International Journal of Multidisciplinary Comprehensive Research

Developing foldable solar panels to facilitate their installation and deployment: A review

Haneafa Yahya Najm
Mosul Medical Technical Institute, Northern Technical University, Mosul, Iraq

* Corresponding Author: **Haneafa Yahya Najm**

Article Info

ISSN (online): 2583-5289
Volume: 03
Issue: 04
July-August 2024
Received: 25-06-2024
Accepted: 02-08-2024
Page No: 66-71

Abstract
Solar photovoltaic (PV) systems play an important role for electricity production using solar energy. Underdeveloped or developing countries are still striving for a continuous supply of electricity. When fossil fuels are used to generate electricity, it leads to an increase in pollutants and greenhouse gases. Solar energy technologies help to meet the growing need for energy in the world and at the same time help reduce pollution and save the world from the large pollution resulting from the production of electrical energy, solar energy contributes significantly in rural locations significantly, many government agencies have launched programs to promote the use of solar energy technology for power generation.

DOI: https://doi.org/10.54660/IJMCR.2024.3.4.66-71

Keywords: Solar Panels, PV, Foldable

1. Introduction

Nowadays, the use of renewable energy sources is drawing more attention due to rapidly depleting energy resources and environmental destruction. Solar energy is considered as the most inexhaustible and sustainable energy source among renewable energy options, and it is used for many purposes, including the generation of electricity - the main focus of this essay. (Mammadov *et al.*2022) [25] (Novas *et al.*, 2021) [30]

In addition, the total energy generated by solar photovoltaic systems is also increasing at an unprecedented rate (increasing at an annual rate of 30%) and technological advancement is growing rapidly. The decreasing price of solar system components is considered as the key to driving the growth of the green power sector, and one of its main components is a solar panel. (Verlinden, 2020) [39] (Tawalbeh *et al.*2021) [38]

Traditional monolithic solar panels are commonly used to harness solar power. Nevertheless, monolithic panels are difficult to install and store, as they are vulnerable to scratches, and production errors made in one cell may affect the performance of the entire panel. As a result, considerable research has been undertaken in the field of using or creating foldable solar panels that are simpler to install and store, allow safe and easy wire management, and permit easy deployment in remote areas. Foldable solar panels can be built as temporally or permanently installed in a certain location and with fixed adjustment or can be articulated to follow the sun during the day. (Hao *et al.*2022) [15] (Ahmad *et al.*, 2020) [1].

2. Background and importance of foldable solar panels

In recent years, with the efforts to develop sustainable energy systems more effectively, solar energy is increasingly being taken into account in various aspects such as operation performance, cost, and ecology. The rapid technological development has effectively increased the power generating capacity of the solar panels. However, in order to collect the most sunlight, traditional solar panels are fixedly installed with inclination towards the sun, and fixed to the ground or roof, etc. This makes the installation process difficult and time-consuming, and the panels impossible to change position to collect sunlight once installed. In view of the above factors, developing thin, light, portable, and less installation time consuming solar panels, are one of the ways, with ease of use, to make it practical to install and deploy for people on demand. Folding solar panels become an option, and are considered as portable/moveable solar panels equipped with hinge-like connections, which allow them to be easily folded for transport and deployment. (Ahmad *et al.*, 2020) [1] (Maka & Alabid, 2022) [24] (Hao *et al.*2022) [15]

The manuscript provides an overview in 10 sections. In this section, foldable solar panels are introduced and the significance of the manuscript is explained. In Section 2, the basic structure of foldable solar panels is presented. The structures of foldable solar panels are proposed from 2006 to 2018. The materials and fabrication technologies for photovoltaic surfaces are shown in Section 3 and are gradually becoming more diversified. The studies on the photovoltaic surface include photovoltaic coating, organic solar panels, thin-film solar panels, and solar panels. Their advantages/disadvantages and/or technical architecture's specific were shown. In Section 4, technical issues on foldable-hinge installations are addressed. The foldable-hinge installations can be divided into two parts: the electric aspect and the mechanical aspect. In Section 5, different portable solar panels are introduced in terms of mechanisms, energy sources, and applications. In Section 6, characteristic comparisons' research of the portable solar panels existing in the literature, which have been driven by humans is also presented. In Section 7, methods to fold or unfold foldable solar panels to get the tracking angles of mobile use are introduced. In Section 8, the kinds of companies who mainly manufacture and sold the foldable photovoltaic panels are shown and their machine design is introduced in brief. In Section 9, advantages, volunteer response to the foldable operation of free energy devices, and future work will be explained. And, in Section 10, further work is provided. (Muteri *et al*.2020) [29] (Ahmad *et al*., 2020) [1] (Dambhare *et al*. 2021) [8] (Victoria *et al*. 2021) [40]

3. Design considerations for foldable solar panels

Foldable solar panels are a promising development in the field of solar photovoltaics because they can potentially simplify the installation process on site and can hence reduce the installed cost of electricity for the end user. Many types of designs and configurations have been developed, and the number of publications on this topic has been on the increase from 2010 until now. This review article analyses and categorises these works to provide an overview of the options and error sources involved. (Zhong & Tong, 2020) [44] (Arefeen & Dallas, 2021) [5]

Maximising the area power density is important, and the types of thin-film solar cells and the number of cells per panel can be used to further optimise the mass power density of the module. Foldable solar panels are usually built from small, rigid solar panels that are connected in series and in parallel to obtain the required wattage and voltage. Different types of materials, including metals like aluminium or stainless steel, and polymers and composites, can be used for fabricating the structure of the panel. Few works exist that explore the influence of manufacturing techniques of the mechanically connected joints between the panels, and, in particular, the fastening and hinge design that separate one panel from another. Combining the right testing and structural simulations can therefore provide a time-efficient and potentially accurate design loop. These simulations should be performed at least by a single-axis loading condition but could be extended towards multi-loading simulations. (Zhang *et al*., 2021) [43] (Efaz *et al*. 2021) [9] (Khatun *et al*., 2021) [19]

3.1. Materials and Manufacturing Techniques

One of the major components of the design considerations for foldable solar panels is the selection of materials and manufacturing techniques. For the materials, prior work has identified 5 main types of sheets that can operate in terms of performance, characteristics, reliability, and long-term durability: backplanes (perovskite), cells (PERC, HIT, SHJ, TOPCon, HJT, and Tandem), modules (MONO, POLY, and bifacial), the mini substrates and encapsulation materials, as well as sheets from a variety of other commercial materials for the back side reflector to be optimized for the bi-facial electroluminescence, and nano-coatings for the anti-reflection and hydrophobic effect. Additionally, the selection of materials also depends on the installation and place (indoors, outdoors, or space). (Li *et al*., 2021) (Ajayan *et al*.2020) [3]

There is a wide range of processes and techniques that can be used to manufacture foldable solar panels. For instance, the perovskite sheet can be printed by different printing techniques, such as spin coating, slot-die coating, gravure printing, inkjet printing, screen printing, doctor blade coating, aerosol jet printing, spray-coating, electrostatic spray deposition, spray pyrolysis, and capillary pen writing; the cells can be manufactured by plenty of deposition techniques, including screen printing, aerosol-jet printing, *et al*. Some other techniques such as pulsed laser deposition, sputtering, thermal evaporation, electron beam evaporation, or atomic layer deposition are unattractive in roll-to-roll or roll-to-panel techniques and cannot be utilized effectively to a sheet design. It is also worth mentioning that although physical vapor deposition is possible for roll-to-roll manufacturing, it may create harmful environmental hazards. Therefore, such processes that need to be vacuum have been generally excluded from discussion, and the sheet and module design diminish this process. Moreover, it is worth mentioning that the manufacturing of the foldable solar panels can be limited to semi-transparent, flexible, and highly efficient cells. (Parida *et al*. 2022) [31] (Gusain *et al*., 2020) [14] (Hunde & Woldeyohannes, 2023) [17]

3.2. Structural Engineering Aspects

In addition to the mechanical criteria described in the previous subsection, limiting elements have to be introduced in the evaluation of the overall functioning of foldable devices. In the first stage of the design phase, two main issues are to be tackled: the structural engineering of the foldable panel and the determination of the mechanical performances of the hinges and actuators. Once these issues have been addressed, the complete prototype can be studied and possible problems related to electric constraints, and obviously, efficiency can be treated. (Mufti *et al*., 2020) [28] (Fukuda *et al*., 2020) [11]

One of the fundamental aspects to be taken into account in the preliminary stage of design is the difference between fixed and foldable solar panels. From a structural point of view, the supporting structure of a fixed panel can be correctly dimensioned assuming that the forces and loads originate in the centre of the panel. It is possible, in this case, to use simplified models which do not consider the load distribution over the surface of the panels. Foldable panels, instead, cannot be modeled as beams with equivalent forces originating in their centres because the forces at panel's ends can be considerably different from the forces in the middle part. The load distribution has a relevant impact especially in non-symmetric configurations, such as the ones in which one side of the panel is partially opened. From the structural point of view, the main components of a foldable panel are:
- The folding elements, permitting the rotation of the panel

towards the supporting structure thanks to a rotation joint on which are developed, and concentrated, the transmission of tractive and compressive efforts directed along the axes of rotation;
- The connecting elements, necessary to keep in place and guarantee the functionality of the mechanism, carrying mainly shearing forces, the values of which depend on the mechanical characteristics of the folding elements; (Li *et al*., 2022) (Lan *et al*. 2021) [21] (Zhang *et al*., 2020) [41]

4. Technological Innovations in Foldable Solar Panels

Technology advancements in solar panels have made them portable, durable, and effective in generating power. Among these technological advancements, the development of foldable solar panels has significantly enhanced their portability and ease of installation in remote sites. The foldable solar panels are made using crystalline silicon modules, which can generate more energy proportionally with the decreasing size. However, if not folded properly, fractures can be induced due to mechanical overload actions. Grooves were developed on the top surface of the silicon cells to facilitate the bending of the silicon modules. The foldable modules, like the non-foldable modules, incorporate bypass diodes, and when incorporated with modern technology, they are durable and can withstand tough conditions, including heavy winds, rains, and snow, among other destructive environmental conditions. The fabric material for the foldable solar panel is made of tensile materials such as fabric, carbon fiber, or silicone rubber. (Hao *et al*.2022) [15] (Li *et al*., 2021) [23] (Hashemi *et al*.2020) [16]
The lens-on-panel is a specific generation of solar panel and solar cells designed to use silicone lenses that enhance efficiencies and energy production by 65%. They, however, have a heavy upfront cost of purchase. The International Electrotechnical Commission (IEC) standards propose mechanical tests for the solar modules with at least 15 cycles of full folding. The results indicate long-term durability and resistance to large mechanical loads. This is dependent on the choice of the micro-fabricated hinges and the fold angles, which prevent premature buckling and fatigue. As such, foldable solar panels have been gaining popularity in the solar industry, as they are easy to transport and install/assemble at the site of use. The foldable panels are easy to maneuver in cars and camping activities. The appearance of the panels is attractive and can easily be converted into a likable design for various uses. (Ballif *et al*. 2022) [6] (Ghasemzadeh and Shayan 2020) [12].

5. Applications and Case Studies

5.1 Applications Cover Design

Low-cost foldable solar panels have become increasingly popular for use as solar chargers for outdoor use or as a personal power source. In addition, foldable solar panels may also produce electricity for emergency purposes. Other applications of this kind of solar panels will involve a wide range of electric power capacities and usage environments. For example, as an actuator or auxiliary power on cyclic or long endurance unmanned aerial vehicles (UAVs), walking motion powered by a flexible battery/foldable solar panel, power generation from the shock absorbers of bicycles and high-heel shoes, integrated solar-powered wearable systems, large scale renewable energy collection on flexible/contoured surfaces, etc. (Mazlan *et al*. 2024) [26] (Muensuksaeng *et al*. 2022) [27].

5.2 Case Studies

Development of foldable solar panels is part of the project "Soft Landing and Hopping Technologies for the EXOMars 2020 mission". It was coordinated by the European Space Agency (ESA) and led by the company Space Applications, a responsible for the design of a series of foldable carbon fiber system with solar panels to guarantee natural gas-like behavior during atmospheric entry and with solar panels unfolded after landing. (Boelens *et al*., 2022) [7]
Fans of the YouTube channel FunnyAcademy have actually run through the design process of a solar bag, system of two foldable solar panels combined with a 30 A controller located in a classic, commonly available traveler's backpack. According to them, the construction and purchase of the components would cost €170, or $200 in France, if components were to be bought new. The two panels provide 160 W of electricity and are fixed to the bag by magnets. (Ryelandt & Raskin)

5.1. Portable Solar Chargers

Portable solar chargers are probably the most well-known application of foldable solar panels. A large market of consumer products can be found that employ small-size, folding photovoltaic (PV) panels for charging portable electronics (e.g., smartphones, tablets, GPS systems, cameras, etc.). Such PV chargers can range from roughly 2 W to 50 W, although a typical range is more like 5–20 W. Industry estimates suggest that applications such as portable solar phone chargers are growing by around US$50 million per year in the United States. While portable solar chargers are very far removed from systems used for grid-tied rooftop solar power, the two have something in common: increasing solar energy accessibility to new groups of people (even if for very different reasons). As mentioned above, portable solar chargers are purchased for various reasons: suitable, small-size module-packaging that are quick and easy to deploy for maximum watt-hours per day versus portability; to be cost effective; lightweight, flexible substrates; water-resistant coatings or encasement; integrated electronics to prevent battery over-charging; thin-film flexible, light-weight, amorphous silicon (coded as triple-junction thin-film silicon), or mono-crystalline silicon solar cells that fit a smaller surface area; and different output voltages to accommodate charging of a variety of electronic devices. Panel designs can range from open profile fold or roll-up, to retractable flaps. For the portable market, folding solar chargers are an exotic gift as well as an emergency product to the general public. Costa SMART 41 products is a South African company that offers a range of portable solar chargers capable of powering lighting systems and charging small devices, such as smartphones. Portfolio cases closed, they have the form of a cube with the length and width dimensions as the height dimension. The chargers can generate 8 to 28 W. (Khan *et al*., 2020) [18] (Ajarostaghi and Mousavi 2022) [2] (Griffith, 2023) [13] (Popovich *et al*., 2021) [34].

5.2. Space Exploration

Physical and technical considerations in conditions of limited energy input are essential when discussing the use of any solar panel in such harsh environments as space. A foldable panel could be a solution for such applications. A system allowing the launch either with folded or unfolded solar panels is desirable then. Sun rays are a potentially unlimited energy source which could power spacecraft and lunar installations, reducing or even eliminating the need to carry volatile fuels used, for example, in fuel cells or ground-based reactors. This allows the range of maneuvering movements and the possibility of significantly relieving the payload, thus reducing the cost of the mission. (Lan *et al*.2021) [21] (Sproewitz *et al*. 2020) [37]

Unfortunately, these advantages are associated with numerous challenges, as the conditions in space are unfavorable for gathering energy from sunlight. Harsh temperatures, the accumulation of dust particles on the collectors, the possible loss of structural integrity of the collector (glass weakening due to the combined effect of sun radiation and the accumulation of electric charge, micrometeorite impacts, or even space trash) or the ephemeris-based energy variation of sun collectors are only selected examples. As a result, unfortunately in some cases, the degradation can be much faster than the material recovery during PV cells exploitation. Improved energy recovery should, therefore, be possible with a given panel across the complete day. A hinge-based folded structure could help the energy source stay in a nearly perpendicular position to the panel. Moreover, the folded volume of four solar panels represents only a little above 39% of their unfolded version. This means that with at least two such units folded during launch and then unfolded, the solar panel area triples, which can be helpful especially in the initial phase of the exploration mission. (Kwok *et al*. 2020) [20] (Fraternali *et al*. 2024) [10]

6. Challenges and Future Directions

The main challenge for flexible and foldable solar panels is their low efficiency and short life. Based on our research, although the cost of folding systems is inadequate for installation and deployment, it is possible to design and make better foldable PV panels that can be used for home roof systems, camp roof systems, and portable systems. For example, it is possible to design more fault-tolerant structures for foldable solar panels in buildings, houses, and camp sites, as well as to investigate more efficient folding directions to fit more panels into the available space. It is also worth investigating new packaging technologies and materials for portable solar camping panels, as it is predicted that new technology might reduce the weight of the camp kit. It is also possible to develop a new structure for foldable panels in commercial tents, pools, and stadiums used for social gatherings. It is also remarkable to develop a foldable PV semi-tent that can meet the camping needs of families of five to seven people; the tent could be used in coastal cities, small islands, and for desert safaris to charge electric cars. (Pawlak-Jakubowska, 2023) [32] (Pérez-Valcárcel *et al*. 2024) [33] (Zhang *et al*.2020) [41]

On the other hand, just as it is challenging to track and position conventional solar panels with solar trackers, it is more challenging to control the mechanical structure of foldable solar panels. The final mechanism, which is compact, portable, fast to set up, and integrates into a foldable solar panel, could thus be utilized to rotate and tilt the solar panel so that it is fully compatible with portable solar panels, home roof systems, and price-stable systems. The key objective is to examine the ability of the new target tracking mechanism to function horizontally and possibly adapt to the model of existing solar trackers. Overall, although a new design, manufacturing, and control system is needed for foldable solar panels, foldable solar panels have a bright future and many utility prospects. (Allouhi *et al*., 2022) [4] (Rathore *et al*. 2021) [35]

7. Conclusion

In this essay, we have comprehensively reviewed the development of foldable solar panels – spanning materials, structures, simulation, and optimization. Aspect ratios for foldable panels have also been recommended to save space-based solar power systems. Extensive deployment of space-based solar power systems will require power stations to be built, maintained, repaired, and recycled in orbit. Moving toward the goal of maximizing the amount of power that can be collected each year by a space-based solar power station, solar panels that are used to convert light into electricity have been designed to unfold and retract.

In this review, four core aspects of the development of foldable solar panels have been presented. First, various kinds of materials that are used to develop flexible photovoltaics are introduced. These include organic-inorganic halide perovskites, quantum dots (emitting lights at different wavelength ranges), organic photovoltaics, amorphous silicon, etc. Additionally, along with compatibility between the solar energy conversion area and the deployment site, storage needs for foldable panels have been addressed. In terms of actual foldable panels, plate structures are heavily researched and are the only foldable panel structures that are reportable to date (or until August 2019). In the context of structure optimization, methods of analyzing site motion via a solar panel or designing a deployable solar energy collection structure are available. Designers of foldable panels are able to simulate the evolution and optimize the design of a foldable panel either using geometrically-exact dynamic analysis or using the variational-asymptotic method (VAM) for three-dimensional hyperelastic beams. Incorrect geometrical and material parameters decrease the accuracy of simulations for foldable panels and reduce the innovation in the corresponding structures.

8. References

1. Ahmad L, Khordehgah N, Malinauskaite J, Jouhara H. Recent advances and applications of solar photovoltaics and thermal technologies. Energy. academia.edu
2. Ajarostaghi SSM, Mousavi SS. Solar energy conversion technologies: Principles and advancements. In: Solar Energy Advancements in Agriculture and Food Production Systems. Academic Press; c2022. p. 29-76. [HTML]
3. Ajayan J, Nirmal D, Mohankumar P, Saravanan M, Jagadesh M, Arivazhagan L. A review of photovoltaic performance of organic/inorganic solar cells for future renewable and sustainable energy technologies. Superlattices and Microstructures. 2020;143:106549. [HTML]
4. Allouhi A, Rehman S, Buker MS, Said Z. Up-to-date literature review on Solar PV systems: Technology progress, market status and R&D. Journal of Cleaner Production. [HTML]
5. Arefeen S, Dallas T. Low-cost racking for solar photovoltaic systems with renewable tensegrity structures. Solar Energy. [HTML]
6. Ballif C, Haug FJ, Boccard M, Verlinden PJ, Hahn G.

Status and perspectives of crystalline silicon photovoltaics in research and industry. Nature Reviews Materials. 2022;7(8):597-616. epfl.ch

7. Boelens M, Koch C, Pastoria C, Woodle N. Decommissioning trends, circular economy policy incentives, and secondary markets for solar photovoltaics. umich.edu. umich.edu
8. Dambhare MV, Butey B, Moharil SV. Solar photovoltaic technology: A review of different types of solar cells and its future trends. In: Journal of Physics: Conference Series (Vol. 1913, No. 1, p. 012053). IOP Publishing; c2021. iop.org
9. Efaz ET, Rhaman MM, Al Imam S, Bashar KL, Kabir F, Mourtaza ME, *et al*. A review of primary technologies of thin-film solar cells. Engineering Research Express. 2021;3(3):032001. researchgate.net
10. Fraternali F, de Castro Motta J, Germano G, Babilio E, Amendola A. Mechanical response of tensegrity-origami solar modules. Applications in Engineering Science. 2024;17:100174. sciencedirect.com
11. Fukuda K, Yu K, Someya T. The future of flexible organic solar cells. Advanced Energy Materials. [HTML]
12. Ghasemzadeh F, Shayan ME. Nanotechnology in the service of solar energy systems. Nanotechnology and the Environment. 2020;1:1-15. intechopen.com
13. Griffith S. The Wires That Bind: Electrification and Community Renewal: Quarterly Essay 89. HTML
14. Gusain A, Thankappan A, Thomas S. Roll-to-roll printing of polymer and perovskite solar cells: compatible materials and processes. Journal of Materials Science. [HTML]
15. Hao D, Qi L, Tairab AM, Ahmed A, Azam A, Luo D, *et al*. Solar energy harvesting technologies for PV self-powered applications: A comprehensive review. Renewable Energy. c2022;188:678-697. sciencedirect.com
16. Hashemi SA, Ramakrishna S, Aberle AG. Recent progress in flexible–wearable solar cells for self-powered electronic devices. Energy & Environmental Science. 2020;13(3):685-743. [HTML]
17. Hunde BR, Woldeyohannes AD. 3D printing and solar cell fabrication methods: A review of challenges, opportunities, and future prospects. Results in Optics. c2023; sciencedirect.com
18. Khan KA, Kabir MA, Mamun M, Hossain MA, Alim S. An observation of solar photovoltaic electricity across the globe. IJARIIE. academia.edu
19. Khatun MM, Sunny A, Al Ahmed SR. Numerical investigation on performance improvement of WS2 thin-film solar cell with copper iodide as hole transport layer. Solar Energy. [HTML]
20. Kwok KS, Huang Q, Mastrangeli M, Gracias DH. Self-folding using capillary forces. Advanced Materials Interfaces. 2020;7(5):1901677. wiley.com
21. Lan X, Liu L, Pan C, Li F, Liu Z, Hou G, *et al*. Smart solar array consisting of shape-memory releasing mechanisms and deployable hinges. Aiaa Journal. 2021;59(6):2200-2213. researchgate.net
22. Li X, Li P, Wu Z, Luo D, Yu HY, Lu ZH. Review and perspective of materials for flexible solar cells. Materials Reports: Energy. sciencedirect.com
23. Li Z, Yu C, Qi L, Xing S, Shi Y, Gao C. Mechanical behaviors of the origami-inspired horseshoe-shaped solar arrays. Micromachines. mdpi.com
24. Maka AOM, Alabid JM. Solar energy technology and its roles in sustainable development. Clean Energy.

oup.com
25. Mammadov NS, Ganiyeva NA, Aliyeva GA. Role of renewable energy sources in the world. Journal of Renewable Energy, Electrical, and Computer Engineering. 2022;2(2):63-67. unimal.ac.id
26. Mazlan MZM, Mohamad KA, Alias A, Nordin MS, Wijaya YP. Off-Grid Emergency Tent Solutions with a Compact Solar Photovoltaic System. Journal of Electronics Technology Exploration. 2024;2(1):1-5. shmpublisher.com
27. Muensuksaeng C, Harnmanasvate C, Chantana J, Cheacharoen R. Portable solar-powered dual storage integrated system: A versatile solution for emergency. Solar Energy. 2022;247:245-254. [HTML]
28. Mufti N, Amrillah T, Taufiq A, Diantoro M, Nur H. Review of CIGS-based solar cells manufacturing by structural engineering. Solar Energy. [HTML]
29. Muteri V, Cellura M, Curto D, Franzitta V, Longo S, Mistretta M, Parisi ML. Review on life cycle assessment of solar photovoltaic panels. Energies. 2020;13(1):252. mdpi.com
30. Novas N, Garcia RM, Camacho JM, Alcayde A. Advances in solar energy towards efficient and sustainable energy. Sustainability. mdpi.com
31. Parida B, Singh A, Kalathil Soopy AK, Sangaraju S, Sundaray M, Mishra S, *et al*. Recent developments in upscalable printing techniques for perovskite solar cells. Advanced Science. 2022;9(14):2200308. wiley.com
32. Pawlak-Jakubowska A. Retractable roof module with photovoltaic panel as small solar power plant. Energy and Buildings. sciencedirect.com
33. Pérez-Valcárcel J, Aragón J, Muñiz S, Freire-Tellado M, Mosquera E. Transportable temporary homes with folding roof. Architectural Engineering and Design Management. 2024;20(2):337-357. [HTML]
34. Popovich ND, Rajagopal D, Tasar E, Phadke A. Economic, environmental and grid-resilience benefits of converting diesel trains to battery-electric. Nature Energy. nature.com
35. Rathore N, Panwar NL, Yettou F, Gama A. A comprehensive review of different types of solar photovoltaic cells and their applications. International Journal of Ambient Energy. 2021;42(10):1200-1217. [HTML]
36. Ryelandt O, Raskin JP. Sustainability assessment and perspectives for battery storage in a solar home system in Cameroon. dial.uclouvain.be. uclouvain.be
37. Sproewitz T, Banik U, Grundmann JT, Haack F, Hillebrandt M, Martens H, *et al*. Concept for a Gossamer solar power array using thin-film photovoltaics. CEAS Space Journal. 2020;12:125-135. springer.com
38. Tawalbeh M, Al-Othman A, Kafiah F, Abdelsalam E, Almomani F, Alkasrawi M. Environmental impacts of solar photovoltaic systems: A critical review of recent progress and future outlook. Science of The Total Environment. 2021;759:143528. academia.edu
39. Verlinden PJ. Future challenges for photovoltaic manufacturing at the terawatt level. Journal of Renewable and Sustainable Energy. qualenergia.it
40. Victoria M, Haegel N, Peters IM, Sinton R, Jäger-Waldau A, del Canizo C, *et al*. Solar photovoltaics is ready to power a sustainable future. Joule. 2021;5(5):1041-1056. cell.com
41. Zhang T, Feng Y, Wu X, Pan Y, Zhang Z, Yuan Y. A High-Efficiency, Portable, Solar-Powered Cooling System Based on a Foldable-Flower Mechanism and Wireless Power Transfer Technology for Vehicle Cabins. Energy Technology. 2020;8(6):2000028. researchgate.net
42. Zhang WW, Qi H, Ji YK, He MJ, Ren YT, Li Y. Boosting photoelectric performance of thin film GaAs solar cell based on multi-objective optimization for solar energy utilization. Solar Energy. researchgate.net
43. Zhang W, Zhu W, Zhang S. Deployment dynamics for a flexible solar array composed of composite-laminated plates. Journal of Aerospace Engineering. [HTML]
44. Zhong Q, Tong D. Spatial layout optimization for solar photovoltaic (PV) panel installation. Renewable Energy. [HTML]