Available online at www.CivileJournal.org

Civil Engineering Journal

(E-ISSN: 2476-3055; ISSN: 2676-6957)

Vol. 9, No. 11, November, 2023

Review Article

Reducing the Highway Networks Energy Bills using Renewable Energy System

Sami Ayyad [1], Mousa Bani Baker [2], Ahmed Handam [3], Takialddin Al-Smadi [4*]

[1] *Faculty of Engineering, Civil Engineering Department, Amman Arab University, Amman, Jordan Street–Mubis, 11953, Jordan.*

[2] *Faculty of Engineering and Technology, Civil and Infrastructure Engineering Department, Al-Zaytoonah University of Jordan, Amman, Jordan.*

[3] *Assistant Professor at National University College of Technology (NUCT), Amman, Jordan.*

[4] *Faculty of Engineering, Jerash University, Jerash, Jordan.*

Received 02 March 2023; Revised 10 October 2023; Accepted 17 October 2023; Published 01 November 2023

Abstract

Jordan has significant renewable energy potential due to its remarkable geographical location and climate conditions. This potential elevates engaging several innovative renewable alternatives in energy development, which may efficiently minimize the excessive import of traditional energy sources. The objective of this research is to study the potential of utilizing clean and affordable solar energy along roadways such as Jordan's Desert Highway-15 to be in line with the United Nations Sustainable Development Goals (UN-SDG's) by installing selected solar panels that possess adequate friction and the ability to allow solar radiation to reach the solar cells, in addition to allowing the load to be bypassed around the cells. The shoulder of the highway, with a length of 315 km and a width of 3.0 meters, has been exploited in order to supply the neighboring areas with energy for those roads, particularly those paved roads, which are poorly lit at night. Furthermore, this study provides direction and guidance concerning the structural performance of non-traditional pavement materials, which are a form of subgrade or pavement reinforcement. The performance of a prototype board on a variety of structural bases has also been evaluated. Overall, this paper found that it is possible to design a solar road panel to withstand traffic loading and that the concrete structural base allows for a significant improvement of the analyzed prototype design, especially in countries with limited energy sources and dependent on imports such as Jordan.

Keywords: Renewable Energy Source; Renewable Energy; Highway; Pavement Materials; Photovoltaic Cells; Jordan.

1. Introduction

The energy sector is one of the most important sectors that plays an important role in economic prosperity and social development, improving the quality of life for citizens. Energy consumption is growing at a rate of approximately 3.1% in Jordan [1], which imports today 91% of its needs to generate the necessary energy. Reliance on fossil fuels from oil-exporting countries affects the wheel of the economy and makes it dependent on other countries and hostage to the fluctuation of oil prices. Consequently, these factors affected the movement of oil transportation, such as the embargo that occurred at the time of the Corona epidemic, paralyzed most sectors, and played an important role in oil prices. According to these data, the importance of this research has become essential and urgent, which makes alternative energy a priority for Jordan through the implementation of environmentally friendly renewable energy technologies with reasonable prices [2].

* Corresponding author: dsmaditakialddin@gmail.com

http://dx.doi.org/10.28991/CEJ-2023-09-11-019

Energy development requires more technologies, automation, and digitization, which is in line with the goals set by the Jordanian Ministry of Energy, which aim to increase the share of energy obtained from renewable sources and, more specifically, investments in renewable energy, where these sources have witnessed a yearly increase. In Jordan, these investments reached a sum of about $5 billion through the year 2020 [3]. With a significant amount of resources allocated to technologies to obtain low emissions of energy, between 2014 and 2020, Jordan was considered a leading country in providing an attractive environment for investments. However, most probably, when making a comparison with other countries, the amount may be too little given the amount of investment in renewable energy. It is important to note that building biogas plants, wind farms, or PV farms necessitates a suitable site and sufficient space, in comparison with hydroelectric power stations that require a good watercourse and terrain that smooth the progress of the station's work. Recently, the road network in Jordan has undergone great expansion and renewal, especially the highways, which connect Jordan with neighboring countries. Highway 15 in Jordan, or the desert highway that extends from southern Jordan to its north, is Jordan's main artery for transporting goods to and from the port of Aqaba, located on the Red Sea, and on Regional Highway 35 bound for Amman [1, 3, 4].

Based on the general analyses that were performed by the researchers, this research work sheds light on the feasibility of renewable energy-related equipment in road construction. Jordan has invested nearly $1.7 billion over the last five years, with a relatively low return on investment compared to other middle-income countries. Figure 1 shows a flow chart of the research methodology.

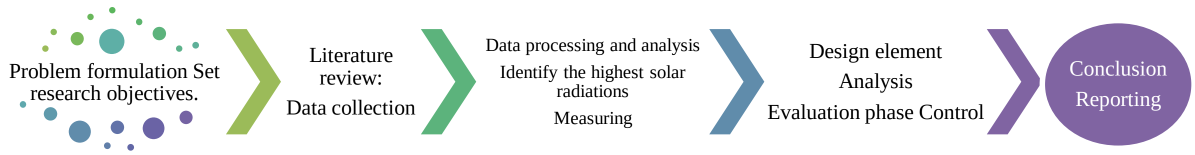

Figure 1. Flow chart of the research methodology

2. Literature Review

Renewable energy is becoming increasingly popular to reduce energy bills and manage the ever-increasing demand for electricity. In particular, it is being used to help power highway networks across the country. With the use of solar panels and other renewable energy sources, we can create an artificial control system to better manage our energy consumption. By optimizing the integration of renewable energy sources into the electric grid, we can achieve a more sustainable energy infrastructure and reduce our dependence on non-renewable sources. The use of solar energy has been growing rapidly due to its reliability, sustainability, and renewability. Photovoltaic pavement and solar roads are some of the latest inventions that aim to revolutionize the use of solar energy. These technologies offer the possibility of harvesting solar energy on the go, for example, while driving or walking. Utilizing these technologies can significantly reduce our dependence on fossil fuels and decrease our carbon footprint. The solar cell is the main electrical element of the photovoltaic coating. It is based on the photoelectric effect, first proposed by Becquerel in 1839 [5–7].

A solar cell consists of a P-type and N-type semiconductor, while a P-N junction is formed at their boundary [8, 9]. When a solar cell is exposed to sunlight, electrons receive energy from photons and move towards the N-type region, making it negatively charged. Accordingly, the holes will move towards the P-type region, making the P-type region positively charged. Thus, the electromotive force is generated on different sides of the P-N junction. When connected to external loads, direct current will be observed. The ideal electrical characteristics of silicon solar cells can be described by a five-parameter model based on the equation of a single diode [10]. The direct current is then converted to alternating current through the inverter. Part of the electricity is intended for the operation of the photovoltaic coating module itself, and the remaining part will be stored in a roadside battery pack or transported to the grid [11]. Solar energy plays a vital role in the energy system around the world. At the same time, since most roads are exposed to sunlight, the collection of solar energy has a high degree of consistency with the road network system, the form of use of which can be divided into three categories: solar thermal systems [12–14], thermoelectric systems [15], and photovoltaic systems [16].

An asphalt solar collector converts solar energy into heat energy through a working fluid in an underground pipeline. However, such a huge pipeline network system makes it difficult to build or maintain. When replacing pipes with drainage asphalt, porous layers can also be considered as a type of solar collector. However the low structural strength and poor permeability of asphalt are its main disadvantages. In addition, the need for auxiliary heat storage units will dramatically increase the cost of the entire solar thermal system. Based on the See Beck effect, a thermoelectric generator can generate electricity when there is a temperature difference between two thermoelectric materials. The thermoelectric system, mainly limited by its low energy conversion efficiency, is also strongly influenced by the local temperature gradient of the layer. In contrast, the photovoltaic system is technically mature with relatively high efficiency and low cost at present, accounting for approximately 3.4% of China's electricity generation in 2020 [17]. Therefore, it is an ideal form of solar energy harvesting technology combined with roads.

Some researchers have put forward a project that combines a photovoltaic system with a noise barrier [18] or arch [19] along the highway. Despite the ease of installation or dismantling, the system output largely depends on the area of the barrier or arch itself. To solve this problem, the concept of photovoltaic (PV) pavement appears [20, 21]. Modified photovoltaic modules are considered a single part of the road structure, equipped with the integral functions of generating electricity and ensuring the movement of vehicles. The main advantage of this technology is the absence of additional occupied land. It can be foreseen that the development of photovoltaic coatings will bring huge benefits in the economic and environmental fields. According to previous studies, large-scale asphalt pavement is considered a significant factor in the urban heat island effect, but photovoltaic pavement can effectively mitigate this phenomenon [22]. In combination with various energy storage technologies [23], such as pumped storage [24], batteries [25], and super capacitors [26], its overall performance can be further improved. At the same time, various new photovoltaic road technologies, such as snow-melting wireless charging and unmanned technologies [27], are expected to be integrated in the future to achieve a more sustainable and intelligent transportation system.

Roadways are a massive spatial resource that can be fully utilized by photovoltaic (PV) pavement, which combines established solar power generation technology with conventional pavement features. Despite the work completed by multiple organizations towards the development of this concept, questions exist about the viability of these panels as a structural pavement surface [28]. The development of solar collector pavement technology has made significant strides, and this trend's various technologies are grouped according to how they might be used in urban settings. The characteristics of each application and the current obstacles that might prevent the solar pavement approach are listed [29].

Table 1 shows the results of more than 450 articles that were analyzed as part of the previous research studies. Keywords in the below table were used to collect and search for information. Publications related to the research topic on the use of renewable energy sources near the road were selected from each group. When searching for topics on renewable energy sources in the databases, there were a very large number of retrievable results. However, a literature search related to Jordan, especially linking renewable energy systems to the development of highways, has changed the values (decreased) [30], which indicates the importance of research in this field.

Table 1. Example results of keyword search in Google Scholar

Key Word	All	Road	Highway	Street	Noise Barrier
Renewable energy source	2,790,000	635,000	77,800	208,000	101,000
Renewable energy in Jordan	108,000	29,000	10,100	18,400	20,500
Wind energy in Jordan	272,000	80,100	25,100	65,900	28,200
Solar Energy in Jordan	233,000	37,000	13,200	27,500	22,200
Photovoltaic in Jordan	31,400	6,290	1,950	4,130	2,990

3. Solar Energy

Solar electromagnetic radiation is defined as high-energy radiation. Studies showed that when it passes through the nucleus from the sun, it reaches the outer limit of the atmosphere. For an estimated energy flow of about 173 pW [31], it is estimated to be 30,000 times the power of all man-made devices [1]. Moreover, about 23% of this radiation reaches the Earth's surface, forcing the oceans to evaporate. In addition to the wind blowing or with the episode of photosynthesis, there is a possibility for solar radiation energy to stay in its unchanging form; moreover, in the form of wind, water, and biomass energy, it is expected that its use, direct or indirect, would produce heat and electricity [32].

3.1. Expected Lifetime of Solar Panel System

Manufacturers of photovoltaic cells generally issue warranties on performance in terms of the power output, which they will continue to deliver when in service. In most cases, these warranties guarantee good performance for a period of twenty to twenty-five years [33]. This period may be conservative, as some of the earliest solar electric panels, made about 35 years ago, are still producing energy today. The few examples of current performance warranties are as follows: (a) Siemens solar modules are designed to withstand the toughest environmental conditions and are characterized by their long service life. Siemens solar modules are covered by a 25-year limited warranty on power output, “your guarantee of trouble-free solar power generation”, (b) Kyocera offers a 25-year warranty, and their quality assurance system ensures that their multi-crystal modules exceed the US government specifications for tests involving thermal cycling, thermal shock, thermal/freezing and high humidity cycling, electrical insulation, hail impact, various mechanical and wind loads, salt mist, light and water exposure, and field exposure, (c) All products manufactured by BP Solar are individually tested and labeled. A 20-year performance warranty guarantees that the solar module will continue to deliver a minimum of 80% of its rated power, with all modules rated at 40w and above. Several modules with higher power output have a 25-year performance warranty; (d) All Astro Power modules carry a 20-year limited warranty and are designed and manufactured to meet all relevant international safety and performance certifications; and (e) Evergreen Solar and Uni-Solar also offer a 20-year limited power warranty on most photovoltaic modules. Uni-solar rigid panels are framed in anodized aluminum, which is highly resistant to corrosion. It should be noted that the performance warranties given above are only a few selected examples, and there are many other manufacturers, some of which may offer a longer warranty. For the purpose of whole-life costing, the assumption of serviceability over 25 years is not unreasonable. After 25 years, the modules may well continue to function, although some reduced efficiency should be assumed [2, 34].

4. Jordan Road Network

Jordan is known to be a passageway country for various merchandise and services to different countries, such as the Palestinian territories and Iraq [35]. This permits Jordan to maintain a well-developed transportation infrastructure internationally. According to the World Economic Forum's Index of Economic Competitiveness, Jordan was classified as one of the highest-ranking countries in developing countries and as having the 35th best infrastructure in the world. Moreover, it ranks way higher than some developed countries like Italy, Ireland, and Greece, as well as it was only two places behind the United Kingdom. The Ministry of Public Works and Housing manages the road network in Jordan, as well as the establishment and maintenance of road networks (main, secondary, rural, and agricultural) outside the organization's boundaries (external roads). Meanwhile, Greater Amman municipalities administer areas within planning boundaries (for internal roads) [3, 36].

Roads in Jordan are classified into main roads with a width of not less than 40 meters that link cities, large residential communities, and border crossings. Secondary roads are characterized by having a campus width of not less than 30 meters, being a link between towns and villages, and connecting with main roads. Rural roads, on the other hand, are those with a campus width of not less than 20 meters that link villages and agricultural areas and connect to main or secondary roads, as shown in Figure 2 (Jordan road map). The road network has developed greatly in terms of design, construction, and maintenance. In the 1950s, the total lengths of the paved network were 895 km for main, secondary, and rural roads, and at the end of 2009, it became about 7,999 km in length [17], with the main roads reaching a length of 3,281 km, secondary roads with a length of 2,190 km, rural roads with a length of 2,491 km, and Route 15, or Desert Road, a line connecting southern and northern Jordan at a distance of 315 km. It starts from Aqaba in the south, crosses Ma'an Governorate, and extends into the Jordanian desert to the east of all the southern cities and villages until it meets Route 35 towards Amman, as shown in Figures 3 and 4.

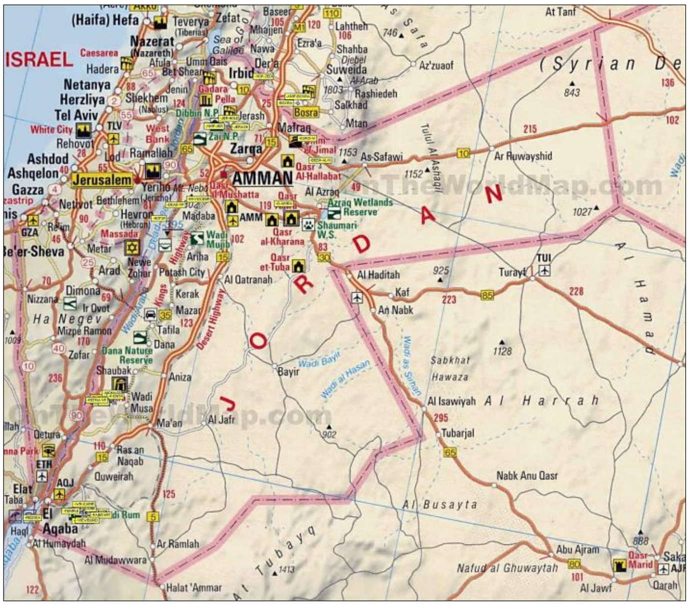

Figure 2. Jordan Road Map (*https://maps-jordan.com/jordan-road-map*)

Figure 3. Jordan Desert Highway

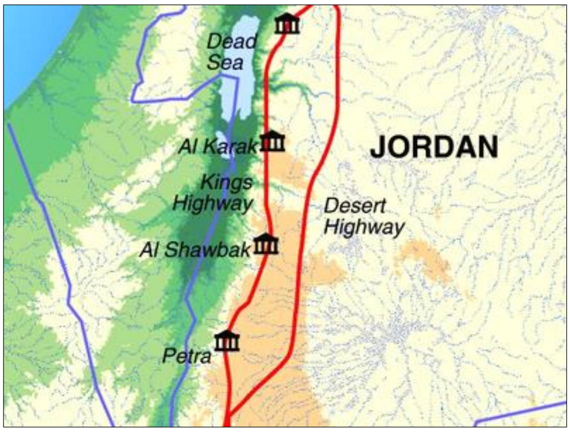

Figure 4. Jordan Desert Highway Map

The Dead Sea Road, or the Royal Road, is a highway linking southern and northern Jordan at a distance of 380 km. It starts from Aqaba in the south, crosses Wadi Araba, and aligns with the Dead Sea and the Jordan Valley until it reaches the western outskirts of Irbid in the far north of the country. The history of this road goes back to ancient times. It was first built in the time of the Romans after they occupied the region, and it was part of the "Hadrian's Road", which was launched on the historic royal road, one of the oldest trade routes in the world [37]. This express line was established as part of a comprehensive Jordanian plan over 25 years to connect all parts of the country together and create ring roads around major cities such as Amman, Irbid, and Salt. The value of the project upon completion is expected to reach approximately $1.8 billion [38]. The Amman Development Corridor, or Route 45, also called Route 100, is a four-lane highway that forms part of a future circumferential road that runs around the Jordanian capital, Amman. It was established in 2017, east of the city, with the aim of linking it with major cities, easing traffic congestion within the capital and its suburbs, and reviving the surrounding poor areas and villages. This road is considered a vital artery for transportation in Jordan and one of the main roads in Amman, as it was implemented according to international standards. The corridor connects the desert road near Queen Alia International Airport with the Azraq Expressway (Route 40) towards the Iraqi border and ends with the free zone in Zarqa with a length of 41 km and side services with a length of 50 km. This distance is the currently implemented part of several parts within a project called the Ring Road, which extends around the capital with a total length of 116 km and was implemented in three bids and financed by three financing bodies, where its construction cost amounted to 160 million dollars. After all, utilizing technology alone cannot convey business outcomes without assuring that the adopted procedure is proactively managed to guarantee that the organization gets the results it expects [38, 39]. The development of highways in Jordan is growing, which demands a necessity for clean and inexpensive energy sources. Table 2 shows the road network in the Kingdom per governorate [24].

Table 2. Roads network in the Kingdom per governorate during the period (2018)

Provinces	City	Main roads (Km)	Secondary Roads (Km)	Village roads (Km)	Agricultural roads (Km)	Main roads (Km)	Secondary roads (Km)	Village roads (Km)	Agricultural roads (Km)
North Province	Irbid	236	335	332	2830	937	815	1202	5185
	Ramtha	36	22	20	135				
	Mafraq	520	260	580	850				
	Jarash	95	108	235	670				
	Ajloun	50	90	35	700				
Central Province	Amman	306	190	529	267	955	595	2064	1732
	Balqa	215	136	287	400				
	Zarqa	303	149	164	590				
	Madaba	131	120	1084	475				
South Province	Karak	295	175	207	820	1442	766	1035	1802
	Tafila	260	163	160	530				
	Ma'an	560	217	590	190				
	Petra	5	39	27	222				
	Aqaba	322	172	51	40				
	Total road lengths (km)	3334	2176	4301	8719				

5. Design Elements

5.1. Pavement Design

The desert road in Jordan is designed using flexible pavements (high-type pavement), which have wearing surfaces that adequately support the expected traffic load without visible distress due to fatigue and, at the same time, are not susceptible to weather conditions, in Jordan most of the pavements are made of asphalt concrete pavements which consist of aggregates, mineral fillers, some additives and bitumen. Asphalt concrete pavements can withstand substantial loads and environmental conditions for a reasonable time and various forms of admixtures have been used to prolong the serviceability life of pavements by alleviating temperature and environmental effect [40-42]. These pavements consist of a bituminous surface underlay, a layer of granular material, and a layer of a suitable mixture of coarse and fine materials [43], as shown in Figures 5 and 6.

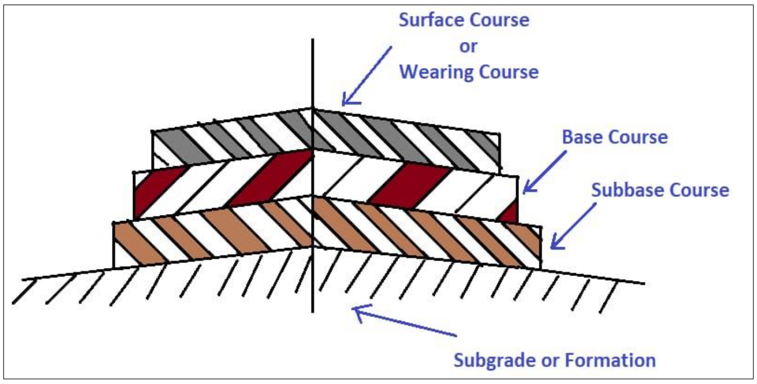

Figure 5. The components of a flexible [26]

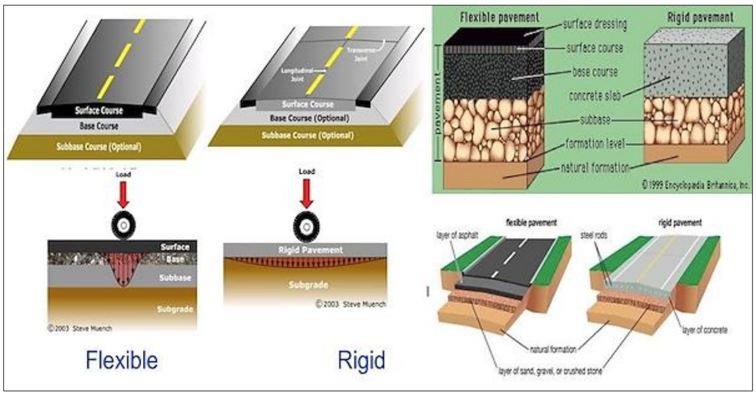

Figure 6. Traffic loads transferring to the pavement underlying supporting materials [26]

5.2. Solar Road Panel Design and Construction

Literature shows that the main structural design requirement is the need for the solar road panels to have the capacity and ability to tolerate the cyclic loading from vehicles [44]. In the field, these panels would be installed on a structured base, on compacted granular materials, or on a paved asphalt or concrete structure, as shown in Figure 7. These together provide greater support to the panel and should be considered important during material selection.

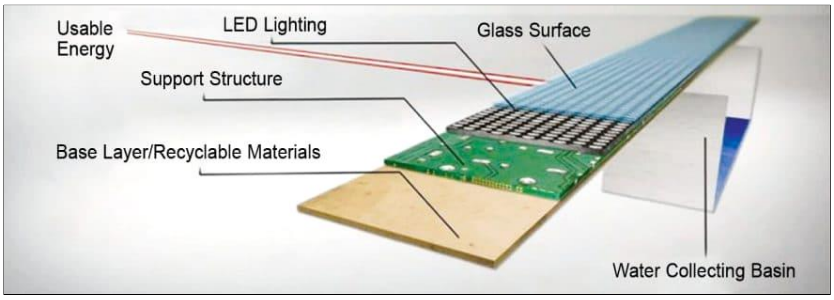

Figure 7. Components of solar roads

In addition, another major structural requirement for this panel is to have the surface capacity or ability to provide adequate friction for vehicles to safely travel through it. However, it is considered the most important challenge because the surface needs to be transparent enough to allow solar radiation to reach the solar cells rooted within the structural layers (Figure 8), in addition to other sorts of texturing that could damage or impair light transmission in the case of an improperly designed situation [45].

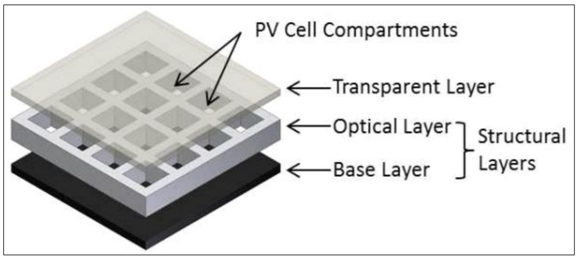

Figure 8. Exploded view of a conceptual solar road panel [45]

Literature shows that a solar road panel component design (Figure 9) needs to allow the load to be bypassed around the cells according to the updated and current standards of high-efficiency solar cell composition that are made from brittle silicon wafers. This can be accommodated by cantilevering the transparent layer over the solar cell compartments. Nonetheless, to avoid any deflection and extra load on the solar cells, it is necessary that the transparent layer be as strong as possible [15].

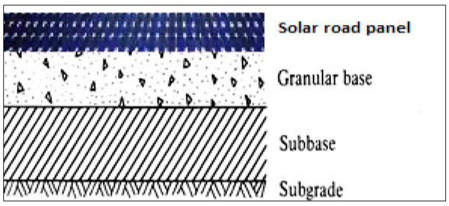

Figure 9. The components of a solar road panel [1]

Having a weatherproof ability of the panel is another condition that needs to be considered during the design period. This condition is important to have for both structural and electrical reasons because the penetration of water and contaminants would destroy the physical or structural integrity of the composite panel as well as damage the implanted electronics. Generally, the electrical design requirements mostly focus on the exposure of the photovoltaic cells to solar radiation as well as the physical robustness of the electrical circuit formed between the individual cells. One of the major concerns for photovoltaic panels is shading since cells that are not exposed to radiation will operate properly as part of the electrical circuit; consequently, rapid panel performance degradation will result. Moreover, the fact that the design requires the solar cells to be recessed from the transparent layer means that special, tremendous care is needed in order to prevent the internal shading of the solar cells by avoiding the ledges of the structural layers. Additionally, the removal of the collected debris on the surface through street sweeping, rubber removal, or other processes is needed, especially if the overall radiation reaching the solar cells begins to show a certain effect [46–48].

5.3. Photovoltaic Cell Selection

The monocrystalline silicon photovoltaic cell is presented in various sizes to satisfy the required needs. The best size for power generation applications that can be produced efficiently is 150 mm^2 of the solar cell. However, this 150 mm^2 is considered a large area for the suspension of the transparent material; therefore, the use of a successive size down of high-efficiency solar cells is preferable, namely the 125 mm^2 solar cell. This provides more surface area than the panel to generate electricity, while at the same time leaving enough space to transfer the load around the cell [49]. The 125 mm^2 cells have been shown to more appropriately fit the need than the 150 mm^2 cells, as described in this section. Figure 10 shows the project's solar cell dimensions, all in millimeters.

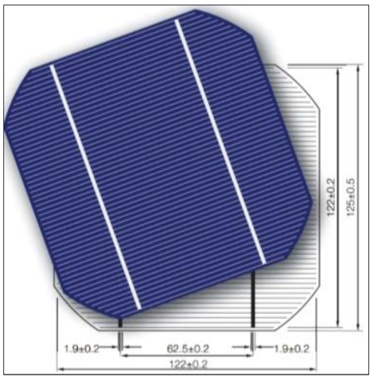

Figure 10. Monocrystalline silicon solar cell (125 mm^2)

5.4. Cell Interconnection

The best way to bond between the solar module's cells is to solder (fuse) a tin-lead strip to the rails above each cell and below the adjacent cell. This works superbly in conventional unit manufacturing because of the low load on the joint, where the cells are adjacent to each other, and with merely slight cell separation. However, these conditions are not obtainable in a solar road panel design. It is important to ensure a strong connection between the carrier cell tape and the electrical conductor; a welded tape is necessary; however, the tape is extended as a small tab of the solar cell, and an electrical wire is bonded or fused between the welded tabs of the inline adjacent cells [39]. It is preferable to use a 22-gauge wire for this application for the reason of the expected electrical load in the unit. This cabling or wiring is made according to the layout shown in Figure 11.

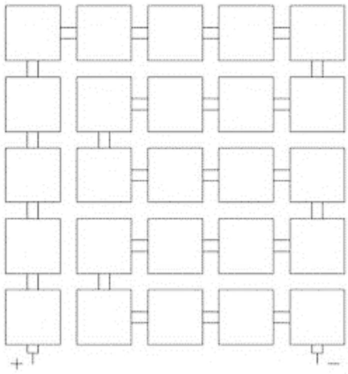

Figure 11. Schematic solar road panel interconnection scheme [45]

5.5. Transparent Layer Design

Consequently, under these previously mentioned conditions, the uppermost load condition would get the load evenly distributed from any passing tire, assuming a pressure of 470 kPa. This information has been applicable to the established strain correlations, using the low-bending theory as shown in Table 3. Figures 12 and 13 show solar roadway prototype panels.

Table 3. Maximum transparent layer bending stress as a function of glass pane thickness

Thickness (mm)	6	8	10	12	14	16	18	20
Maximum bending stress (MPA)	75.11	42.25	27	18.78	13.30	56	8.345	6.760
Maximum deflection (mm)	0.5415	0.2284	0.1170	0.06769	0.04262	0.02856	0.02006	0.01462

Figure 12. Solar Roadways prototype panel

Figure 13. Solar Road prototype panel

5.6. Solar Pavement Consideration

Literature shows that the occurrence of a phenomenon known as 'heat islands' leads to an increase in the urban temperature besides the energy demand for cooling, as well as aggravating and deteriorating the comfort and environmental situations in the urban environment. More specifically, solar irradiation during the summer can heat up asphalt pavements up to 343 K because of their heat-absorbing properties. The alleviation of the latter thermal energy from asphalt thermal collector pavements seems to be probable. The routine use of these asphalts and pavements facilitates lessening the surface temperature of the urban skin by around 284 K and, consequently, reducing the sensible heat released to the atmosphere as well as decreasing the environmental effects [50, 51].

As mentioned beforehand, the materials and design of construction produce an effective system. The analysis aimed to evaluate how feasible it is to use solar pavements as an enduring long-term energy producer to provide electrical energy through the introduction of an innovative energy generator pavement design. The study projected a system that includes several layers of solar cells in addition to an electrical system on the asphalt layer, which meets both the electrical energy requirements and the safety requirements of the road. The general broad design includes a transparent and permeable absorbent surface allowing sunlight to pass through, in addition to the solar cells with their connections and a base to transfer the load to asphalt, as shown in Figures 14 and 15 [37–38]. The main goal of this design was to perform a structural analysis, build a finite element model that duplicates the structural results, and subsequently apply the model to various subgrade, pavement, and structural-base models to determine the optimal characteristics of a solar road panel for use in different settings such as roads, parking lots, and similar infrastructure [52–55]. This would refine the specific glass thickness requirements, solar cell spacing, interconnection routing, and other design parameters as discussed in this report and, moreover, determine the service life of a solar road panel.

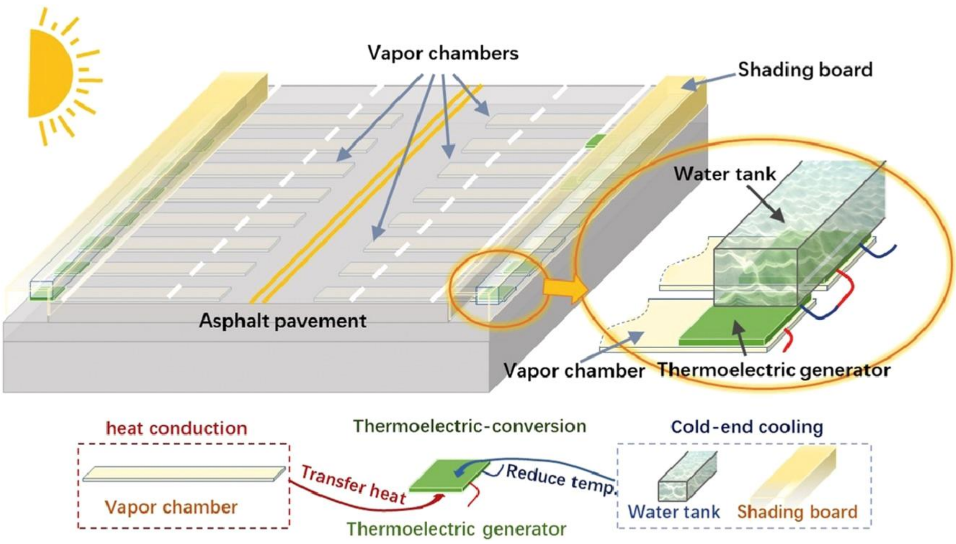

Figure 14. Schematic design of a thermoelectric generator pavement [37]

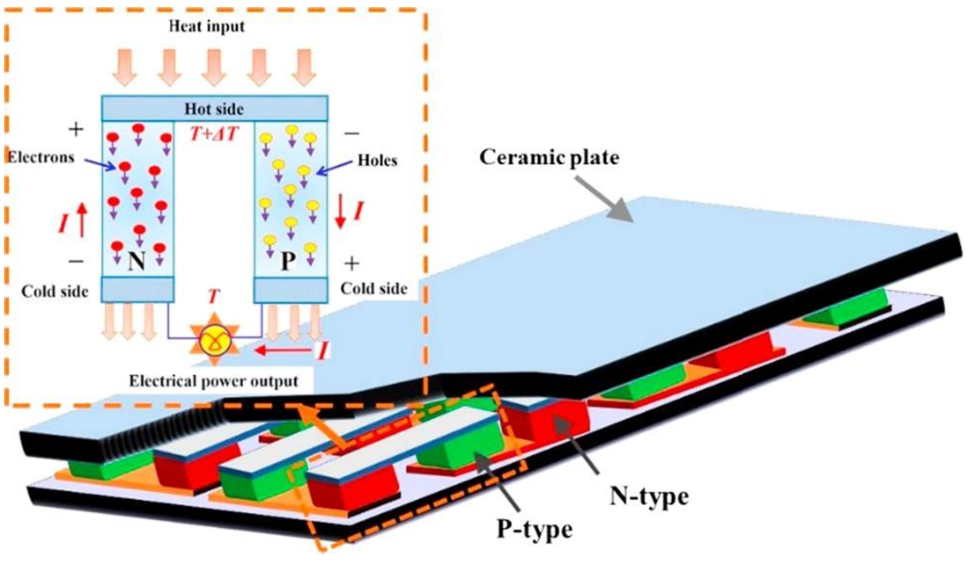

Figure 15. Configuration of thermoelectric generators module [38]

6. Conclusions

This research work reviewed important considerations during different applications of solar collector pavement technology. Thermal and electrical collector technology is employed to cover the thermal and/or electrical needs of the urban environment. Even though the potential claims that it is adequately promising, the large-scale pilots for the past 5 years are quite few. It looks like further research should be conducted with the aim of studying new ways of increasing the efficiency of the systems through different approaches such as new designs, novel implementation, and advanced material science. By securing not only efficiency but also the economic viability and robustness of the system, solar pavement technology can become conventionally mainstream in the future. From this research, the following conclusions can be drawn:

- The combination of the rigidity and the transparent layer materials of the solar cells is very important in order to minimize the strains that the solar cells are subjected to.
- Roads cover around 0.5% of the earth's surface. It is noteworthy that using this technology on public roads, residential streets, driveways, and parking lots will provide us with clean and inexpensive alternative energy.
- Using the solar roads would make it feasible to light roads and surrounding areas with barely minimum cost.
- Using solar panels or solar photovoltaic cells provides a facility for heating the roads, particularly in cold regions, in order to melt the ice and snow.
- Solar panels could be used for traffic safety purposes in terms of alerting drivers by operating alarm devices that warn drivers of any dangers they might encounter on the road.
- The use of renewable energy resources plays an important role in the future carbon-free energy supply for various applications such as heating, electricity, transportation, and safety.

7. Declarations

7.1. Author Contributions

Conceptualization, T.A. and M.B.B.; methodology, M.B.B.; software, S.A.; validation, S.A. and A.H.; formal analysis, T.A.; investigation, M.B.B; resources, S.A.; data curation, S.A.; writing—original draft preparation, M.B.B; writing—review and editing, T.A.; visualization, A.H.; supervision, S.A; project administration. All authors have read and agreed to the published version of the manuscript.

7.2. Data Availability Statement

Data sharing is not applicable to this article.

7.3. Funding

The authors received no financial support for the research, authorship, and/or publication of this article.

7.4. Conflicts of Interest

The authors declare no conflict of interest.

8. References

[1] Li, S., Ma, T., & Wang, D. (2023). Photovoltaic pavement and solar road: A review and perspectives. Sustainable Energy Technologies and Assessments, 55, 102933. doi:10.1016/j.seta.2022.102933.

[2] Handam, A., & Al Smadi, T. (2022). Multivariate analysis of efficiency of energy complexes based on renewable energy sources in the system power supply of autonomous consumer. International Journal of Advanced and Applied Sciences, 9(5), 109–118. doi:10.21833/ijaas.2022.05.014.

[3] Papadimitriou, C. N., Psomopoulos, C. S., & Kehagia, F. (2019). A review on the latest trend of solar pavements in urban environment. Energy Procedia, 157, 945–952. doi:10.1016/j.egypro.2018.11.261.

[4] Hu, H., Vizzari, D., Zha, X., & Roberts, R. (2021). Solar pavements: A critical review. Renewable and Sustainable Energy Reviews, 152, 111712. doi:10.1016/j.rser.2021.111712.

[5] Zhou, B., Pei, J., Nasir, D. M., & Zhang, J. (2021). A review on solar pavement and photovoltaic/thermal (PV/T) system. Transportation Research Part D: Transport and Environment, 93, 102753. doi:10.1016/j.trd.2021.102753.

[6] Takialddin, A. S., Al-Agha, O. I., & Alsmadi, K.A. (2018). Overview of model free adaptive (MFA) control technology. IAES International Journal of Artificial Intelligence, 7(4), 165–169. doi:10.11591/ijai.v7.i4.pp165-169.

[7] Ma, T., Li, S., Gu, W., Weng, S., Peng, J., & Xiao, G. (2022). Solar energy harvesting pavements on the road: comparative study and performance assessment. Sustainable Cities and Society, 81, 103868. doi:10.1016/j.scs.2022.103868.

[8] Nassef, A. M., & Handam, A. (2022). Parameter Estimation-Based Slime Mold Algorithm of Photocatalytic Methane Reforming Process for Hydrogen Production. Sustainability (Switzerland), 14(5), 2970. doi:10.3390/su14052970.

[9] Al-Maitah, M., Al Smadi, T. A., & Al-Zoubi, H. Q. R. (2014). Scalable user interface. Research Journal of Applied Sciences, Engineering and Technology, 7(16), 3273–3279. doi:10.19026/rjaset.7.671.

[10] Gaeid, K. S., Homod, R. Z., Al Mashhadany, Y., Al Smadi, T., Ahmed, M. S., & Abbas, A. E. (2022). Describing Function Approach with PID Controller to Reduce Nonlinear Action. International Journal of Electrical and Electronics Research, 10(4), 976–983. doi:10.37391/ijeer.100437.

[11] Smadi, T. A. A. (2012). Computer application using low cost smart sensor. International Journal of Computer Aided Engineering and Technology, 4(6), 567–579. doi:10.1504/IJCAET.2012.049572.

[12] Alahmer, A., Alahmer, H., Handam, A., & Rezk, H. (2022). Environmental Assessment of a Diesel Engine Fueled with Various Biodiesel Blends: Polynomial Regression and Grey Wolf Optimization. Sustainability (Switzerland), 14(3), 1367. doi:10.3390/su14031367.

[13] Zaidan, M. H., Khalaf, H. J., & Shaker, A. M. (2017). Optimum Design of Parabolic Solar Collector with Exergy Analysis. Tikrit Journal of Engineering Sciences, 24(4), 79–87. doi:10.25130/tjes.24.4.10.

[14] Gagliano, A., Tina, G. M., Aneli, S., & Nižetić, S. (2019). Comparative assessments of the performances of PV/T and conventional solar plants. Journal of Cleaner Production, 219, 304–315. doi:10.1016/j.jclepro.2019.02.038.

[15] Abdulfatah, A. S., & Sae'd, E. K. (2016). Modeling and Simulation Control of Buck Converter Applied to Solar Energy. Tikrit Journal of Engineering Sciences, 23(4), 31–35. doi:10.25130/tjes.23.4.04.

[16] Zapar, W. M., Gaeid, K. S., Mokhlis, H. Bin, & Al Smadi, T. A. (2023). Review of the Most Recent Work in Fault Tolerant Control of Power Plants 2018 – 2022. Tikrit Journal of Engineering Sciences, 30(2), 103–113. doi:10.25130/tjes.30.2.11.

[17] Al-Husban, Y., Al-Ghriybah, M., Handam, A., Al Smadi, T., & Al Awadi, R. (2022). Residential Solar Energy Storage System: State of the Art, Recent Applications, Trends, and Development. Journal of Southwest Jiaotong University, 57(5), 750–769. doi:10.35741/issn.0258-2724.57.5.61.

[18] Dezfooli, A. S., Nejad, F. M., Zakeri, H., & Kazemifard, S. (2017). Solar pavement: A new emerging technology. Solar Energy, 149, 272–284. doi:10.1016/j.solener.2017.04.016.

[19] Jiang, W., Sha, A., Xiao, J., Li, Y., & Huang, Y. (2015). Experimental study on filtration effect and mechanism of pavement runoff in permeable asphalt pavement. Construction and Building Materials, 100, 102–110. doi:10.1016/j.conbuildmat.2015.09.055.

[20] Al-Husban, Y., Al-Ghriybah, M., Gaeid, K. S., Takialddin, A. S., Handam, A., & Alkhazaleh, A. H. (2023). Optimization of the Residential Solar Energy Consumption Using the Taguchi Technique and Box-Behnken Design: a Case Study for Jordan. International Journal on Energy Conversion, 11(1), 25–33. doi:10.15866/irecon.v11i1.22672.

[21] Garber, N. J., & Hoel, L. A. (2019). Traffic and highway engineering. Cengage Learning, Boston, United States.

[22] Northmore, A. B., & Tighe, S. L. (2016). Performance modelling of a solar road panel prototype using finite element analysis. International Journal of Pavement Engineering, 17(5), 449–457. doi:10.1080/10298436.2014.993203.

[23] Kayal, M. (1995). Rock of Ages: Petra. Jordan's Ancient City of Temples and Tomb. The library, The Washington Post, Washington, United States.

[24] MPWH. (2018). The road network in the Kingdom by governorates. Ministry of Public Works & Housing, Amman, Jordan. Available online: https://www.mpwh.gov.jo/Default/Ar (accessed on May 2023).

[25] Liu, Y., Su, P., Li, M., You, Z., & Zhao, M. (2020). Review on evolution and evaluation of asphalt pavement structures and materials. Journal of Traffic and Transportation Engineering (English Edition), 7(5), 573–599. doi:10.1016/j.jtte.2020.05.003.

[26] K. S. Gaeid, T. Al Smadi, and U. Abubakar, "Double control strategy of PMSM rotor speed-based traction drive using resolver," Results in Control and Optimization, vol. 13, p. 100301, Dec. 2023, doi: 10.1016/j.rico.2023.100301.

[27] Lee, K W. W., Greenfield, M., DeCotis, A., & Lapierre, K. (2022). Solar Energy Harvesting and Pavement Sensing. Road and Airfield Pavement Technology. Lecture Notes in Civil Engineering, 193, Springer, Cham, Switzerland. doi:10.1007/978-3-030-87379-0_18.

[28] Ali, N. M., & Ammari, H. (2022). Design of a hybrid wind-solar street lighting system to power LED lights on highway poles. AIMS Energy, 10(2), 177–190. doi:10.3934/ENERGY.2022010.

[29] Qaiser, I. (2022). A comparison of renewable and sustainable energy sector of the South Asian countries: An application of SWOT methodology. Renewable Energy, 181, 417–425. doi:10.1016/j.renene.2021.09.066.

[30] Gulagi, A., Alcanzare, M., Bogdanov, D., Esparcia, E., Ocon, J., & Breyer, C. (2021). Transition pathway towards 100% renewable energy across the sectors of power, heat, transport, and desalination for the Philippines. Renewable and Sustainable Energy Reviews, 144, 110934. doi:10.1016/j.rser.2021.110934.

[31] Afsharzade, N., Papzan, A., Ashjaee, M., Delangizan, S., Van Passel, S., & Azadi, H. (2016). Renewable energy development in rural areas of Iran. Renewable and Sustainable Energy Reviews, 65, 743–755. doi:10.1016/j.rser.2016.07.042.

[32] Aguirre-Mendoza, A. M., Díaz-Mendoza, C., & Pasqualino, J. (2019). Renewable energy potential analysis in non-interconnected islands. Case study: Isla Grande, Corales del Rosario Archipelago, Colombia. Ecological Engineering, 130, 252–262. doi:10.1016/j.ecoleng.2017.08.020.

[33] Al-Dousari, A., Al-Nassar, W., Al-Hemoud, A., Alsaleh, A., Ramadan, A., Al-Dousari, N., & Ahmed, M. (2019). Solar and wind energy: Challenges and solutions in desert regions. Energy, 176, 184–194. doi:10.1016/j.energy.2019.03.180.

[34] Yang, M., Zhang, X., Zhou, X., Liu, B., Wang, X., & Lin, X. (2021). Research and exploration of phase change materials on solar pavement and asphalt pavement: a review. Journal of Energy Storage, 35, 102246. doi:10.1016/j.est.2021.102246.

[35] Dezfooli, A. S., Nejad, F. M., Zakeri, H., & Kazemifard, S. (2017). Solar pavement: A new emerging technology. Solar Energy, 149, 272–284. doi:10.1016/j.solener.2017.04.016.

[36] Khalaf, K. A., Gamil, A., Attiya, B., & Cuello, J. (2023). Exploring the potential of concentrating solar power technologies for vertical farming in arid regions: The case of Western Iraq. Energy for Sustainable Development, 77, 101310. doi:10.1016/j.esd.2023.101310.

[37] Jiang, W., Xiao, J., Yuan, D., Lu, H., Xu, S., & Huang, Y. (2018). Design and experiment of thermoelectric asphalt pavements with power-generation and temperature-reduction functions. Energy and Buildings, 169, 39-47. doi:10.1016/j.enbuild.2018.03.049.

[38] Jiang, W., Yuan, D., Xu, S., Hu, H., Xiao, J., Sha, A., & Huang, Y. (2017). Energy harvesting from asphalt pavement using thermoelectric technology. Applied Energy, 205, 941-950. doi:10.1016/j.apenergy.2017.08.091.

[39] Ma, T., Yang, H., Gu, W., Li, Z., & Yan, S. (2019). Development of walkable photovoltaic floor tiles used for pavement. Energy Conversion and Management, 183, 764–771. doi:10.1016/j.enconman.2019.01.035.

[40] Bani Baker, M. I., Abendeh, R. M., & Khasawneh, M. A. (2022). Freeze and Thaw Effect on Asphalt Concrete Mixtures Modified with Natural Bentonite Clay. Coatings, 12(11), 1664. doi:10.3390/coatings12111664.

[41] Baker, M. B., & Abendeh, R. (2022). Improving asphalt concrete resistance to rapid freeze–thaw effect using HIPS polymer. Emerging Materials Research, 11(3), 356–366. doi:10.1680/jemmr.21.00129.

[42] Khedaywi, T., Bani Baker, M., & Al-Kattab, T. (2023). Effect of Waste Ceramic Powder on the Properties of Asphalt Binder and Asphalt Concrete Mixtures. International Journal of Pavement Research and Technology. doi:10.1007/s42947-023-00375-y.

[43] Smadi, T. A., Handam, A., Gaeid, K. S., Al-Smadi, A., Al-Husban, Y., & Khalid, A. Smadi. (2023). Artificial Intelligent Control of Energy Management PV System. Results in Control and Optimization, 100343. doi:10.1016/j.rico.2023.100343.

[44] Gan, P. Y., & Li, Z. (2015). Quantitative study on long term global solar photovoltaic market. Renewable and Sustainable Energy Reviews, 46, 88–99. doi:10.1016/j.rser.2015.02.041.

[45] Northmore, A.B., Tighe, S. (2012). Developing innovative roads using solar technologies. In Proceedings of the 2012 Annual Conference of the Canadian Society for Civil Engineering, Edmonton, AB, Canada, 6–9 June 2012; Volume 2, 1348–1355.

[46] Dezfooli, A. S., Nejad, F. M., Zakeri, H., & Kazemifard, S. (2017). Solar pavement: A new emerging technology. Solar Energy, 149, 272–284. doi:10.1016/j.solener.2017.04.016.

[47] Ma, T., Yang, H., & Lu, L. (2014). Development of a model to simulate the performance characteristics of crystalline silicon photovoltaic modules/strings/arrays. Solar Energy, 100, 31–41. doi:10.1016/j.solener.2013.12.003.

[48] Northmore, A. B., & Tighe, S. L. (2014). Performance modelling of a solar road panel prototype using finite element analysis. International Journal of Pavement Engineering, 17(5), 449–457. doi:10.1080/10298436.2014.993203.

[49] Smadi, T. A., & Al-Maitah, M. (2020). Artificial intelligent technology for safe driver assistance system. International Journal of Computer Aided Engineering and Technology, 13(1-2), 183-191. doi:10.1504/IJCAET.2020.108112.

[50] Coutu, R. A., Newman, D., Munna, M., Tschida, J. H., & Brusaw, S. (2020). Engineering Tests to Evaluate the Feasibility of an Emerging Solar Pavement Technology for Public Roads and Highways. Technologies, 8(1), 9. doi:10.3390/technologies8010009.

[51] Trrad, I., Smadi, T.A., & Al_wahshat, H. (2019). Application of fuzzy logic to cognitive wireless communications. International Journal of Recent Technology and Engineering, 8(3), 2228–2234. doi:10.35940/ijrte.B2065.098319.

[52] Wang, M., Mao, X., Gao, Y., & He, F. (2018). Potential of carbon emission reduction and financial feasibility of urban rooftop photovoltaic power generation in Beijing. Journal of Cleaner Production, 203, 1119–1131. doi:10.1016/j.jclepro.2018.08.350.

[53] Dai, Y., Yin, Y., & Lu, Y. (2021). Strategies to facilitate photovoltaic applications in road structures for energy harvesting. Energies, 14(21), 7097. doi:10.3390/en14217097.

[54] Manasrah, A., Al Zyoud, A., & Abdelhafez, E. (2021). Effect of color and nano film filters on the performance of solar photovoltaic module. Energy Sources, Part A: Recovery, Utilization and Environmental Effects, 43(6), 705–715. doi:10.1080/15567036.2019.1631907.

[55] Al-Smadi, T.A., & Ibrahim, Y. K. (2007). Design of speed independent ripple carry adder. Journal of Applied Sciences, 7(6), 848–854. doi:10.3923/jas.2007.848.854.