohamad, A., and M. Yousif. 2017. "Feasibility Study for Using Piezoelectric Energy Harvesting Floor in Buildings' Interior Spaces." *Energy Procedia* 115: 114–26.

Naresh, K., A. Balaji, M. Rambabu, and G. Nagaraju. 2018. "Practical Oriented Foot Step Electric Power Generation by Using Piezo Material and Microcontroller in Campus." *International Research Journal of Engineering and Technology* 5 (7): 1590–6.

Sadano, H. A., D. J. Inman, and G. Park. 2004. "A Review of Power Harvesting from Vibrations Using Piezoelectric Materials." *The Shock and Vibration Digest* 36: 197–206.

Seow, Z. L., S. T. Chen, and N. B. Khairudin. 2011. *An Investigation into Energy Generating Tiles – Pavegen*. UBC Social Ecological Economic Development Studies (SEEDS) Student Report.

Sharpes, N., D. Vučković, and S. Priya. 2016. "Floor Tile Energy Harvester for Self-Powered Wireless Occupancy Sensing." *Energy Harvesting and Systems* 3: 43–60.

Shreeshayana, R., L. Raghavendra, and V. G. Manjunath. 2017. "Piezoelectric Energy Harvesting Using PZT in Floor Tile Design." *International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering* 6 (12): 8872–9.

Taliyan, S. S., B. B. Biswas, R. K. Patil, G. P. Srivastava, and T. K. Basu. 2010. "Electricity from Footsteps." *BARC Newsletter* 313: 47–50.

Taliyan, S. S., B. B. Biswas, R. K. Patil, and G. P. Srivastava. 2013. "Electricity from Footsteps." *International Journal for Innovative Research in Science* 1–3. https://doi.org/10.1109/icresh.2010.5779590.

Webster, G. 2011. *Green Sidewalk Makes Electricity One Footstep at a Time*. CNN Tech.

Xu, X., and D. Cao. 2017. "Application of Piezoelectric Transducer in Energy Harvesting in Pavement." *International Journal of Pavement Research and Technology* 11: 388–95.