INTERNATIONAL JOURNAL of RENEWABLE ENERGY RESEARCH
A. F. Ahmad et al., Vol.11, No.3, September, 2021

Energy Harvesting on Pavement: A Review

A. F. Ahmad*, A. R. Razali*‡, F. R. M. Romlay*, I. S. M. Razelan**

* Faculty of Mechanical and Automotive Engineering Technology, Universiti Malaysia Pahang, 26600 Pekan, Pahang, Malaysia

** Faculty of Civil Engineering Technology, Universiti Malaysia Pahang, Lebuhraya Tun Razak, 26300 Gambang, Kuantan, Pahang, Malaysia

(amaninafarhana.ahmad@gmail.com, akhtar@ump.edu.my, fadhlur@ump.edu.my)

‡ A. R. Razali; A. F. Ahmad, Tel: +609 4246214, akhtar@ump.edu.my,

Received: xx.xx.xxxx Accepted:xx.xx.xxxx

Abstract- Rapid urbanization has increased the Malaysian economy's dependence on imports of fossil fuels such as oil, petroleum, and natural gas for energy output. Excessive use of fossil fuels contributes to high greenhouse gas emissions and this causes climate change and affects the ecological balance. Therefore, energy generation through harvesting technology is much needed to improve the ecological balance. The process for energy harvesting begins with capturing and accumulating the wasted energy then storing it to be used later. According to a study conducted by the World Economic Forum, roads in Malaysia are among the best in the world on par with Korea and better than some of the European countries. Malaysia's road network that connects the states, districts, and villages are also growing every year for the convenience of the people. Good road structure throughout Malaysia can give benefit the country by using it as an energy source. The energy sources that can be exploited from the pavement are solar radiation, mechanical energy generated from moving vehicles or pedestrians, and geothermal energy. This paper analyzes key issues in pavement energy harvesting and proposing the best energy harvesting technique for Malaysia climate. The keys issues were addressed accordingly and gaps that existed in the field were presented. The outcomes of the review are brief in a concise manner.

Keywords Renewable energy; Pavement; Solar; Piezoelectric; Thermoelectric; Geothermal

1. Introduction

Rapid urbanization demands improvement and very efficient transportation infrastructure. Efficient transportation infrastructure may only be achieved by the wide coverage of pavement. Pavement in Malaysia has been constructed over 160,000km. Figure 1 shows the development of road construction in Malaysia from 2005 to 2016 [1]. Besides that, energy consumption also increases which leads to pollution. More than 13,813 Mtoe energy consumed worldwide in 2019 and among this energy, Malaysia alone consumed over 93 Mtone [2]. Figure 2 presents the annual energy consumption in Malaysia from 2009 to 2019. Figure 3 show the increasing trend of carbon dioxide (CO2) emission in Malaysia from 2009 to 2019 [3]. Carbon dioxide emission increased because the energy consumption in Malaysia increased and this contributes to the increased rate of pollution in the country.

In that case, a number of studies have been focusing on renewable energy technology intending to apply the ecology concept in the pavement. As part of the global initiative, sustainable pavements were already introduced to build efficient renewable energy harvesting technology. Temperature gradients, light, electromagnetic radiation, chemical energy, and motion are examples of energy sources that can be used as ambient sources [4]. These diverse sources of energy are turned into electrical energy, which is a more useful form of energy [5]. There are several sources of renewable energies which are geothermal heat, solar radiation, and vibration due to mechanical load, hydro, wave, and wind [6]. Solar radiation, vibration due to traffic load, and geothermal heat are the three energies that are continuously exposed on pavement and all these provide a good potential to harvest renewable energy from the pavement. Vibration due to vehicle load on pavement can be harvested by piezoelectric energy harvesters [7]. Solar radiations cause a thermal gradient to exist in the road layers, along with geothermal heat which is converted into useful energy via harvesting of solar energy, thermoelectric energy, geothermal energy, and composite energy [8].

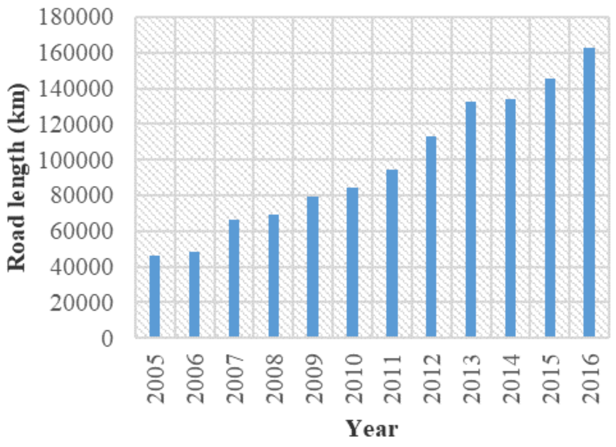

Fig. 1. Road length in Malaysia (km)

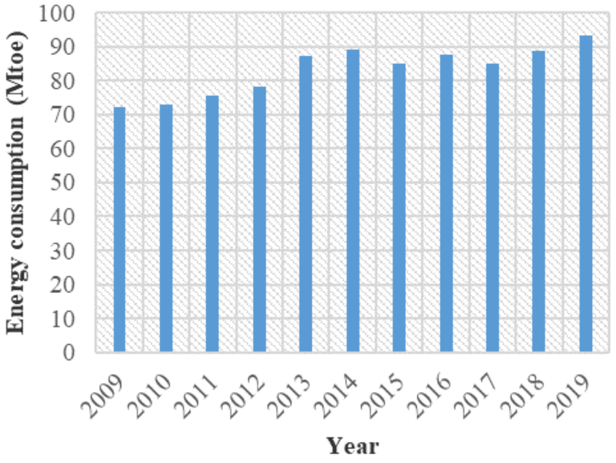

Fig. 2. Energy consumption in Malaysia (Mtoe)

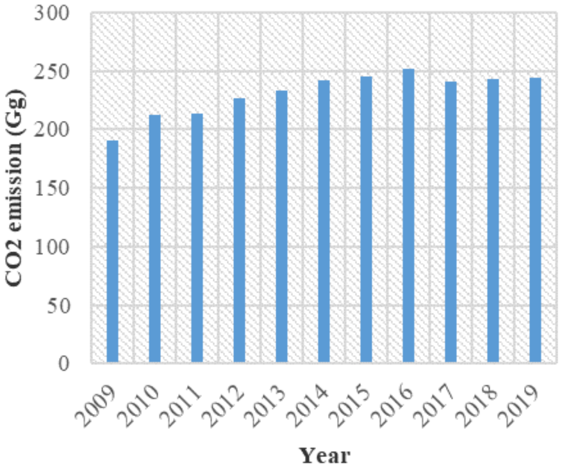

Fig. 3. CO2 emission in Malaysia (Gg)

A lot of effort has been made to study this green technology based on a different focus. Dowson et al focused on design and development discussed the benefits and limitations of energy harvesting technology for pavement [9]. Wang et al summarized working principles and energy harvesting technologies application methods on roads and bridges with a discussion of new trends and issues of these technologies [10]. Durte and Ferreira were generally discussed about solar harvesting technologies and vehicle-induced energies with also some review on energy harvesting technologies for pavement application [11]. In 2013, Shi and Lai were done some specific research on green and low carbon technologies. They have summarized the reviews quantitatively between 1994 to 2010 in various countries without having comprehensive technical design or engage with the limitation of any green technology [12].

2. Road Harvesting Technology on Road Pavement

Road pavement contains a variety of green energy sources such as mechanical, light, and thermal energy. Existing and developing technology may make it possible to harvest green energy from the pavement. Table 1 shows the various form of green energy exist in pavement [13]. Figure 4 presents a power density of solar, geothermal, and piezoelectric [14]. Collected energy from the pavement can be carried away from powering small-scale road devices such as traffic lights, roadside advertisements, or airport signage.

Table 1. Green energy exist in pavement [13]

Category	Form – Origin	Energy harvesting technologies
Mechanical Energy	Traffic induced deformation and vibration	Piezoelectric
Light Energy	Sunlight	Solar
Thermal Energy	Temperature gradient inside the pavement	Thermoelectric & Geothermal

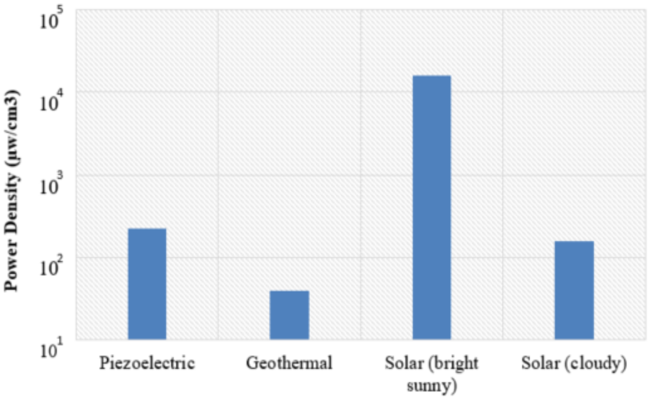

Fig. 4. The power density of different green technologies Source: [14]

There were no any projects about renewable energy from the pavement in Malaysia. Malaysia's effort to introduce renewable energy started in the national energy mix under the 8th Malaysia Plan in 2001. In this plan, Malaysia had set a target to achieve 5% of electricity generation from renewable energy by 2005 [15]. However, this target was not reached in that year which ends up reaching only 0.3% [16]. There are five renewable energy resources that have the potential to be harnessed commercially in Malaysia which are biomass, biogas, municipal waste, solar, and mini-hydro. In 2018, renewable energy accounted for around 3.5% of Malaysia's total electricity generating mix [17]

2.1 Piezoelectric

Piezoelectric energy harvesting occurs when dynamic mechanical energy is converted into electrical energy by using piezoelectric materials [18]. The flow of this energy harvesting was mostly focused on low-level energy harvesting which starts from microwatt to milliwatt to generate low-power electricity. Piezoelectric materials typically operate at much lower energy levels compared to solar and thermal energy which are capable of producing high watts [19]. This energy can generate without the presence of solar and thermal energy. It is also capable to work in an embedded system. The demand for the piezoelectric system was increase every year and this was proved when $22billion of the piezoelectric device reported as annual revenue in 2012 and it increased to $37billion in 2017 [18, 20].

Piezoelectric vibration energy harvesting can be applied in aerospace system [21, 22], building [18, 23], bridge[18, 24], and human body [25]. Normally, the power that generate from vibration can be converted through electromagnetic [26, 27], piezoelectric [28-30], electrostatic [31, 32], triboelectric converter [33-35] and magnestrictive [36-38]. The advantage of this energy harvesting compared to others is it can be installed in any roadway, is weather-independent, and can be built in a wide range of sizes and shapes [39]. Host structures are required to attach the piezoelectric harvester in case it allows vibration energy to be captured. Vibratory energy can be transferred well from host to harvester with help of the host structure.

2.1.1 Piezoelectric Energy Harvesting on Road

The harvesting of excessive energy from pavement using a piezoelectric energy harvester is efficient and feasible [40, 41]. Roshani et al.[42] was evaluate the effect of field simulated variables such as speed and traffic load with regard to electric power generation. From their research, it shows that the amount and placement of the piezoelectric sensor change the stresses applied to lead to variations in the output power produced. Besides that, the output power is also affected by loading time and magnitude. Najini and Muthukumaraswamy [43] designed a MATLAB-Simulink Model to study the ability of Piezoelectric energy harvesting from pavements and economic review regarding roads in the United Arab Emirates. The parameters for their research are vehicle mass, speed, and temperature. Wang et al. in 2018 [44] was designed and tested the piezoelectric energy harvester by considering the energy output and road binding; optimization of piezoelectric energy harvester size depends on tire trace patterns, vehicle wheel-path distribution, and vehicle roller compaction conditions. Their result shows that optimal power generation output can be achieved when power generation device at dimension 100mm x 100mm. Chen et al. in 2018 [45] develop and analyze a composite beam piezoelectric energy harvester made of plane strain state with two asphalt mixture layers and a piezoelectric layer in between. Cao et al. in 2020 [29] studied to quantify the energy output of piezoelectric transducer under vehicle load and then the daily energy output of pavement was estimated. Their results show that a larger amount of energy power can be generated when the vehicle speed faster and the load larger.

It is possible to store energy from harvesters in batteries that can power other electric sensors and signal light [46]. With the growing use of piezoelectric technologies in pavement and bridges, it is helpful to decrease the consumption of non-renewable fossil fuel which leads to more sustainable and resilient pavement structures. This technology also can be access infinity without worry about the weather.

2.2 Solar

Solar energy harvesting technology is now growing well day by day [47]. Among the other renewable technology, solar is one of the most vital role due to their availability and technology growth [48]. The solar panel is commercially available proves that electricity through this technology is affordable [49, 50]. In various countries, there are a number of examples for roadside solar panel installation [51]. The main current issue for the installation of solar panel technology is the need for physical space. An application has been introduced by installing solar panels on the pavement which serve as the driving surface [52]. Although the installation of this technology on the road can solve the problem of physical space needs, the safety and capabilities of the structure should also be taken into consideration [49]. The differential temperature gradient between the top and the lower pavement layers is the factor of extracting heat energy from pavement [53]. During the daytime in a hot climate, the pavement surface temperature usually higher than the bottom layer and this situation is contrary during cold climate. There are many applications that used this temperature gradient for electricity generation [54] or use it for other purposes such as deicing [55]. The other advantage of heat harvesting from the pavement in a hot climate is urban heat island (UHI) effect can be reduced when the road surface has the potential to be cooled [56]. Besides that, rut resistance and cracking also can be improved when the operating temperature of the asphalt surface reduce [57, 58]. Rutting on pavement can occur during hot climate because of bitumen characteristics which become soft during hot temperature and this makes the aggregate on pavement slightly move [59, 60].

2.2.1 Solar Energy Harvesting on pavement

Many energy harvesting technologies have been developed to collect energy from the sun for a sufficient period during the daytime. The key advantage of solar energy harvesting is that sunlight is able to supply solar radiation globally [61]. There are three common methods for harvesting solar energy include the installation of solar panels as the photovoltaic pavement under a transparent surface layer, installation of the solar panel along roadways, and pavement solar collectors with heat extraction through embedding pipe systems [49]. In figure 5, solar radiation was harvested through the installation of the solar panel along the roadway. This also contributes to external energy reduction and greenhouse gas emission [6, 62]. This design was commonly used to power signals and traffic lights on the roadways. Photovoltaic panel would convert the light energy to electricity [63]. Previous studies have found that photovoltaic technology has the highest peak productivity for energy harvesting compared to other renewable energy technologies, but the productivity is limited by brightening conditions [64].

Figure 6 shows the collector of solar energy through photovoltaic. Photovoltaic pavement surface consists of high strength transparent layer on the top and solar panel was installed below it [6]. The top layer works as a waterproof layer and allows sunlight to pass through it. Photovoltaic pavement is made of tempered glass, which is installed between two porous rubber layers [65]. Qin et al in 2017 developed a small project with an automatic data-acquisition system on the use of solar pavement energy and analyze the efficiency of pavement solar systems in energy conversion [66]. Senji et al. was proposed a pavement integrated photovoltaic thermal (PIPVT) module to evaluate the performance of solar radiation. Their result shows that an increase in solar radiation, ambient temperature, and transmissivity of the anti-slip layer could give a positive effect on overall performance [67]. Although many studies have been done, this photoelectric road are still not feasible due to high construction cost and the possibility of short lifespan.

Figure 7 shows the collector of solar energy through a piping system installed in asphalt pavement and it is stored as electric energy. To compare with geothermal energy harvesting, pavement solar collectors with embedding pipe systems was harvest thermal energy from solar radiation instead of by geothermal source [6, 68]. However, it was used a similar pipe system design. Sedgwick and Ptrick in the year 1981 was a founder for pavement solar collectors with an inbuilt pipe system. They have embedded a 20mm plastic pipe under the asphalt surface of a tennis court which gives the result of constant temperature [69] In order to remove snow during winter, Wu et al proposed to use black asphalt as a solar collector for direct heating and cooling [70]. The main problem is to maintain the temperature in the piping system and to prevent pipe blockage over time. Among the factors that affect heat, collection are the albedo of the surface layer, the latitude of pavement, pipe diameter, depth of pipe, the distance between pipe, and thermal conductivity of the surface layer[71]. Johnsson & Adl-Zarrabi in 2020 [72] was reported the findings of the investigation from summer 2018 and how the efficiency of solar collectors is affected by change the flow rate of fluid, pipe spacing, and albedo.

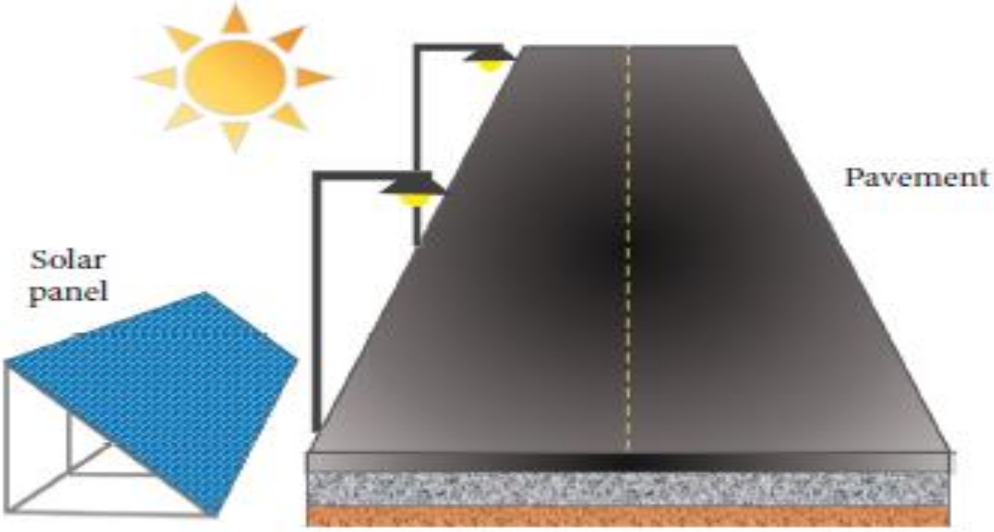

Fig. 5. Solar harvesting energy through solar penal for pavement [6, 73]

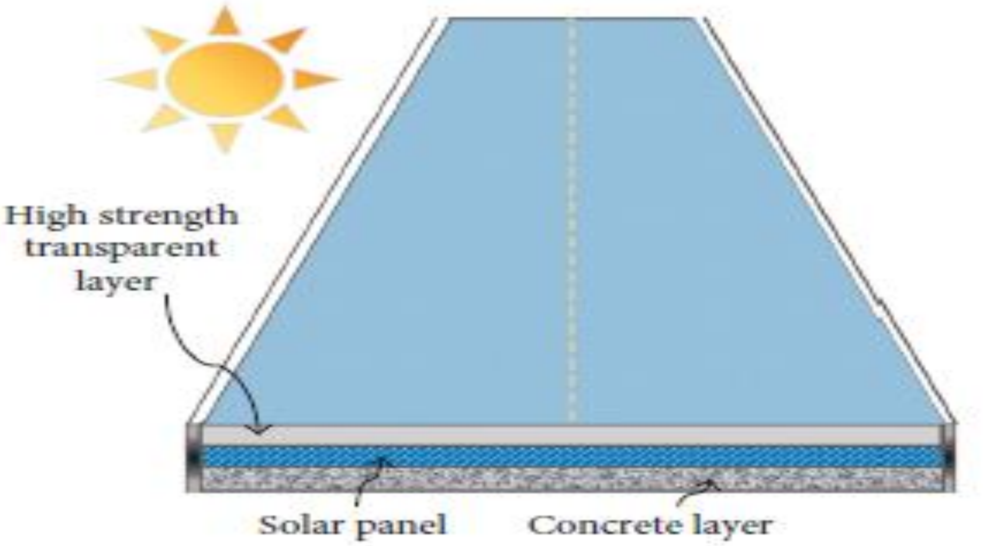

Fig. 6. Solar harvesting energy through photovoltaic for pavement [6, 52]

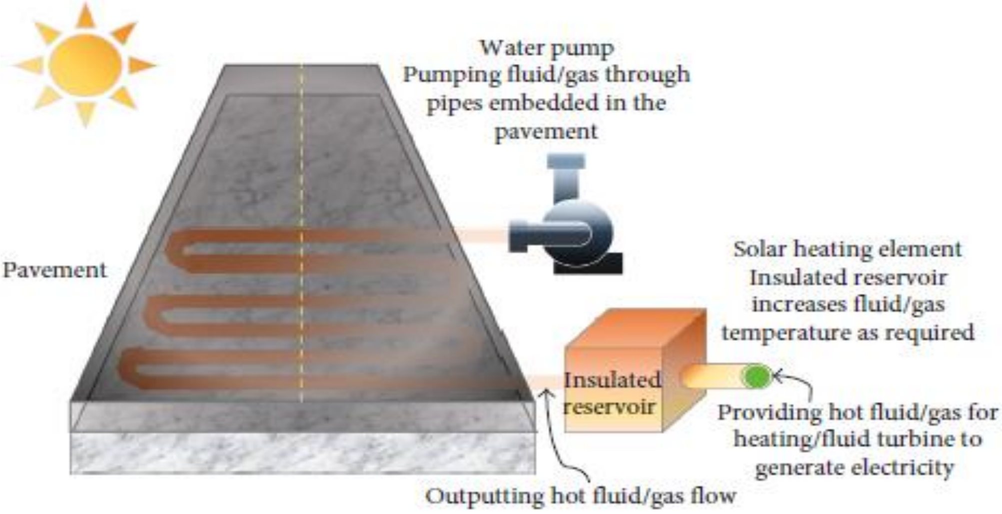

Fig. 7. Solar harvesting energy through heat extraction with the piping system for pavement [6, 74]

2.3 Thermoelectric

Electricity can be generated by collecting the heat from the pavement then provide the heat to the surrounding building and reducing the UHI effect [75]. In pavement application, the utilization of thermoelectric material serves as an energy collector. Widely, thermoelectric materials have high energy productivity at high heat flux state (over 180°C) [76, 77]. In pavement, the temperature gradient is likely to be low and this may cause a smaller heat flux [78]. Therefore, in order to achieve a good energy conversion efficiency for widely use in pavement application, thermoelectric energy harvester should be optimized in terms of device design and material design [79].

2.3.1 Thermoelectric energy harvesting on pavement

In 2014, the thermoelectric behavior of carbon fiber reinforced cement composite (CFRC) was studied by Wei et al [80]. After 4 years, their recent study was shown a great thermoelectric behavior when they use graphite or cement-based composites [81]. Rew et al [82] was research the effect of powdery carbon-based additives on asphalt composite such as carbon black and graphite. Lee et al [83] have conducted a study on the temperature difference between the road surface and the concrete structure below the surface. Their research was extended to generate electricity by using the temperature difference between the surface of the highway concrete barrier and the lower layer [84]. Datta in 2017 [76] has conducted similar studies in which he used a TEG prototype measuring 64mm x 64mm to be applied on the pavement in South Texas. The surface of the pavement during summer is 55°C while the soil in the lower layer has a temperature between 27°C to 33°C. By using this TEG prototype, the electric power can generate about an average 10MW in 8 hour period continuously. Lee et al [85] and Kim et al [86] was also done similar work on TEG systems for pavement energy harvesting.Jiang et al. in 2018 [87] was develop and test the improved thermoelectric generator system in concern of plastic deformation of pavement and urban heat island (UHI) effect. From their testing, it is shown that the pavement surface temperature reduced by 8-9°C in the hot season. This can help to reduce the UHI effect and at the same time can generate electric power.

2.4 Geothermal

Compared to others, natural geothermal resources are obtained from thermal energy stored in the solid underground. Natural geothermal resources are generally caused by the melting of high temperatures in the shallow crust and the decay of certain radioactive elements [88]. Figure 8 shows the electricity generation through geothermal energy which is collected with a pipe network. Electricity generation through this method has been practiced by many countries such as Turkey [89] and Mexico [90]. Geothermal energy is also used to heat the road for the deicing purpose [91]. Thermal exchange in pipe networks is influenced by fluid operation parameters such as flow rate and temperature [92]. Therefore, in order to achieve maximum conversion efficiency and optimal fluid operating parameters, pipe network construction should be the focus on design, installation depth, and pipe size.

2.4.1 Geothermal energy harvesting in the pavement

Wang et al were studied melt snow on pavement through a small-scale geothermal system. From their research, the results show that the melting process of snow consists of a staring period, linear period, and accelerated period [91]. Liu et al evaluated asphalt concrete pavement heat transfer and snow melting and also paved the pavement with electric heating pipe [93, 94]. Mauro and Grossman have developed a lower enthalpy geothermal harvester in which the temperature gradient was generated by high thermal conductivity material to remove annual fluctuation in street temperature [95]. I-Hsuan Ho in 2020 [96] was discussed the optimization of the Hydronic heating pavement (HHP) subject to different weather conditions. Their research was carried out in western North Dakota which has high heat demands due to extreme weather. Because of that situation, the volumetric flow rates, suitable water temperatures, pipes layouts, thermal conductivity of pavement, and mechanical properties of piped pavement were analyzed. The initial investment in the use of geothermal energy for road heating at airports is a relatively high cost compared to traditional snow removal. However, it is still a safe and good application for the environment [97]. Even though geothermal energy is one of the good renewable energy sources, it still has an issue which are geological limitations and geographical availability. The most popular applications for geothermal energy harvesting are deicing and snow removal in sidewalks, airports, and bridges [98]

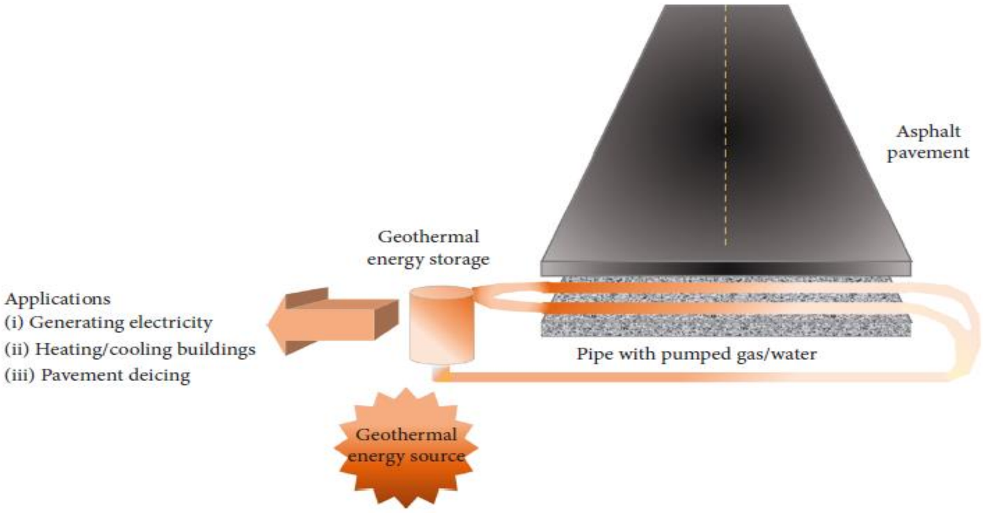

Fig. 8. Harvesting energy through Geothermal pavement [6, 91]

3.0 Comparison Between The Energy Harvesting

The introduction of green technology application on the pavement enables the transportation infrastructure to be independent without relying on the external power grid in case of a power outage in a destructive event [42, 99, 100]

Table 2 shows the difference between energy harvesting technology on the road, according to the method of energy conversion, conversion efficiency, and technology readiness level (TRL). The highest conversion efficiency for energy generation is geothermal energy harvesting. The method of harvesting is the energy harvested from geothermal energy into electrical energy. Based on the design scheme, the harvesting efficiency of piezoelectric energy in converting mechanical energy to electrical energy is at low-medium level conversion. Piezoelectric energy harvesting was considered by a previous study to be one of the technologies that can provide the largest power density compared to the voltage envelope [101]. On the other hand, solar energy harvesting has a medium-high conversion efficiency where this energy harvesting occurs when solar radiation is converted to electrical energy or thermal energy. The renewable energy harvest from this technology is able to contribute to the generation of electrical devices in the pavement such as signal lights, street lights, and traffic lights. In addition, it is also able to provide electricity to devices that help in terms of monitoring pavement health such as temperature, humidity pavement content, or monitor pavement temperature during cold weather [6]. The viability of energy harvesting from pavement has been shown by many pilot studies. The TRL was assessed using a scale range between 1 to 9 where the highest readiness level is 9 and the lowest level is 1 [10, 39, 102]. Geothermal energy harvesting and solar energy harvesting technologies are both relatively mature while thermoelectric energy harvesting technologies are the most immature where it has a low energy conversion rate.

Table 2. Comparison of pavement harvesting technology

Energy harvesting technology	**Energy conversion method**	**Energy conversion efficiency [6]**	**Technology readiness level (TRL) [10, 39]**
Solar harvesting energy	Solar to electrical Or Solar to thermal	Medium to high	9 4
Piezoelectric harvesting energy	Mechanical to electrical	Low - Medium	4
Thermoelectric harvesting energy	Thermal to electrical	Low	3
Geothermal harvesting energy	Geothermal to electrical	High	9

3.1 Installation Of Energy Harvesting

Each of these energy harvesting installations has its dependent factors. It is also costly based on the condition of the road. Some types of energy harvesting need to be rebuilt the road for the installation process such as geothermal energy requires the planting of pipes in the road. However, some of the energy harvesters did not need to rebuild the pavement for example as in figure 5 where solar radiation was harvested through the installation of the solar panel along the roadway. There are some distinctions between rebuilt and new roads in terms of energy harvester installation. The focus for the former should be on turning a conventional road structure into a harvesting energy pavement. [103]. Table 3 summarized some features that should be considered during the installation of energy harvesting and the installation cost of each energy harvest

Table 3. Installation Feature And Cost

Technology	**Installation Features of Energy Harvester**	**Installation Cost**
Piezoelectric	The generated electrical power can be affected by factors such as piezoelectric material, depth of embedment of the piezoelectric enclosure, element configuration, position of vehicle wheels concerning the enclosure, vehicle class, traffic volume, and vehicle speed. [104].	The construction cost of a single piezoelectric transducer is 5 ¥ and the manufacturing cost is 15 ¥. A total of 40 000 ¥ has been spent on the cost of 100m piezoelectric pavement [24].
Solar	When utilized on pavement, photovoltaic panels should be able to endure loads, be durable, and weatherability [105]. The generated electrical power can be affected by geometrical and operational parameters, such as depth of pipe, pipe spacing, and fluid flow rate [106]	Wattway, the world's first solar road, was built in Tourouvre, Normandy, France in 2016 at a cost of €5,000,000 along 1 km of country road. [107]
Thermoelectric	Before installing thermoelectric pavement, it is required to conduct extensive research on how to properly utilize temperature differences in the pavement structure and sustain thermoelectric conversion efficiency under a variety of environmental circumstances. [103]	The 2 TEGs and 4 TEGs cost $94 and $190, respectively [76], Jiang et al [87] research which still under laboratory circumstances, the road's construction cost was around $90,000.
Geothermal	The maximum energy conversion efficiency and optimal fluid operation can be achieved when pipe networks are carefully designed, in terms of installation depth and pipe diameter.[6]	The SERSO pilot plant's installation costs were, as expected, quite high: more than 2'500 Euro/m^2 [108]. The first year's installation and utility costs were $1,590,502, and the second year's maintenance costs were $31,741. [109]

4.0 Key Issue Related To Energy Harvesting On Pavement

There are many specific issues related to different areas, which could be addressed in future researches. The followings are some typical issues to be addressed which are categorized in terms of harvesting energy.

4.1 Solar Harvesting Energy Key Issue

Solar harvesting energy is able to obtain medium-high efficiency conversion [6]. Although this is considered a mature technology, it still has some problems to deal with. The key issues for solar harvesting energy are weather, safety, and type of solar collector.

4.1.1 Weather Limited

In solar harvesting energy, sunlight plays a very important role. Sun radiation can only be obtained to the maximum during direct sunlight, but it is limited on rainy days and nights [6]. A study conducted by Cuong and Ancheta in 2018 was found that the energy produced during sunny days is 8,211Wh. However, it was reduced to 4,738Wh during cloudy days and able to reach 2,419Wh on rainy days [110]. Besides that, by using Malaysia climate as a guide in 2018, Mohammad et. al. was found that the average daily global radiation during the drier season (January-July) is higher compared to rain season (August-December) [111]. Malaysia is known as one of the wet-climate nations. There is a relatively high level of temperature and humidity in the Malaysian climate [112].

4.1.2 Safety issue

The environment will be in danger if the solar panel is not properly managed when it has become a hazardous waste by the end of its life span. During the first 25 years of solar panel development, it was not a concern to recycle waste panels [113, 114]. Solar photovoltaic panels waste is estimated to reach between 60 to 78 million tons by 2050 [113]. If a solution has not been found, the process of disposal of these solar panels could threaten the world. Recently there are some companies that produced recyclable photovoltaic panels but there is still a lot of room for improvement. Many researchers are still studying this matter and there are still no mature research results. Nain & Kumar state that, during the process of disposing of solar panels in landfills, toxic material such as lead, silver, and chromium contained in the solar panels will break down and will pose a new environmental hazard [115]. In addition, the use of toxic material in solar panels can also threaten public health. In 2020, Erten & Utluhas stated that improperly regulated solar panel manufacturing may result in the release of Cadmium (Cd) compounds into the air as a by-product which will affect human health [116]. Persons exposed to cadmium dust and smoke for more than eight hours may face serious health problems such as bronchial exposure, pulmonary exposure, and also death[117].

4.1.3 solar collector

There are some problems that arise when solar energy is collected through embedded pipes. When metallic pipes are used, it will cause problems in terms of corrosion and difficulties in installation or maintenance. In addition, when polymer pipes are used, their thermal conductivity value is less than the thermal conductivity of metallic pipes. This has been proved by Al-Saad et al [118] which study the selection of proper pipe materials in solar collectors. From their study, the solar collector efficiency for plastic pipes is 33.1% and steel pipes are 40%. The use of polymer pipes also causes more complicated milling and future re-use of the asphalt mix are drawbacks [119, 120]. To address these problems, Muñoza et al. [119] have introduced a new type of asphalt solar collector by replacing the common pipe network system with a highly porous asphalt layer. Although they can achieve good thermal efficiency, the flow rates are low. Another issue with this system is that all pipes need to be interconnected and if one of them is broken, the liquid will leak and damage the asphalt concrete. In 2014, Garcia and Part [74] was do some research about parallel air conduits instead of pipes filling with liquid. The study concludes that overall system efficiency has been improved by generating the different airflow rates between air temperature and pavement temperature. However, their study has not yet been applied to real roads. It is considered an immature study because it does not yet know the effects that will arise if this study is applied to a real pavement.

4.1.4 Dust Deposition

The output of a photovoltaic panel is not only influenced by solar radiation but also has several other parameters that can affect energy production [121]. One of the parameters is dust deposition on the solar panels [122]. Based on the study by Smith et al. [123] which was conducted in Portland metropolitan area, they found that the power output was significantly reduced when dust deposition occurred on the surface of the PV panel. Two factors regulate the efficiency of photovoltaic panels namely the alterable factor and the unalterable factor. Dust is one example of an unalterable factor where it falls under environmental factors that depend on classification [124]. Solar radiation that reaches the surface of the photovoltaic panel will be reduced when the dust particles that are in the atmosphere have a larger size than the wavelength of sunlight that enters the surface of the panel. This effect will be even worse if it is combined with the effects of air pollution [125]. Caseres et al [126] were done research about the PV systems in Santiago, Chile and they found that the presence of dust on the photovoltaic panels would increase the LCOE as the efficiency reduction increase from 0% to 10 %. This situation could be explained by the fact that, under this scenario, homes will require a battery bank to store excess energy because they will not be able to sell it back into the market. The LCOE range of photovoltaic systems is expected to increase when storage is factored in. Table 4 show the LCOE of PV system when efficiency loss in increase.

Table 4. Levelized cost of electricity (LCOE) when it is dusty and causes increased efficiency loss on the panel [126]

LCOE (USD/kWh)	Efficiency Loss (%)
0.1500	0
0.1500	0.05
0.1500	0.05
0.2250	5
0.4250	10

4.2 Piezoelectric Harvesting Energy Key Issue

One of the advantages of piezoelectric harvesters is useful in the situation where solar and thermal energy is absent. However, this technology is not yet fully ready and still needs improvement [39]. There are several key issues that need to be addressed to improve this technology such as depth of installation, construction cost, and low power output.

4.2.1 Installation

A piezoelectric energy harvesting device must be installed near the pavement surface which the vehicular stresses are highest and this may obstruct pavement maintenance [39, 127]. The position of piezoelectric materials is able to affect the generation of electrical energy [104]. The road surface of 50mm depth from the top often faces repair work. Therefore, piezoelectric material should be installed below 50mm so that it will not interrupt the maintenance work [42]. They are exposed to around 90% of the stresses that are delivered to the surface, but they allow unfettered routine rehabilitation [128]. Zhang et al were stated that the output power will drop to zero if the distance between transducer and wheel more than 4 meters [104]. The installation of piezoelectric material closest to the road surface is able to provide better power output. However, this condition also contributes to material damage. Piezoelectric materials have high compressive strength properties but low tensile strength. They can be damaged by bending stresses and eccentric compressive [129].

4.2.2 High cost

Piezoelectric harvesting energy is categorized as quite expensive technology [39]. Based on the research from Yang et al. in 2018 [130], the cost for their piezoelectric harvesting energy project was calculated. The construction cost of a single piezoelectric transducer is 5 ¥ and the manufacturing cost is 15 ¥. A total of 40 000 ¥ has been spent on the cost of 100m piezoelectric pavement. The maximum amount of electricity that can be generated in one day is 1.93 x 106 J. Assume the price of electricity is 1 ¥ / (kW $ h), then the economic benefit for a day is about 0.65 ¥. From that calculation, it can be seen that the construction cost for piezoelectric pavement is considered quite high. [29]. Wang et al in 2018 also do research about energy harvesting technologies in roadway and bridges for different applications. From their study, they have done a comparison about the Levelized cost of electricity (LCOE) between each technology [10]. The cost of producing the same unit quantity of electrical energy was calculated using the LCOE approach, which is defined as total costs divided by total electrical energy generated ($/kWh) [10, 102]. The comparison proves that the highest LCOE was piezoelectric with 106.387$/kWh while the lowest LCOE was photovoltaic technology with 0.45$/kWh. Table 5 shows the LCOE between the technologies.

Table 5. Comparison of Levelized cost of electricity between green technology

Technology	Energy output	Cost ($)	LCOE ($/kWh)
Solar (solar panel)	1781000 kW h/lane-mile	4.4 million/lane-mile	0.45
Solar (solar collector in embedded pipe)	588.634 kWh/Lane-mile	9.812 million/lane-mile	4.21
Thermoelectric	0.748 kW/hLane-mile	12.781 million/lane-mile	95.74
Geothermal	4447.270 kWh/Lane-mile	15.2 million/lane-mile	0.1561
Piezoelectric	188 kW h/Lane-mile	7.5 million/lane-mile	106.387

4.2.3 Low power output

There are many factors that can influence the output energy of a piezoelectric device for example shape, dimensions, materials, and the number of piezoelectric element installations [39]. Piezoelectric arrays have been installed at Tokyo railway station by JR East of Japan. The output energy is enough to power a 100 watt light bulb for 80 minutes. However, due to system degradation, energy generation drops after three weeks [131]. Jasim et al., 2017 studied energy output and mechanical failure of the piezoelectric energy harvesters. From their study, it shows that energy output can increase when loading magnitude and loading frequency increase which achieves 26.6mW under 0.7MPa loading stress at 5Hz [79]. Their research has proved that speed, vehicle weight, and embedment location of the energy module can influence energy harvesting performance. If back to the real situation, low power output is still one of the problems that need to be a concern because if the road is not traversed by many vehicles, the power output will below [132].

4.3 Thermoelectric Harvesting Energy Key Issue

Thermoelectric technology shows high potential for harvesting energy which this technology can reduce the UHI effect by absorbs the heat from the pavement [133]. However, this technology still has several issues that need to be addressed such as low efficiency and high Levelized cost of energy.

4.3.1 Low efficiency

One of the main issues of this technology is to generate a high-efficiency generator by using a small temperature gradient. Some low-temperature thermoelectric generators were created, which could be utilized in the pavement environment [134, 135]. Nevertheless, the current efficiency of the thermoelectric system is below 1%/K. [13, 136]. One of the methods to improve the efficiency is by increase the working temperature difference of the material so that the material can function in a high-temperature difference environment. However, there is quite a limited temperature difference on asphalt pavement [137]. When the temperature difference between pavement layers is low, the efficiency and energy output will also small. Table 6 shows the comparisons of energy output between other technologies. In order to compare all available technologies, the one-lane mile roadway is selected to calculate energy output [10].

Table 5. Comparison of energy output between technologies

Technology	System configuration	Energy output
Photovoltaic	Pavement system supported by solar panels	1781000 kWh/lane-mile
Solar collectors	SERSO system in swiss with piping under the pavement	588.634 kWh/Lane-mile
Thermoelectric	Two-TEG prototype (64mm×64 mm)	0.748 kWh/Lane-mile
Piezoelectric	Cymbal shape under typical truck loading	188 kW h/Lane-mile

From the table, it proves that thermoelectric technology has the lowest efficiency which drops to the lowest energy output among other technologies.

4.3.2 High Levelized Cost of Energy

To compare with solar energy harvesting, the thermoelectric harvesting technology appears to be more costly. [6, 39]. Given an 8 h operating day, the thermoelectric energy harvesting prototype from Seyed Amit Tahami et al, 2020 [138] can generate 0.876 kWh per year. The Levelized energy cost (LCOE) would therefore be obtained at $8.56/kW-h per square meter. Photovoltaic technology is one of the types of solar energy harvesting in pavements. It showed an LCOE of Photovoltaic technology which is $3.1/kW-h per square meter [138]. Therefore it proves that the LCOE of thermoelectric energy harvesting prototype is higher with $8.56/kWh per square meter compared to LCOE of Solar harvesting energy with $3.1/kW-h per square meter.

4.4 Geothermal Harvesting Energy Key Issue

Geothermal technology is commonly used for snow removal and surface deicing in sidewalks, airports, and bridges [139]. However, this technology still has many issues to be addressed such as limited geological and environmental side effects.

4.4.1 Location Restricted

The main disadvantage of geothermal energy is that it is geologically limited [6]. Some areas are not suitable for the construction of Geothermal plants because they need to construct in a place where the energy is accessible in a limited number of areas [140, 141]. These areas are frequently located distant from towns and cities. As a result, geothermal energy will likely never be a choice for large-scale energy generation. However, this will not be a problem for some countries like Iceland because these countries have geothermal energy which is readily accessible [141]. Power capacity, spacing of wells, size of reservoirs, and associated building, as wells as the type of conversion cooling systems all affect the size of land needed for a geothermal power plant [142]. U.S. Department of Energy [143] states that Geothermal power’s land is used between 4.7 to 10 acres per MW depending on the technology. Thomas in 2019 wrote a blog about the energy used in lighting and his article stated that one LED bulb consumes about 5W to 9W [144]. Therefore, it can be assumed that if geothermal technology is applied on the pavement, it can help to turn about 100 of the streetlights and traffic lights. However, this dream is difficult to achieve in Malaysia because it is not easy to find the right location that has the right type of hot rocks. The rock should be found at an acceptable depth to make drilling work easier. High volcanic locations are ideal for geothermal energy production[145, 146]. The utilization of land is a crucial environmental factor. Energy production will have less of an impact on natural ecosystems if less land is required to create energy [147, 148].

4.4.2 Environmental Side Effect

Even though geothermal energy usually does not emit greenhouse gases, many of these gases are stored under the surface of the Earth and emitted into the environment during digging. [140, 149]. While these gases are also naturally emitted into the environment, the rate rises near geothermal plants. [149, 150]. However, the gas released is still far below those associated with fossil fuels [141]. Furthermore, the de-icing salt used has been shown to be environmentally damaging and to cause groundwater salinization. [151]. Besides that, clearing operations are also capable to damage the roads [152] and damage that cannot be avoided is damage caused by frost blasting [153]. Enhanced Geothermal System (EGS) works by pumping liquid into the cracked rock to extract heat. This can cause seismic disturbances which are also known as seismicity. This condition can result in dangerous changes to the geology and the environment becoming unsafe [154]. Another negative environmental impact of geothermal energy is noise pollution, which has a harmful influence on both wildlife and humans [155]. The level of noise is measure in decibels (dB) [156]. Drilling and maintenance and fluid discharge are two sources of noise pollution during the building and operation stages of a geothermal power plant. The range of noise produced during drilling and maintenance ranges from about 90 to 120dB while the fluid discharge process produced about 120dB [157]. This noise pollution may interfere with the growth of children because based on studies by Costa et al in 2013 they found that noise levels over 55dB exposed to children will result in a lack of social adaptability and low attention [158].

5.0 Summary

The majority of energy harvesting technologies have the ability to harvest energy from the pavement. Clearly, some are better adapted than others, and some are along in their development. Below is a summarized of the most promising technologies:

i. Solar harvesting technology, which uses either air or liquid to collect energy, has a wide range of applications, including gather energy for neighboring building cooling/heating, preventing ice formation or snow accumulation, and dispersing heat from pavements to reduce UHI and rutting. There are three common methods for harvesting solar energy include the installation of solar panels as the photovoltaic pavement under a transparent surface layer, installation of the solar panels along roadways, and pavement solar collectors with heat extraction through embedding pipe systems. Solar harvesting technology depends on the albedo of the surface layer, the latitude of pavement, pipe diameter, depth of pipe, the distance between pipe, and thermal conductivity of the surface layer. Solar harvesting through photovoltaic is considering very mature and the energy conversion efficiency is at a medium to a high level. Even though this technology is very mature, it still faces some constraints which are weather, safety, and type of solar collector.

ii. Piezoelectric harvesting technology can generate electricity through vibration or pressure-induced by passing vehicles. They often generate high voltages with a low amperage, resulting in low power output. Based on the literature review, this technology can provide electrical energy to operate low-power pavement devices like embedded sensors and LED lighting. This technology is considered very semi-mature because the TRL was on a scale of 4 and the energy conversion efficiency is at a low to medium level. Even though this technology can be access infinity without worry about the weather, it still has some issues that need to be addressed with are depth of installation, construction cost, and low power output.

iii. Thermoelectric harvesting technology works by collecting the heat from the pavement then provide the heat to the surrounding building and reducing the UHI effect. This technology has a promising future harvesting technology, however, its LCOE is high and efficiency is low. The TRL was on the lowest scale with 3 which shows this technology needs more study to increase their readiness.

iv. Geothermal harvesting technology can generate electricity by obtained from thermal energy stored in the solid underground. Geothermal is widely used to heat the road for deicing purposes. Thermal exchange in an embedded pipe network is influenced by fluid operation parameters such as flow rate and temperature. Therefore, in order to achieve maximum conversion efficiency and optimal fluid operating parameters, pipe network construction should be the focus on design, installation depth, and pipe size. This technology reaches a very high scale of TRL which is scale 3 and it can be said to be a very mature technology. Regardless this technology is very mature, but it still has some issues which are limited geological and environmental side effects. Implementation of geothermal technology on pavement have some constrain because the need to find a right location with a good hot rock at an acceptable depth to make drilling work easier. Some of the environmental side effects are seismicity and noise pollution.

6.0 Conclusion

In conclusion, there is great interest from all over the world has been given to renewable energy harvesting on the pavement. Renewable energy that is often used in the pavement is solar harvesting energy, piezoelectric harvesting energy, thermoelectric harvesting energy, and geothermal harvesting energy. Among these renewable energies, geothermal harvesting energy has the best conversion efficiency to use and it is also among the most mature technology. However, geothermal harvesting technology was not the best choice to be implemented in Malaysia because of the Malaysian climates and geological. Other than that, piezoelectric technology is now gaining attention among researchers, the actual application is still limited in laboratory studies and it is at the prototype level. This is because this energy is not able to provide high energy conversion efficiency and also the fragile material of piezoelectric materials. Even though most piezoelectric harvesting systems operate at the microwatt to milliwatt scale, they still can provide energy for low-power electronics such as wireless sensor nodes, embedded electronics, and portable electronics. Piezoelectric harvesting devices can provide a long-term, self-sustaining power source that requires no replacement or maintenance. Compared to traditional energy sources, like batteries, the autonomous operation can reduce costs associated with battery replacement. Furthermore, autonomous power supplies allow electronic devices to be embedded into structures or placed in remote locations. In addition, although solar energy harvesting technology has high maturity in development, it still needs a more in-depth study to increase its conversion efficiency especially energy extraction through embedding pipe systems. Solar panel technology is highly recommended to be implemented in Malaysia because of the high level of temperature climate and the roads network in Malaysia is among the best in the world. Furthermore, thermoelectric energy harvesting also needs more attention from researchers due to low maturity and low energy conversion efficiency. However, all these renewable energy harvestings on the pavement still have a bright opportunity in the future if all key issues are addressed properly.

Acknowledgments

The authors would like to acknowledge Universiti Malaysia Pahang for funding through the Doctoral Research Scheme (DRS) scholarship. In addition, further appreciation was also given to the Ministry of Education Malaysia for providing the Fundamental Research Grant Scheme FRGS/1/2018/TK05/UMP/02/15 @ RDU 190155. Finally, big thanks to the UMP Research and Innovation Department for providing the Postgraduate Research Grants Scheme (PGRS) under grant no PGRS1903173.

References

[1] CEIC. "Malaysia Road Length: Peninsular Malaysia: State." ISI Emerging Markets Group Company. https://www.ceicdata.com/en/malaysia/road-length-statistics/road-length-peninsular-malaysia-state (accessed.

[2] Enerdata. "Global Energy Statistical Yearbook 2020." https://yearbook.enerdata.net/total-energy/world-consumption-statistics.html (accessed.

[3] B. Looney, "Full report–BP statistical review of world energy 2020," ed: BP plc, London, 2020.

[4] Z. Tang, Y. Deng, C. Su, W. Shuai, and C. Xie, "A research on thermoelectric generator's electrical performance under temperature mismatch conditions for automotive waste heat recovery system," *Case Studies in Thermal Engineering*, vol. 5, pp. 143-150, 2015.

[5] F. Hidayanti, E. K. Wati, and M. F. Miftahudin, "Design of Energy Harvesters on Motorcycle Exhaust using Thermoelectric Generator for Power Supply Electronic Device," *International Journal of Renewable Energy Research (IJRER)*, vol. 10, no. 1, pp. 251-259, 2020.

[6] W. Sun *et al.*, "The state of the art: Application of green technology in sustainable pavement," *Advances in Materials Science and Engineering*, vol. 2018, 2018.

[7] G. Ding, X. Zhao, J. Wang, and C. Xu, "Vibration energy harvesting from roads under traffic loads," *Road Materials and Pavement Design*, vol. 21, no. 3, pp. 780-799, 2020.

[8] R. Freer and A. V. Powell, "Realising the potential of thermoelectric technology: A Roadmap," *Journal of Materials Chemistry C*, vol. 8, no. 2, pp. 441-463, 2020.

[9] A. Dawson, R. Mallick, A. G. Hernandez, and P. K. Dehdezi, "Energy harvesting from pavements," in *Climate Change, Energy, Sustainability and Pavements*: Springer, 2014, pp. 481-517.

[10] H. Wang, A. Jasim, and X. Chen, "Energy harvesting technologies in roadway and bridge for different applications–A comprehensive review," *Applied energy*, vol. 212, pp. 1083-1094, 2018.

[11] F. Duarte and A. Ferreira, "Energy harvesting on road pavements: state of the art," *Proceedings of the Institution of Civil Engineers-Energy*, vol. 169, no. 2, pp. 79-90, 2016.

[12] Q. Shi and X. Lai, "Identifying the underpin of green and low carbon technology innovation research: A literature review from 1994 to 2010," *Technological Forecasting and Social Change*, vol. 80, no. 5, pp. 839-864, 2013.

[13] H. D. Zhao, J. M. Ling, and P. C. Fu, "A review of harvesting green energy from road," in *Advanced Materials Research*, 2013, vol. 723: Trans Tech Publ, pp. 559-566.

[14] H. Xiong, "Piezoelectric Energy Harvesting for Roadways," Virginia Tech, 2015.

[15] A. H. Hashim, A. K. Khairuddin, and J. B. Ibrahim, "Integration of renewable energy into grid system-the Sabah Green Grid," in *2015 IEEE Eindhoven PowerTech*, 2015: IEEE, pp. 1-6.

[16] N. F. Khairudin, R. Bidin, A. Akhiar, F. Ideris, and A. Abd Rahman, "Renewable energy development in Malaysia: Communication barriers towards achieving the national renewable energy target," in *IOP Conference Series: Earth and Environmental Science*, 2020, vol. 476, no. 1: IOP Publishing, p. 012080.

[17] S. F. Salleh, M. E. M. Roslan, A. Abd Rahman, A. H. Shamsuddin, T. A. R. T. Abdullah, and B. K. Sovacool, "Transitioning to a sustainable development framework for bioenergy in Malaysia: policy suggestions to catalyse the utilisation of palm oil mill residues," *Energy, Sustainability and Society*, vol. 10, no. 1, pp. 1-20, 2020.

[18] M. Safaei, H. A. Sodano, and S. R. Anton, "A review of energy harvesting using piezoelectric materials: state-of-the-art a decade later (2008–2018)," *Smart Materials and Structures*, vol. 28, no. 11, p. 113001, 2019.

[19] C. Covaci and A. Gontean, "Piezoelectric energy harvesting solutions: A review," *Sensors*, vol. 20, no. 12, p. 3512, 2020.

[20] K. Uchino, "Piezoelectric energy harvesting systems—Essentials to successful developments," *Energy Technology*, vol. 6, no. 5, pp. 829-848, 2018.

[21] S. R. Anton, A. Erturk, and D. J. Inman, "Multifunctional unmanned aerial vehicle wing spar for low-power generation and storage," *Journal of Aircraft*, vol. 49, no. 1, pp. 292-301, 2012.

[22] M. Q. Le *et al.*, "Review on energy harvesting for structural health monitoring in aeronautical applications," *Progress in Aerospace Sciences*, vol. 79, pp. 147-157, 2015.

[23] S. Ali, M. Friswell, and S. Adhikari, "Analysis of energy harvesters for highway bridges," *Journal of Intelligent Material Systems and Structures*, vol. 22, no. 16, pp. 1929-1938, 2011.

[24] A. Erturk, "Piezoelectric energy harvesting for civil infrastructure system applications: Moving loads and surface strain fluctuations," *Journal of Intelligent Material systems and structures*, vol. 22, no. 17, pp. 1959-1973, 2011.

[25] M. Amin Karami and D. J. Inman, "Powering pacemakers from heartbeat vibrations using linear

and nonlinear energy harvesters," *Applied Physics Letters,* vol. 100, no. 4, p. 042901, 2012.

[26] Y. Tan, Y. Dong, and X. Wang, "Review of MEMS electromagnetic vibration energy harvester," *Journal of Microelectromechanical Systems,* vol. 26, no. 1, pp. 1-16, 2016.

[27] T. Asai, Y. Araki, and K. Ikago, "Energy harvesting potential of tuned inertial mass electromagnetic transducers," *Mechanical Systems and Signal Processing,* vol. 84, pp. 659-672, 2017.

[28] Y. Zhang, T. Wang, A. Luo, Y. Hu, X. Li, and F. Wang, "Micro electrostatic energy harvester with both broad bandwidth and high normalized power density," *Applied energy,* vol. 212, pp. 362-371, 2018.

[29] Y. Cao, A. Sha, Z. Liu, J. Li, and W. Jiang, "Energy output of piezoelectric transducers and pavements under simulated traffic load," *Journal of Cleaner Production,* vol. 279, p. 123508, 2020.

[30] S. Wang, C. Wang, G. Yu, and Z. Gao, "Development and performance of a piezoelectric energy conversion structure applied in pavement," *Energy Conversion and Management,* vol. 207, p. 112571, 2020.

[31] Y. Zhang *et al.*, "Electrostatic energy harvesting device with dual resonant structure for wideband random vibration sources at low frequency," *Review of Scientific Instruments,* vol. 87, no. 12, p. 125001, 2016.

[32] V. Dragunov, D. Ostertak, and R. Sinitskiy, "New modifications of a Bennet doubler circuit-based electrostatic vibrational energy harvester," *Sensors and Actuators A: Physical,* vol. 302, p. 111812, 2020.

[33] M.Toyabur Rahman, SM Sohel Rana, Md. Salauddin, Pukar Maharjan, Trilochan Bhatta, Hyunsik Kim, Hyunok Cho, Jae YeongPark, "A highly miniaturized freestanding kinetic-impact-based non-resonant hybridized electromagnetic-triboelectric nanogenerator for human induced vibrations harvesting," *Applied Energy,* vol. 279, p. 115799, 2020.

[34] Liang Xu, Tao Jiang, Pei Lin, Jia Jia Shao,, Chuan He,, Wei Zhong, Xiang Yu Chen, Zhong Lin Wang, "Coupled triboelectric nanogenerator networks for efficient water wave energy harvesting," *ACS nano,* vol. 12, no. 2, pp. 1849-1858, 2018.

[35] B. Chen, Y. Yang, and Z. L. Wang, "Scavenging wind energy by triboelectric nanogenerators," *Advanced Energy Materials,* vol. 8, no. 10, p. 1702649, 2018.

[36] S.-i. Yamaura, T. Nakajima, Y. Kamata, T. Sasaki, and T. Sekiguchi, "Production of vibration energy harvester with impact-sliding structure using magnetostrictive Fe-Co-V alloy rod," *Journal of Magnetism and Magnetic Materials,* vol. 514, p. 167260, 2020.

[37] Z.-W. Fang, Y.-W. Zhang, X. Li, H. Ding, and L.-Q. Chen, "Integration of a nonlinear energy sink and a giant magnetostrictive energy harvester," *Journal of Sound and Vibration*, vol. 391, pp. 35-49, 2017.

[38] huying Cao, Xueyuan Wang, Jiaju Zheng, Shuyu Cao, Jingfeng Sun, Zhihua Wang, Changgeng Zhang, "Modeling and design of an efficient magnetostrictive energy harvesting system with low voltage and low power," *IEEE Transactions on Magnetics*, vol. 54, no. 11, pp. 1-5, 2018.

[39] M. Gholikhani, H. Roshani, S. Dessouky, and A. Papagiannakis, "A critical review of roadway energy harvesting technologies," *Applied Energy,* vol. 261, p. 114388, 2020.

[40] T. A. Baig, A. Mukhtar, and M. M. Ali, "Piezoelectric Energy Harvester for Smart Lights."

[41] G. H. Hurtado, J. A. Romero, and C. S. López-Cajún, "Energy harvesting simulator," in *2016 12th Congreso Internacional de Ingeniería (CONIIN),* 2016: IEEE, pp. 1-7.

[42] H. Roshani, S. Dessouky, A. Montoya, and A. Papagiannakis, "Energy harvesting from asphalt pavement roadways vehicle-induced stresses: A feasibility study," *Applied Energy,* vol. 182, pp. 210-218, 2016.

[43] H. Najini and S. A. Muthukumaraswamy, "Piezoelectric energy generation from vehicle traffic with technoeconomic analysis," *Journal of Renewable Energy,* vol. 2017, 2017.

[44] C. Wang, S. Wang, Q. J. Li, X. Wang, Z. Gao, and L. Zhang, "Fabrication and performance of a power generation device based on stacked piezoelectric energy-harvesting units for pavements," *Energy Conversion and Management,* vol. 163, pp. 196-207, 2018.

[45] Y. Chen, H. Zhang, L. Quan, Z. Zhang, and C. Lü, "Theoretical assessment on piezoelectric energy harvesting in smart self-powered asphalt pavements," *Journal of Vibration Engineering & Technologies,* vol. 6, no. 1, pp. 1-10, 2018.

[46] H. Xiong and L. Wang, "Piezoelectric energy harvester for public roadway: On-site installation and evaluation," *Applied Energy,* vol. 174, pp. 101-107, 2016.

[47] K. Kajiwara, N. Matsui, and F. Kurokawa, "A new MPPT control for solar panel under bus voltage fluctuation," in *2017 IEEE 6th International Conference on Renewable Energy Research and Applications (ICRERA)*, 2017: IEEE, pp. 1047-1050.

[48] K. Okedu, H. Nadabi, and A. Aziz, "Prospects of Solar Energy in Oman: case of oil and gas industries," *International Journal of Smart Grid-ijSmartGrid,* vol. 3, no. 3, pp. 138-151, 2019.

[49] A. S. Dezfooli, F. M. Nejad, H. Zakeri, and S. Kazemifard, "Solar pavement: A new emerging technology," *Solar Energy,* vol. 149, pp. 272-284, 2017.

[50] E. M. Malatji, "The use of Dynamic Tariff by The Utilities to Counter act The Influence of Renewable Energy Sources," in *2019 7th International Conference on Smart Grid (icSmartGrid),* 2019: IEEE, pp. 103-107.

[51] S. Kim, Y. Lee, and H.-R. Moon, "Siting criteria and feasibility analysis for PV power generation projects

using road facilities," *Renewable and Sustainable Energy Reviews*, vol. 81, pp. 3061-3069, 2018.

[52] C. Efthymiou, M. Santamouris, D. Kolokotsa, and A. Koras, "Development and testing of photovoltaic pavement for heat island mitigation," *Solar Energy*, vol. 130, pp. 148-160, 2016.

[53] P. Pan, S. Wu, Y. Xiao, and G. Liu, "A review on hydronic asphalt pavement for energy harvesting and snow melting," *Renewable and Sustainable Energy Reviews*, vol. 48, pp. 624-634, 2015.

[54] S. A. Tahami, M. Gholikhani, R. Nasouri, S. Dessouky, and A. Papagiannakis, "Developing a new thermoelectric approach for energy harvesting from asphalt pavements," *Applied energy*, vol. 238, pp. 786-795, 2019.

[55] W. Yu, X. Yi, M. Guo, and L. Chen, "State of the art and practice of pavement anti-icing and de-icing techniques," *Sci. Cold Arid Reg*, vol. 6, no. 1, pp. 14-21, 2014.

[56] R. B. Mallick, B.-L. Chen, and S. Bhowmick, "Harvesting energy from asphalt pavements and reducing the heat island effect," *International Journal of Sustainable Engineering*, vol. 2, no. 3, pp. 214-228, 2009.

[57] M. Santamouris, "Using cool pavements as a mitigation strategy to fight urban heat island—A review of the actual developments," *Renewable and Sustainable Energy Reviews*, vol. 26, pp. 224-240, 2013.

[58] J. Scheffe, "Integrated solar lighting for pedestrian crosswalk visibility," 2016.

[59] A. Ahmad, A. Razali, I. Razelan, and W. Hamizan, "Effect of waste polyethylene terephthalate (PET) on properties of road aggregate," in *IOP Conference Series: Materials Science and Engineering*, 2019, vol. 469, no. 1: IOP Publishing, p. 012056.

[60] A. Ahmad, A. Razali, I. Razelan, S. Jalil, M. Noh, and A. Idris, "Utilization of polyethylene terephthalate (PET) in bituminous mixture for improved performance of roads," in *IOP Conference Series: Materials Science and Engineering*, 2017, vol. 203, no. 1: IOP Publishing, p. 012005.

[61] C. Psomopoulos, "Solar energy: Harvesting the sun's energy for a sustainable future," *Solar Energy*, vol. 1, no. 117, p. 2, 2013.

[62] P. Sharma and T. Harinarayana, "Solar energy generation potential along national highways," *International Journal of Energy and Environmental Engineering*, vol. 4, no. 1, p. 16, 2013.

[63] A. Harrouz, A. Temmam, and M. Abbes, "Renewable energy in algeria and energy management systems," *International Journal of Smart Grid-ijSmartGrid*, vol. 2, no. 1, pp. 34-39, 2018.

[64] T. Voigt, H. Ritter, and J. Schiller, "Utilizing solar power in wireless sensor networks," in *28th Annual IEEE International Conference on Local Computer Networks, 2003. LCN'03. Proceedings.*, 2003: IEEE, pp. 416-422.

[65] C. Fitzpatrick, "Research and development: Ridin'on sunshine," *Electrical Connection*, no. Spring 2014, p. 24, 2014.

[66] Y. Qin, J. Liang, K. Tan, and F. Li, "The amplitude and maximum of daily pavement surface temperature increase linearly with solar absorption," *Road Materials and Pavement Design*, vol. 18, no. 2, pp. 440-452, 2017.

[67] S. Li *et al.*, "Numerical simulation of a novel pavement integrated photovoltaic thermal (PIPVT) module," *Applied Energy*, p. 116287, 2020.

[68] D. Correia and A. Ferreira, "Energy Harvesting on Airport Pavements: State-of-the-Art," *Sustainability*, vol. 13, no. 11, p. 5893, 2021.

[69] R. Sedgwick and M. Patrick, "The use of a ground solar collector for swimming pool heating," *Proceedings of ISES, Brighton, England*, 1981.

[70] S. Wu, B. Li, P. Pan, and F. Guo, "Simulation study of heat energy potential of asphalt solar collectors," *Materials Research Innovations*, vol. 18, no. sup2, pp. S2-436-S2-439, 2014.

[71] R. Mirzanamadi, C.-E. Hagentoft, P. Johansson, and J. Johnsson, "Anti-icing of road surfaces using hydronic heating pavement with low temperature," *Cold regions science and technology*, vol. 145, pp. 106-118, 2018.

[72] J. Johnsson and B. Adl-Zarrabi, "A numerical and experimental study of a pavement solar collector for the northern hemisphere," *Applied Energy*, vol. 260, p. 114286, 2020.

[73] D. R. Green, J. Ward, and N. Wyper, "Solar-powered wireless crosswalk warning system," ed: Google Patents, 2008.

[74] A. García and M. N. Partl, "How to transform an asphalt concrete pavement into a solar turbine," *Applied Energy*, vol. 119, pp. 431-437, 2014.

[75] R. Mallick, J. Carelli, L. Albano, S. Bhowmick, and A. Veeraragavan, "Evaluation of the potential of harvesting heat energy from asphalt pavements," *International Journal of Sustainable Engineering*, vol. 4, no. 02, pp. 164-171, 2011.

[76] U. Datta, S. Dessouky, and A. Papagiannakis, "Harvesting thermoelectric energy from asphalt pavements," *Transportation Research Record*, vol. 2628, no. 1, pp. 12-22, 2017.

[77] A. Belkaid, I. Colak, K. KAYISLI, R. BAYINDIR, and H. I. BULBUL, "Maximum power extraction from a photovoltaic panel and a thermoelectric generator constituting a hybrid electrical generation system," in *2018 International Conference on Smart Grid (icSmartGrid)*, 2018: IEEE, pp. 276-282.

[78] J. Chen, R. Chu, H. Wang, L. Zhang, X. Chen, and Y. Du, "Alleviating urban heat island effect using high-conductivity permeable concrete pavement," *Journal of cleaner production*, vol. 237, p. 117722, 2019.

[79] A. Jasim, G. Yesner, H. Wang, A. Safari, A. Maher, and B. Basily, "Laboratory testing and numerical simulation of piezoelectric energy harvester for roadway applications," *Applied energy*, vol. 224, pp. 438-447, 2018.

[80] J. Wei, Z. Nie, G. He, L. Hao, L. Zhao, and Q. Zhang, "Energy harvesting from solar irradiation in cities using the thermoelectric behavior of carbon

fiber reinforced cement composites," *Rsc Advances*, vol. 4, no. 89, pp. 48128-48134, 2014.

[81] J. Wei, L. Zhao, Q. Zhang, Z. Nie, and L. Hao, "Enhanced thermoelectric properties of cement-based composites with expanded graphite for climate adaptation and large-scale energy harvesting," *Energy and Buildings*, vol. 159, pp. 66-74, 2018.

[82] Y. Rew, A. Baranikumar, A. V. Tamashausky, S. El-Tawil, and P. Park, "Electrical and mechanical properties of asphaltic composites containing carbon based fillers," *Construction and Building Materials*, vol. 135, pp. 394-404, 2017.

[83] J. J. Lee, D. H. Kim, S. T. Lee, and J. K. Lim, "Fundamental study of energy harvesting using thermoelectric effect on concrete structure in road," in *Advanced Materials Research*, 2014, vol. 1044: Trans Tech Publ, pp. 332-337.

[84] J. Lee, C. Lim, D. Kim, and S. Kwon, "Implementation of thermoelectric effects to road facilities," *IRF Examiner: Winter 2015, Sustainable Transport Practices*, vol. 8, pp. 1-6, 2015.

[85] J. Lee, C. Lim, J. Lim, S. Yang, and J. Im, "Application of solar thermoelectric generation system for health monitoring system of civil infrastructures," *KSCE Journal of Civil Engineering*, vol. 22, no. 1, pp. 110-116, 2018.

[86] J. Kim, S.-T. Lee, S. Yang, and J. Lee, "Implementation of thermal-energy-harvesting technology on pavement," *Journal of Testing and Evaluation*, vol. 45, no. 2, pp. 582-590, 2017.

[87] W. Jiang, J. Xiao, D. Yuan, H. Lu, S. Xu, and Y. Huang, "Design and experiment of thermoelectric asphalt pavements with power-generation and temperature-reduction functions," *Energy and Buildings*, vol. 169, pp. 39-47, 2018.

[88] B. Tian *et al.*, "An improved volumetric method of geothermal resources assessment for shallow ground combining geophysical data," *Renewable Energy*, vol. 145, pp. 2306-2315, 2020.

[89] S. Simsek, O. Mertoglu, N. Bakir, I. Akkus, and O. Aydogdu, "Geothermal Energy Utilisation, Development and Projections–Country Update Report (2000-2004) of Turkey," in *Proceedings*, 2005, pp. 24-29.

[90] M. Flores-Armenta, M. Ramírez-Montes, and L. Morales-Alcalá, "Geothermal activity and development in Mexico–keeping the production going," *Proceedings of the Geothermal Training Programme*, 2014.

[91] H. Wang, J. Zhao, and Z. Chen, "Experimental investigation of ice and snow melting process on pavement utilizing geothermal tail water," *Energy Conversion and Management*, vol. 49, no. 6, pp. 1538-1546, 2008.

[92] N. Tang, S. P. Wu, M. Y. Chen, P. Pan, and C. J. Sun, "Effect mechanism of mixing on improving conductivity of asphalt solar collector," *International Journal of Heat and Mass Transfer*, vol. 75, pp. 650-655, 2014.

[93] K. Liu, S. Huang, H. Xie, and F. Wang, "Multi-objective optimization of the design and operation for snow-melting pavement with electric heating pipes," *Applied Thermal Engineering*, vol. 122, pp. 359-367, 2017.

[94] K. Liu, S. Huang, F. Wang, H. Xie, and X. Lu, "Energy consumption and utilization rate analysis of automatically snow-melting system in infrastructures by thermal simulation and melting experiments," *Cold Regions Science and Technology*, vol. 138, pp. 73-83, 2017.

[95] A. Mauro and J. C. Grossman, "Street-heat: Controlling road temperature via low enthalpy geothermal energy," *Applied Thermal Engineering*, vol. 110, pp. 1653-1658, 2017.

[96] I.-H. Ho, "Optimization of Hydronic Heating Pavement Design Using Geothermal Hot Water in Western North Dakota," *Geotechnical and Geological Engineering*, pp. 1-16, 2020.

[97] W. Shen, K. Gopalakrishnan, S. Kim, and H. Ceylan, "Airport apron heated pavement system operations: analysis of energy consumption, greenhouse gas emissions, and operating costs," in *Geo-Chicago 2016*, 2016, pp. 513-522.

[98] S. Ahmad, M. Abdul Mujeebu, and M. A. Farooqi, "Energy harvesting from pavements and roadways: A comprehensive review of technologies, materials, and challenges," *International Journal of Energy Research*, vol. 43, no. 6, pp. 1974-2015, 2019.

[99] S. Charlesworth, A. Faraj-Llyod, and S. Coupe, "Renewable energy combined with sustainable drainage: Ground source heat and pervious paving," *Renewable and Sustainable Energy Reviews*, vol. 68, pp. 912-919, 2017.

[100] W. Sun, P. Bocchini, and B. D. Davison, "Resilience metrics and measurement methods for transportation infrastructure: the state of the art," *Sustainable and Resilient Infrastructure*, vol. 5, no. 3, pp. 168-199, 2020.

[101] K. A. Cook-Chennault, N. Thambi, and A. M. Sastry, "Powering MEMS portable devices—a review of non-regenerative and regenerative power supply systems with special emphasis on piezoelectric energy harvesting systems," *Smart materials and structures*, vol. 17, no. 4, p. 043001, 2008.

[102] J. Pei, F. Guo, J. Zhang, B. Zhou, Y. Bi, and R. Li, "Review and Analysis of Energy Harvesting Technologies in Roadway Transportation," *Journal of Cleaner Production*, p. 125338, 2020.

[103] J. Pei, B. Zhou, and L. Lyu, "e-Road: The largest energy supply of the future?," *Applied energy*, vol. 241, pp. 174-183, 2019.

[104] Z. Zhang, H. Xiang, and Z. Shi, "Modeling on piezoelectric energy harvesting from pavements under traffic loads," *Journal of Intelligent Material Systems and Structures*, vol. 27, no. 4, pp. 567-578, 2016.

[105] B. Zhou *et al.*, "Solar/road from ‘forced coexistence’to ‘harmonious symbiosis’," *Applied energy*, vol. 255, p. 113808, 2019.

[106] K. Matrawy and I. Farkas, "Comparison study for three types of solar collectors for water heating,"

Energy conversion and management, vol. 38, no. 9, pp. 861-869, 1997.

[107] H.-f. JIANG, Y.-q. CEN, X.-d. ZHA, and Q.-s. ZHANG, "Current Situation and Development Trend of Solar Pavement Technology," *DEStech Transactions on Environment, Energy and Earth Sciences*, no. epe, 2018.

[108] W. J. Eugster, "Road and bridge heating using geothermal energy. Overview and examples," in *Proceedings European geothermal congress*, 2007, vol. 2007.

[109] W. Ziegler, "Radiant heating of airport aprons," *Airport Operations and Maintenance Challenge. Binghamton University*, 2009.

[110] D. M. Cuong and A. Ancheta, "Energy Yields of a GPS-based Dual-Axis Solar Tracker and a Fixed Mount PV Panel Operating in Different Weather Conditions," *Journal of Science, Engineering and Technology*, vol. 6, pp. 43-56, 2018.

[111] S. T. Mohammad, H. H. Al-Kayiem, M. A. Aurybi, and A. K. Khlief, "Measurement of global and direct normal solar energy radiation in Seri Iskandar and comparison with other cities of Malaysia," *Case Studies in Thermal Engineering*, vol. 18, p. 100591, 2020.

[112] M. T. Islam, N. Huda, and R. Saidur, "Current energy mix and techno-economic analysis of concentrating solar power (CSP) technologies in Malaysia," *Renewable Energy*, vol. 140, pp. 789-806, 2019.

[113] M. S. Chowdhury *et al.*, "An overview of solar photovoltaic panels' end-of-life material recycling," *Energy Strategy Reviews*, vol. 27, p. 100431, 2020.

[114] Y. Xu, J. Li, Q. Tan, A. L. Peters, and C. Yang, "Global status of recycling waste solar panels: A review," *Waste Management*, vol. 75, pp. 450-458, 2018.

[115] P. Nain and A. Kumar, "Metal dissolution from end-of-life solar photovoltaics in real landfill leachate versus synthetic solutions: One-year study," *Waste Management*, vol. 114, pp. 351-361, 2020.

[116] B. Erten and Z. Utlu, "Photovoltaic system configurations: an occupational health and safety assessment," *Greenhouse Gases: Science and Technology*, vol. 10, no. 4, pp. 809-828, 2020.

[117] M. Aman *et al.*, "A review of Safety, Health and Environmental (SHE) issues of solar energy system," *Renewable and Sustainable Energy Reviews*, vol. 41, pp. 1190-1204, 2015.

[118] M. Al-Saad, B. Jubran, and N. Abu-Faris, "Development and testing of concrete solar collectors," *International journal of solar energy*, vol. 16, no. 1, pp. 27-40, 1994.

[119] P. Pascual-Muñoz, D. Castro-Fresno, P. Serrano-Bravo, and A. Alonso-Estébanez, "Thermal and hydraulic analysis of multilayered asphalt pavements as active solar collectors," *Applied energy*, vol. 111, pp. 324-332, 2013.

[120] C. Papadimitriou, C. Psomopoulos, and F. Kehagia, "A review on the latest trend of Solar Pavements in Urban Environment," *Energy Procedia*, vol. 157, pp. 945-952, 2019.

[121] J. Kaldellis and A. Kokala, "Quantifying the decrease of the photovoltaic panels' energy yield due to phenomena of natural air pollution disposal," *Energy*, vol. 35, no. 12, pp. 4862-4869, 2010.

[122] I. K. Larissi, K. V. Koukouletsos, K. P. Moustris, A. Antoniou, and A. G. Paliatsos, "PM10 concentration levels in the greater Athens area, Greece," *Fresen Environ Bull*, vol. 19, no. 2, pp. 226-231, 2010.

[123] M. K. Smith, C. C. Wamser, K. E. James, S. Moody, D. J. Sailor, and T. N. Rosenstiel, "Effects of natural and manual cleaning on photovoltaic output," *Journal of solar energy engineering*, vol. 135, no. 3, 2013.

[124] F. M. Zaihidee, S. Mekhilef, M. Seyedmahmoudian, and B. Horan, "Dust as an unalterable deteriorative factor affecting PV panel's efficiency: Why and how," *Renewable and Sustainable Energy Reviews*, vol. 65, pp. 1267-1278, 2016.

[125] H. Pang, J. Close, and K.-h. Lam, "Study on effect of urban pollution to performance of commercial copper indium diselenide modules," in *2006 IEEE 4th World Conference on Photovoltaic Energy Conference*, 2006, vol. 2: IEEE, pp. 2195-2198.

[126] G. Cáceres, S. Nasirov, H. Zhang, and G. Araya-Letelier, "Residential solar PV planning in Santiago, Chile: Incorporating the PM10 parameter," *Sustainability*, vol. 7, no. 1, pp. 422-440, 2015.

[127] H. Zhao, L. Qin, and J. Ling, "Synergistic performance of piezoelectric transducers and asphalt pavement," *International Journal of Pavement Research and Technology*, vol. 11, no. 4, pp. 381-387, 2018.

[128] H. Roshani, P. Jagtap, S. Dessouky, A. Montoya, and A. Papagiannakis, "Theoretical and experimental evaluation of two roadway piezoelectric-based energy harvesting prototypes," *Journal of Materials in Civil Engineering*, vol. 30, no. 2, p. 04017264, 2018.

[129] S. Roundy, P. K. Wright, and J. Rabaey, "A study of low level vibrations as a power source for wireless sensor nodes," *Computer communications*, vol. 26, no. 11, pp. 1131-1144, 2003.

[130] H. Yang, L. Wang, B. Zhou, Y. Wei, and Q. Zhao, "A preliminary study on the highway piezoelectric power supply system," *International Journal of Pavement Research and Technology*, vol. 11, no. 2, pp. 168-175, 2018.

[131] K. Fujino, "The Research and Development Center of JR East Group," *Japanese Railway Engineering*, vol. 49, no. 2, 2009.

[132] I. Jung, Y.-H. Shin, S. Kim, J.-y. Choi, and C.-Y. Kang, "Flexible piezoelectric polymer-based energy harvesting system for roadway applications," *Applied Energy*, vol. 197, pp. 222-229, 2017.

[133] A. A. Elqattan and G. M. Elrayies, "Developing a novel solar-driven cool pavement to improve the

urban microclimate," *Sustainable Cities and Society,* vol. 64, p. 102554, 2021.

[134] S. Karabetoglu, A. Sisman, Z. F. Ozturk, and T. Sahin, "Characterization of a thermoelectric generator at low temperatures," *Energy Conversion and Management,* vol. 62, pp. 47-50, 2012.

[135] G. Wu and X. Yu, "Thermal energy harvesting across pavement structure," 2012.

[136] S. Priya and D. J. Inman, *Energy harvesting technologies*. Springer, 2009.

[137] X. Zhu, Y. Yu, and F. Li, "A review on thermoelectric energy harvesting from asphalt pavement: configuration, performance and future," *Construction and Building Materials,* vol. 228, p. 116818, 2019.

[138] S. A. Tahami, M. Gholikhani, and S. Dessouky, "Thermoelectric Energy Harvesting System for Roadway Sustainability," *Transportation Research Record,* vol. 2674, no. 2, pp. 135-145, 2020.

[139] W. Zhao, Y. Zhang, L. Li, W. Su, B. Li, and Z. Fu, "Snow melting on the road surface driven by a geothermal system in the severely cold region of China," *Sustainable Energy Technologies and Assessments,* vol. 40, p. 100781, 2020.

[140] E. T. Sayed *et al.*, "A critical review on Environmental Impacts of Renewable Energy Systems and Mitigation Strategies: Wind, Hydro, Biomass and Geothermal," *Science of The Total Environment,* p. 144505, 2020.

[141] T. L. H. Office). "What are the Advantage and Disadvantage of Geothermal Energy?" The Welding Institute. https://www.twi-global.com/technical-knowledge/faqs/geothermal-energy/pros-and-cons (accessed.

[142] J. Lofthouse, S. Policy, R. T. Simmons, and R. M. Yonk, "Reliability of Renewable Energy: Geothermal," *Utah Institute of Political Economy, Report,* 2015.

[143] U. S. D. o. Energy. "Geothermal Power Plants - Minimizing Land Use and Impact." Office of Energy Efficiency & Renewable Energy. https://www.energy.gov/eere/geothermal/geothermal-power-plants-minimizing-land-use-and-impact (accessed 4 June, 2021).

[144] A. Thomas, "kW vs. kWh: How much energy is my lighting using?," in *Lighting Insights Blog* vol. 2021, ed: RL Headquarters, 2019.

[145] M. Soltani *et al.*, "A comprehensive review of geothermal energy evolution and development," *International Journal of Green Energy,* vol. 16, no. 13, pp. 971-1009, 2019.

[146] C. Clauser and M. Ewert, "The renewables cost challenge: Levelized cost of geothermal electric energy compared to other sources of primary energy–Review and case study," *Renewable and Sustainable Energy Reviews,* vol. 82, pp. 3683-3693, 2018.

[147] P. Denholm, M. Hand, M. Jackson, and S. Ong, "Land use requirements of modern wind power plants in the United States," National Renewable Energy Lab.(NREL), Golden, CO (United States), 2009.

[148] S. Ong, C. Campbell, P. Denholm, R. Margolis, and G. Heath, "Land-use requirements for solar power plants in the United States," National Renewable Energy Lab.(NREL), Golden, CO (United States), 2013.

[149] M. Bošnjaković, M. Stojkov, and M. Jurjević, "Environmental impact of geothermal power plants," *Tehnički vjesnik,* vol. 26, no. 5, pp. 1515-1522, 2019.

[150] R. Shortall, B. Davidsdottir, and G. Axelsson, "Geothermal energy for sustainable development: A review of sustainability impacts and assessment frameworks," *Renewable and sustainable energy reviews,* vol. 44, pp. 391-406, 2015.

[151] T. D. H. Le, V. C. Schreiner, M. Kattwinkel, and R. B. Schäfer, "Invertebrate turnover along gradients of anthropogenic salinisation in rivers of two German regions," *Science of The Total Environment,* vol. 753, p. 141986, 2021.

[152] W. A. Nixon, *Improved cutting edges for ice removal* (no. SHRP-H-346). 1993.

[153] Z. Zhang, Q. Liu, Q. Wu, H. Xu, P. Liu, and M. Oeser, "Damage evolution of asphalt mixture under freeze-thaw cyclic loading from a mechanical perspective," *International Journal of Fatigue,* vol. 142, p. 105923, 2021.

[154] Loes Buijze, , Lonneke van Bijsterveldt, Holger Cremer, Bob Paap, Hans Veldkamp, Brecht B.T. Wassing, Jan-Diederik van Wees, Guido C.N. van Yperen, Jan H. ter Heege, "Review of induced seismicity in geothermal systems worldwide and implications for geothermal systems in the Netherlands–CORRIGENDUM," *Netherlands Journal of Geosciences,* vol. 99, 2020.

[155] A. Dhar, M. A. Naeth, P. D. Jennings, and M. Gamal El-Din, "Geothermal energy resources: potential environmental impact and land reclamation," *Environmental Reviews,* vol. 28, no. 4, pp. 415-427, 2020.

[156] M. M. Anees, M. Qasim, and A. Bashir, "Physiological and physical impact of noise pollution on environment," *Earth Science Pakistan,* vol. 1, no. 1, pp. 08-11, 2017.

[157] H. K. Gupta and S. Roy, *Geothermal energy: an alternative resource for the 21st century*. Elsevier, 2006.

[158] G. d. L. Costa, A. B. M. d. Lacerda, and J. Marques, "Noise on the hospital context: impact on nursing professionals' health," *Revista CEFAC,* vol. 15, no. 3, pp. 642-652, 2013.