The Effect of Piezo-Bumps on Energy Generation and Reduction of the Global Carbon Emissions

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Abstract: - Nowadays, renewable energy sources are taking high place in research agenda. In the last centuries, human activities are overloading the environment and the atmosphere with pollutant and carbon emissions which affect negatively the climate and produce global problems such as ozone depletion and global warming. Electricity could be considered as the most contributor part in these climate problems, the production of electricity overloads the environment by carbon emissions. Moreover, the production of domestic oil and natural gas are decreasing every day and relying on these type of Energy sources is no longer an option. Developing and implementing renewable energy approach within the urban context is the scope of this research. New technologies and devices have been invented such as piezoelectric cells to generate electricity using a renewable energy source in order to solve the Shortage of the electricity and the shortage of the fuel resources. The main concern of this research is that the percentage of carbon emission in the high population counties such as china and Egypt is increasing and it is affecting the public health. Moreover, developing countries with high population density is not well electrified, which effects the growth of this counters. This research intends to develop a system that generates electricity from integrating piezoelectric cells with streets bumps and get advantage of the huge traffic density in developing countries to generate renewable and Eco- friendly electrical energy. This research will introduce a new element called "Piezo-bumps" which integrated piezoelectric cells with street bumps.

Key-Words: - Electricity generation; Piezoelectric cells; Piezo-bumps; Street bumps; CO_2 reduction

1 Introduction

Recently cresting sustainable cities become the main goal for all the governments in developed and developing countries, to overcome the climatic and environmental pollutions [1]. In recent years, interest in energy harvesting has increased rapidly, and harvesting vibration energy using piezoelectric materials has attracted a great deal of attention [2; 3; 4 & 5]. Different types of piezoelectric transducer can be used to harvest vibration energy, including monomorph, bimorph, stack or membrane [6; 7 & 8]. Each configuration has its own advantages and limitations, and in general it is not possible for an energy harvester to perform well in all applications. For this reason, energy harvesters are normally designed for a specific application and a particular frequency range of operation [3].

Theoretical models of piezoelectric energy harvesters are widely available, but it produce low amount of energy and most of these models are based on linear models [9 & 11].

Areas such as safety, practicality, durability, maintainability, and development optimization aims to utilize energy harvesting technology in transport systems with high energy efficiency [11; 12; 13 & 14]. Previous research states that Energy harvesters from roads and transport systems are noteworthy which this research intend to prove otherwise.

Unfortunately, there are still economic, environmental and social challenges that stand against the usefulness of harvesting energy form piezoelectric sources. This challenge is concentrating on concerns about environmental damage and climate change which could be caused from increasing the thermal micro climate of roads and transportation sector. In fact, energy harvesting from roads is a clean source of efficient energy and environmental conservation. Solar, vibration, acoustic waves are the types of energy sources that can be harvested from roads and transportation systems. This paper is focused on extracting energy from speed bumps vibration integrated with piezoelectric cells. Previous research concentrated on energy harvesting systems from road and traffics [15; 16; 17; 18 &19].

The most widely recognized energy harvesting techniques are designed to generate energy from using the mechanical stress or strain generated by traffic [2 & 20]. Moreover, the willingness to diversify the use of piezoelectric energy has continued [21]. From the economic perspective of using piezoelectric energy harvesting technology, the cost efficiency for road installation of energy harvesting equipment is declining and this technology is still a new field in research [19; 22 and 23].

Types of piezoelectric technology were classified according to the main technical specifications in Table (1) and by the same order according to uses and features, this main types are covering the factor of available products, the basis of the feasibility study. Table (1) presents the product and the energy produced from each product, the cost of each product and the lifespan [25].

Table 1. The technical specifications, price and lifespan of Piezoelectric types

Company - Technology	Product Dimension	Generated Energy	Price/ USA $ (2017)	Life span by years
Waynergy Floor	40 x 40 cm	10 W per step	444.5$	20
Sustainable Energy floor (SEF)	75 x 75 cm or 50 x 50 cm	Up to 30 watt	1,666.66$	15
pavegen tiles	V3 Tile 50cm each edge	5 Watts / footsteps	388.9$	20
(EAPs) Electro-Active Polymers	Sheets	1W	Unknown	20
Sound Power	50 x 50 cm tile	0.1 watt per 2 steps	Unknown	20
PZT ceramic (Lead zirconate titanate)	Manufacturing in a smal l size	8.4mW	Unknown	20
Parquet PVDF layers	Layers	2.1mWs per pulse with loads of about 70 kg	Unknown	20
Drum Harvesters - Piezo buzzer Piezoelectric Ceramics	Vary	Around 2.463 mW	Estimated 55$ /tile	20
POWER leap PZT	Tile 24" x 24"	0.5mW per step	The project has stopped	20
hybrid energy floor -	75 x 75 cm tile OR	up to 250 kWh per year, per tile	Estimated 1,666.66	20
combines human power with solar energy	1 x 2 meter tile			
PZT Nanofibre - nanogenerator &PZT textile nanogenerator	Sheets The volume of the material used is 0.2cm3	6mW/cm3 0.03 μW power density up to 2.4 μW/cm3 [20]	available commercially at low cost and in a variety of designs	20
Pvdf nanofibre	4μW/cm 37.2pW	unknown	unknown	20
ZnO nanowire VINGs	5 pW 11 mW/cm 22.7 mW/cm 3	very economically	2.22$	(energy floors, 2017)
BaTiO3	~7 mW/cm 3	available commercially at low cost and in a variety of designs	(energy floors, 2017)	

2 Study Methods

This research uses an empirical method for examining the capability of Piezo-bumps to generate amount of electricity which is enough for street lights to work depending on this renewable energy system. This empirical method consists of two stages. The first stage is the design model in which a design for piezoelectric bump will be done to create a bump with maximum efficiency, the second stage is applying the designed Piezo-bumps on a case study in order to examine the efficiency of Piezo- Bumps in terms of energy generation and carbon emission reduction.

2.1 Stage One

In this study, to overcome the disadvantages of past road energy harvesters that are difficult to install, we built a module that is easy to install by using it in a speed bump. The main role of stage one is to design Piezo-Bump and creates an electrical circle in a way that is suitable to be applied in the case study of this research. The graphical abstract below clarifies the process and the electricity generation from designing Piezo-Bumps system.

When cars move above the Piezo-Bump, they act as a force or load. These loads exert forces on the hump in which it leads to vibration in the springs that connect the bumps with the piezoelectric cells.

The vibration transfers the kinetic energy to the piezoelectric cells. Then piezoelectric cells convert the kinetic energy into electrical energy and to be transferred to deep cycle lead acid battery model number DC2-3000 that has a capacity of 3000 Ah and 2 voltages as shown in fig. 1. According to Hill et, al., (2014) [24], the PZT type of piezoelectric cells with a dimension of 20*20cm has the capability to generate 16.45 - 41.25 Watts per one car moving above it. Then the electrical energy to be transferred to neighborhood electricity line. The neighborhood electricity line supplies the lighting units and the advertisement units in the street by the electricity they need to work daily.

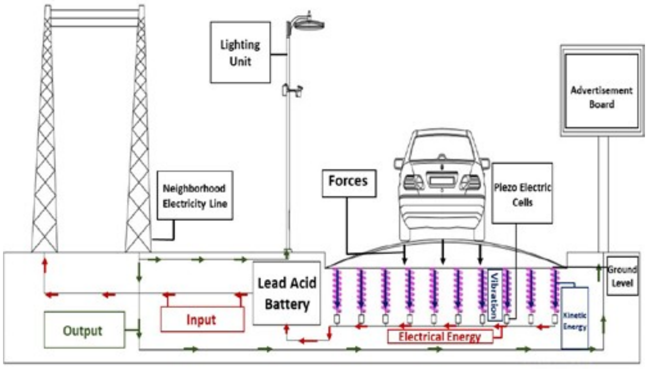

Fig.1: Graphical Abstract

2.2 Stage Two

This research uses an empirical method for measuring the level of carbon emission in the study area more over it present a solution for reducing the carbon emissions using Piezo-Bumps. This empirical method consists of two phases. Phase one; is calculating the existing level of carbon emission produced from electricity generation and traffic density. Phase two; is redesigning the study road using Piezo-Bumps to reduce the carbon emissions from electricity generation. The results will be presented in the form of tables and charts.

2.2.1 Study Area

Mubarak road in El-Sherouk city, Cairo-Egypt has been chosen randomly to be the study area of this research because it is one of the most crowded and important roads in the Egyptian new urban settlements such as El-Sherouk city. It represents a gateway that connects two highway roads which are Cairo-Ismalia Desert Road and Cairo-Suez Desert Road, which makes Mubarak road one of largest density roads in El-Sherouk City as shown in fig. (2 & 3). El- Sherouk city is one of the most crowded new urban settlements in Egypt due to the location of two private high educational facilities “the British university in Egypt (BUE)” and “El-Sherouk Academy” as shown in fig. (3).

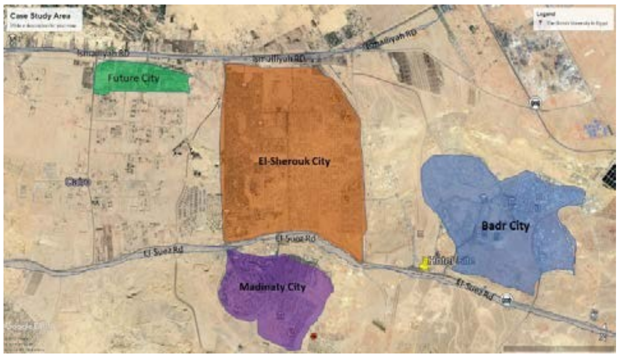

Fig.2: The location and surroundings of El-Sherouk city

2.2.2 Location and components of Mubarak Road

Mubarak Road is located in El-Sherouk City, Cairo-Egypt. The length of Mubarak road is around 8 Km and it divide El-Sherouk city into two halves’ as it shown in the above fig. (2). Mubarak Road is an arterial main road in El-Sherouk City because on the north side of Mubarak road there is Cairo- Ismalia Desert Road. The south side of Mubarak road there is Cairo-Suez Desert Road which connects El-Sherouk city to main destination which are Madinaty City and New Cairo as shown in fig. (2). Moreover, Mubarak road connects El-Sherouk sub roads together which makes it the most important road in El-Sherouk City. Mubarak Road is a two-way road as shown in fig. (3).

Fig.3: The Study Area-Mubarak Rd

Mubarak road is a main street with two directions, each direction has three lanes and has a width of 7 meters. Sidewalks are existing on the right side of each direction to provide pedestrian facility. The width of sidewalks is 1 meter and height of 20 cm in addition for a landscape strips that cuts the street into two directions with a width of 1m and height of 20cm as shown in fig. (4).

Fig.4: A section View for -Mubarak Road

Street bumps are existing in the two directions of the road with three bumps in each direction. The dimensions of these bumps are 20cm High, 60cm Width, 7m long as shown in fig. (4), Circular shape. Lighting units are existing on the both sides of each direction with 35 meters between each lighting unit. The total number of lighting units is 456 lighting unit for each direction. Trees and shrubs are existing in the street Landscape strips. The case study will focus only on one direction only.

2.2.3 Data Collection

The data collected in this research was through site observations and data documentations for the selected road. Two types of data were collected in this research, data collection one and data collection two. The data collection one (Electricity Supply), it is focusing on the source and amount of electricity consumed in Mubarak road. While the data collection two (Traffic Density), is a site survey for calculating the road traffic density by calculating the number and type of vehicles (Cars, Buses, trucks) crossing the road in working days and in weekends.

2.2.3.1 Data Collection One (Electricity Supply)

The data collected in this part was targeting the source and amount of electricity consumption in Mubarak road such as number of lighting features, number of advertisement boards and the number of traffic controlling devices as shown in table (2).

Table 2. Annual Electricity consumption in Mubarak Road

Type	Lighting Column	Advertisement Boards	Traffic controlling device
Number of Units	456	4	0
Electricity Consumption (Per Hour)	500 W	750 W	500 W
Winter working hours	5pm–6am =13h	5pm – 6am =13h	6am – 5am= 24h
Summer working hours	7pm – 5am = 10 h	7pm – 5 am = 10 h	6am – 5am = 24h
Electricity Consumption in Winter/ day	2964000 W	39000 W	0
Electricity Consumption in Summer/ day	2280000 W	30000 W	0
Number of summer days	180 day	180 day	180 day
Number of winter days	180 day	180 day	180 day
Annual Electricity Consumption	943920000	12420000	0
Street Total Annual Consumption	943920000+ 12420000+ 0= 956340000 W		

2.2.3.2 Data collection Two (Traffic Density)

The data collected in this section illustrate the traffic density in Mubarak Road as well as it identifies the types of vehicles crossing this road. The traffic density was calculated through site survey which took place on Saturday 11, Tuesday 14, Thursday 16 and Friday 17 February 2018, these four days were chosen to represent the traffic density in Mubarak Road on the working days and weekends, knowing that Friday is a formal weekend in Egypt were all the companies and facilities is considered this day as a day off. While, the second day off in Egypt is divided between Saturdays or Sunday, some companies and facilities considered Saturday as the second weekend while the others are using Sunday as a day off. The traffic density was calculated during four different hours which represent the rush hours, average traffic density and low traffic density hours. Knowing that the rush hours in Egypt is between 7:30am till 9:30 and between 2:30 till 4:30 with a total of 4 hours every day. Moreover, the average traffic density is between 9:30am till 2:30pm and between 4:30pm till 12:30am with a total of 13 hours every day. While, the low traffic density hours are between 12:30am till 7:30 am with a total of 7 hours every day. Knowing that the average car speed in the study are is between 60 to 80 km/hour.

Table 3. The Traffic density in Mubarak Road per day

Working day (next day		Working day				weekend for some companies while in others it is a working				Days/ Date
Thursday 16/11/2017		Tuesday 14/11/2017				Saturday 11/11/2017				
3:00-4:00pm	8:30-9:30am	2:00-3:00am	8:30-9:30pm	3:00-4:00pm	8:30-9:30am	2:00-3:00am	8:30-9:30pm	3:00-4:00pm	8:30-9:30am	Time
870	2260	73	1500	1980	2250	48	690	920	1050	Small vehicles (Cars)
998	1507	6	195	1005	1520	0	58	680	598	Big vehicles (Bus & trucks)
((2260+870)/2)=1565*4 =6260 vehicle		((2250+ 1980)/2)=2115*4 =8460 vehicle				((1050+920)/2)=985*4 =3940 vehicle				Average Number of Small vehicles in Rush hours/ day
((1507+998)/2) = 1252.5*4		((1520+1005)/2)=1262.5*4 =5050 vehicle				((598+680)/2)= 639*4 =2556 vehicle				Average Number of big vehicles in Rush hours /day
(378*13)+ (101*7) = 5621		(1500*13)+ (73*7) = 20011				(690*13)+ (48*7) = 9306				Average Number of Small vehicles in normal & low density hours /day
(66*13)+ (3*7) = 879		(195*13)+ (6*7) = 2577				(58*13)+ (0*7) = 754				Average Number of big vehicles in normal & low density hours/ day
6260+5621=11881		8460+20011 = 28471				3940+9306 = 13246				Average Number of small Vehicles/ day
5010+879=5889		5050+ 2577 = 7627				2556+754 = 3310				Average Number of Big Vehicles/ day

Weekend					
Friday 17/11/2017					
2:00-3:00am	8:30-9:30pm	3:00-4:00pm	8:30-9:30am	2:00-3:00am	8:30-9:30pm
21	70	210	128	101	378
7	13	40	29	3	66
((128+210)/2) =169*4					
((29+40)2) =34.5*4					
(70*13)+ (21*7) =1057					
(13*13)+ (7*7) = 218					
676+ 1057= 1733					
138+ 218=356					

Table (3) calculate the average number of vehicles in Rush hours/ day by calculating the average number of cars that has been found in the site survey which was held between 8:30-9:30am and 4:00-5:00 pm, this hour represents the rush hours in Egyptian roads. The average number of cars has been multiplied by 4 which represent the rush hours in Egyptian roads. While, the average number of vehicles in normal and low density hours/day was calculated by multiplying the number of vehicles in the hour between 8:30-9:30 pm which represent the normal traffic density/hour by 13 which represent the total number of normal traffic density in Egyptian roads/day. Moreover, the normal traffic density in Egyptian roads/day is added to the number of vehicles found in the hour between 2:00-3:00 am which represent the low traffic density in Egyptian roads/hour and multiplying it with 7 hours which is the average of low traffic density in Egyptian roads/day.

2.2.4 Equipment's

The equipment used in this research is a Piezo-Bumps, the Piezo-Bumps is a piezoelectric speed bump which integrate piezoelectric cells with the rood speed bumps. It is designed according to the specs of the case study road in terms of dimensions' shape and location of piezoelectric accessories. The design of Piezo-Bumps which will be used in Mubarak road is a 7 m Length, 60 cm width and 20 cm height, Piezo-Bumps has 44 piezoelectric pieces with a dimension of 20*20 cm divided into two rows. These pieces are connected to deep cycle lead acid battery model DC2-3000 with a capacity of 3000 Ah with a dimension of 90*90 cm and to be fixed beneath the sidewalk that has a width of 1m. The piezoelectric cells will generate electrical energy and to be transferred to the battery. The battery transfers the electrical charges to the neighbourhood electricity line, neighbourhood electricity line will distribute the electricity on the lighting fixtures as shown in figures (5 & 6), the site survey revealed that there is 3 speed bumps in study area therefore the designed Piezo-Bumps will be executed in the study area three times because it will replace the road speed bumps.

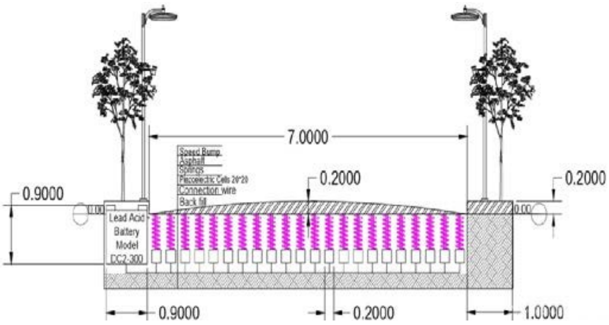

Fig.5: The Designed Piezo-bump – Section View

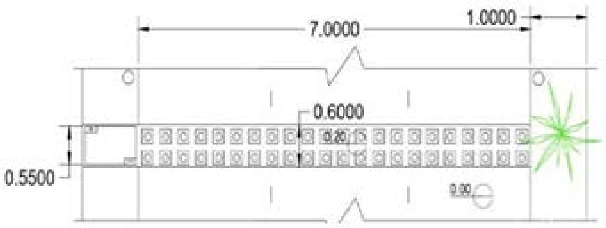

Fig.6: The Designed Piezo-bump – Plan View

2.2.5 Procedures

The process of this research took places within several steps, the first step was documenting and analysing the study area (Mubarak Rd, El-Sherouk City) using site survey as a part of data collection process, this step intends to study the dimensions of the existing road (Mubarak road), the location and dimensions of the existing street bumps and analysing their designs, calculating the number of lighting features and advertisement boards and document any element that consume electricity. The second step includes an observational survey to identify the type and traffic density in Mubarak road, the survey took place in 4 different days and 4 different hours in order to take the most appropriate average of vehicles that daily cross the study area. The third step is designing and applying Piezo- Bumps in Mubarak road. The fourth and final step is calculating the amount of electrical energy harvested from Piezo-Bumps and comparing it with the amount of electricity consumed. Moreover, the research calculated the amount of carbon emission reduced form generating energy from Piezo-Bumps.

3 Results

As stated by [24] a piezoelectric panel with dimensions of 90*150 cm will generate 17.5 W per human step. According to this research a piezoelectric cell 20*20 cm produced 16.5 W per small vehicles and 41.1 W per big vehicles as shown in table (4). Since that each Piezo- bumps contains 44 piezoelectric cell, therefore the amount of energy generated from Piezo- bumps has been calculated by multiplying 16.5W with 44 for small vehicles and 41.1 multiplied by 44 for big vehicles.

Table 4. Amount of Electricity Could be Generated by Single PZ Piece

Size of Piezoelectric cell/ cm	Weight of the object (Load)	Energy Generated from Piezoelectric cell	Energy generated from Piezo-bumps
90*150	80 kg	17.5 W	
20*20	800 kg	16.5 W	726 W
20*20	20000 kg	41.1 W	1808 W

The observational survey which was presented in the data collection section, revelled the average number of big and small vehicles that crosses Mubarak Road in Saturday, Tuesday, Thursday and Friday. Fig. (7) Presents the energy generated from a Piezo-bumps/ day that is installed in Mubarak road.

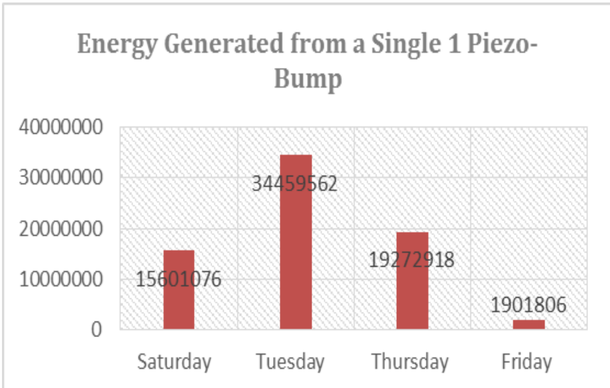

Fig.7: The average Energy generated from Piezo-Bumps in Watt

Since the case area has three existing street Bumps, therefore these three bumps will be replaced with Piezo-Bumps, the three Piezo-Bumps will generate weekly a total electricity of 420,463,458 W as shown in table (5). While the data collection revealed that the street consumes 2964000 W/ day in the summer and it consume

2280000 W/ day in winter. Therefore, the weekly consumption of Mubarak road in summer is (2964000 *7) = 20,748,000 W while the weekly consumption of Mubarak road in winter is (2280000*7) = 15,960,000 W. the comparison revealed that using Piezo-bumps in Mubarak road will generate almost 20 time more energy than the road consumes.

Table 5. Amount of Energy Generated weekly from a Single 1 Piezo-Bumps

Days/ Date	Saturday 11/11/2017	Tuesday 14/11/2017	Thursday 16/11/2017	Friday 17/11/2017
Average Number of small Vehicles/ day	13246	28471	11881	1733
Average Number of Big Vehicles/ day	3310	7627	5889	356
Energy Generated from small Vehicles crossing 1 Piezo-Bump	13246*726 = 9616596	28471*726= 20669946	11881*726 = 8625606	1733*726= 1258158
Energy Generated from big Vehicles crossing 1 Piezo-Bump	3310*1808 = 5984480	7627*1808= 13789616	5889*1808 = 10647312	356*1808= 643648
Daily energy generated from 1 Piezo-Bump	15,601,076 W	34,459,562 W	19,272,918 W	1,901,806 W
Weekly Energy generated from 1 Piezo-Bump	140,154,486 W			
Reduction of CO_2 emissions/ Week	131745.2168 kg			

According to McLean, 2017 every 1000 W produced by coal fire plants and fossil fuel generate 0.94 kg of CO_2. Resulting from that the amount of CO_2 emissions eliminated from Cairo atmosphere is 131745.2168 kg/week as shown in table (5).

4 Conclusion

Energy is an essential sector for economic development. Today, the activity of the energy sector mostly depends on fossil fuel such as; coal, oil and natural gas. Recently, many researches proved that fossil fuel will disappear in the upcoming years because it's non-renewable energy. Renewable energy is strongly recommended because of its expected need in the upcoming future taking into consideration the growth of the population and the increasing demand in energy. Furthermore, the human activities are overloading the environment with carbon dioxide and global warming emissions which results in increasing temperature and spread harmful effects on health and human body. Generating electricity is a significant part of this activities because it is generated by coal-fired power plants and natural gas-fired power plants. Increasing the supply of renewable energy will allow the world to reduce the growth of environmental problems such as global warming and climatic change. This research integrated piezoelectric cells with street bumps to benefit from the vehicles weight in generating electricity. This research proved that the use of piezoelectric Bumps is effective in high density roads which is a problem in 3rd world countries. The 3rd world counties can benefit from its high traffic density and solve their energy problems using Piezo-Bumps and protect their environment.

References:

[1] Moussa, R.R. (2019). The Reasons For Not Implementing Green Pyramid Rating System In Egyptian Buildings. *Ain Shams Engineering Journal,* 10(4); 917-927

[2] Anton, SR., Sodano, HA. (2007). A review of power harvesting using piezoelectric materials (2003–2006). *Smart Mater Struct;16:R1.*

[3] Mak, K. H., McWilliam, S., Popov, A. A., Fox, C. H. J. (2011). Performance of a cantilever piezoelectric energy harvester impacting a bump stop. Journal of Sound and Vibration 330; 6184–6202.

[4] Moussa, R.R. (2018). The role of energy-scape elements in creating sustainable economic project in Egyptian parks. Ain Shams Engineering Journal, 9(4); 3045-3053. Retrieved from: https://doi.org/10.1016/j.asej.2018.09.001

[5] Moussa, R.R., and Mahmoud, A.H., (2017). Energy-scape Elements: An Approach on Integrating Landscape Elements with Renewable Energy Devices. Journal of Cleaner Production, 153; 114-130. Retrieved from: https://www.sciencedirect.com/science/article/pii/S0959652617305127

[6] Shenck, N.S., Paradiso, J.A. (2001). Energy scavenging with shoe-mounted piezoelectrics, IEEE Micro, 21;30–42.

[7] Wang, Z.L. Song, J. (2006). Piezoelectric nanogenerators based on zinc oxide nanowire arrays, Science, 312; 242–246.

[8] Feenstra, J., Granstrom, J., Sodano, H. (2008). Energy harvesting through a backpack employing a mechanically amplified

piezoelectric stack, Mechanical Systems and Signal Processing, 22:721–734.
[9] Sodano, H.A., Park, G.D., Inman, J. (2004). Estimation of electric charge output for piezoelectric energy harvesting, Strain, 40; 49–58.
[10] Erturk, A., Inman, D.J. (2008). On mechanical modeling of cantilevered piezoelectric vibration energy harvesters, Journal of Intelligent Material Systems and Structures. 19;1311–1325.
[11] Harb, A. (2011). Energy harvesting: State-of-the-art. Renew Energy, 36:2641–54.
[12] Tan, Y., Zhong, Y., Lv, J., Ouyang, J., Zhou, S. (2013). Preparation and properties of PZT/asphaltbased piezoelectric composites used on pavement. J Build Mater, 16:975–80.
[13] Wang, C., Wang, H., Li, Y. (2016). Study on technology of power pavement based on integration of piezoelectric material and pavement material. J Highw Transp Res Dev, 33:14–9.
[14] Orrego, S., Shoele, K., Ruas, A., Doran, K., Caggiano, B., Mittal, R., et al. (2017). Harvesting ambient wind energy with an inverted piezoelectric flag. Appl Energy, 194:212–22.
[15] Zhou, Z., Wang, X., Zhang, X., Chen, G., Zuo, J., Pullen, S. (2015). Effectiveness of pavement-solar energy system – an experimental study. Appl Energy, 138:1–10.
[16] Guldentops, G., Nejad, AM., Vuye, C., Van den bergh, W., Rahbar, N. (2016). Performance of a pavement solar energy collector: model development and validation. Appl Energy, 163:180–9.
[17] Lu, Z., Zhang, H., Mao, C., Li, CM. (2016). Silk fabric-based wearable thermoelectric generator for energy harvesting from the human body. Appl Energy, 164:57–63.
[18] Roshani, H., Dessouky, S., Montoya, A., Papagiannakis, AT. (2016). Energy harvesting from\ asphalt pavement roadways vehicle-induced stresses: a feasibility study. Appl Energy, 182:210–8.
[19] Song, G.J., Kim, K., Cho, J.Y., Woo, M.S., Ahn, J.H., Eom, J.H., Ko, S.M., Yang, C.H., Hong, S.D., Jeong, S.Y., Hwang, W.S., Woo. S.B., Jhun, J.P., Jeon, D.H., Sung, T.H. (2019). Performance of a speed bump piezoelectric energy harvester for an automatic cellphone charging system. Applied Energy, 247; 221-227.
[20] Najini, H., Muthukumaraswamy, S.A. (2016). Investigation on the selection of piezoelectric materials for the design of an energy harvester system to generate energy from traffic. International Journal of Engineering and Applied Sciences (IJEAS), 3; 43-49.
[21] Wang, X., Chen, C., Wang, N., San, H., Yu, Y., Halvorsen, E., et al. (2017). A frequency and bandwidth tunable piezoelectric vibration energy harvester using multiple nonlinear techniques. Appl Energy, 190:368–75.
[22] Wang, C., Zhao, J., Li, Q., Li, Y. (2018). Optimization design and experimental investigation of piezoelectric energy harvesting devices for pavement. Appl Energy, 229:18–30.
[23] Xiong, H., Wang, L. (2016). Piezoelectric energy harvester for public roadway: on-site installation and evaluation. Appl Energy, 174:101–7.
[24] Hill, D., Agarwal, A., Tong, N. (2014). Assessment of piezoelectric materials for roadway energy harvesting: cost of energy and demonstration roadmap: final project report: California Energy Commission; 2014.
[25] Solban, M.M. and Moussa, R.R. (2019). Piezoelectric Tiles Is a Sustainable Approach for Designing Interior Spaces and Creating Self-Sustain Projects. (November, 28 -30). (BSCairo2019) Simulation for a Sustainable Built Environment, Cairo_ Egypt. IOP Conf. Series: Earth and Environmental Science 397-012020. Retrieved from: doi:10.1088/1755-1315/397/1/012020.