Application of solar energy for traffic light system in developing countries

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Key Messages

- Recent global trends in renewable energy deployment create opportunities for application of solar technology in developing countries.
- Advances in solar photovoltaics (PV) technology coupled with decentralized feasibility promise a high potential for application in traffic light systems.
- Urging technological innovations in power storage and system designs are emphasized to be the key for wide application of solar energy.
- Governments in developing countries should initiate such projects by implementing policies for application in certain areas, as well as incentive policies on ecological labeling, and preferential interest rates for investment loans on solar energy.

Introduction

In developing countries, traffic lights and street lighting systems consume electric power generated from fossil fuels which creates burdens on air pollution as well as human health. Street lighting accounts for 15 – 40% of the total electricity consumed by municipalities in standard cities worldwide.[1,2] The power supply is in the form of a centralized system which can create system errors, difficulties in fixation, high cost of installation, electrical accidents in extreme climate conditions, and unavailability in remote or inaccessible areas.

Street lighting and traffic light systems based on solar photovoltaics (PV) are promoted, which are smart and more sustainable alternatives to overcome the aforementioned problems. Installation and maintenance costs of solar power streetlights are respectively 25% and 60% lower than those of conventional grid systems.[3] In addition, the global average price of solar photovoltaic (PV) modules reduced dramatically counting for $0.38 per Watt in 2019 instead of 106.09$ per Watt in 1976.[4] The current cost of solar PV is continuing to increase its feasibility for application in developing countries. Moreover, solar PV is the ideal technology for increasing light visibility in remote communities with intermittent power supply or coverage.[5] There are applicable modes of solar traffic lights for certain locations and climate conditions (i.e. mono solar and hybrid lights) which can be added to available systems and are suited to utilizing other natural resources such as wind. This technology is aligned with the UN sustainable development goals (SDGs) 7 – affordable and clean energy, 11 – sustainable cities and communities, 13 – climate action, and 9 – industry, innovation, and infrastructure.

This policy brief explores the potential application of solar photovoltaic (PV) for traffic light systems using SWOT analysis, literature reviews combined with in-depth interviews with a wide range of expert stakeholders such as solar PV manufacturers, power suppliers, solar project developers and academics.

Current situation

Traffic lights are signaling devices placed at road intersections, pedestrian crossings and other locations to support traffic control.[2] High-intensity discharge lamps include high-pressure sodium, metal halide lamps with quartz arc tubes, metal halide lamps with ceramic arc tubes, low pressure sodium lamps and high pressure mercury lamps commonly used in street lighting.[2] In developing countries like Vietnam, traffic lights use old bulbs which show obvious weaknesses, such as short life, small area of lighting, insufficient light intensity, damaging easily and vast energy consumption. Solar traffic lights are rarely used in developing country contexts.

Currently, the trend of using renewable energy like solar energy is being encouraged globally. This is a clean, unlimited and decentralized energy source. It can be used not only in urban areas, but also in remote areas with complex terrain. Besides, moving away from fossil fuels is how investors and project managers in developing countries seek to reduce their carbon footprint. Solar traffic lights are a low-carbon development investment and can be used as a tool for climate action.[6,7] The recent COP 26 in Glasgow, UK showed the efforts and determination of many countries around the world to effectively decarbonize to align with the Paris Agreement. There was consensus amongst the experts consulted that the potential of this technology supported shifting away from traditional fossil fuel-based energy sources towards solar energy.

Technology description

Solar traffic lights consist of four main parts: The solar panel, which is a key part which converts solar energy into electricity that the lamps can use, the lighting/signaling facility, a rechargeable battery and a traffic light support arm (pole).[8] Currently, LED lamps are being widely used to replace conventional incandescent filament lamps in traffic light system as they provide lower cost of energy, maintenance, and operations.[2] The examples of specifications of solar traffic light are described below.[9]

Table 1. Specifications of solar traffic lights and solar streetlights

Parameter	Solar traffic lights	Solar streetlights
Cost (USD/ equipment)	15,20 – 781,59	20,19 – 151,98
Capacity	0,6 - 75W	20W - 180W
Solar panel	4V 0,5W - 18V 60W	9v 7w - 18v 180w
LED	2835 LED 132PCS 1800K	520pcs SMD5730
Power storage	Lead-acid -12v 60AH	Lithium-Ion 6.4V 4AH - Lithium-ion 7.4V 20AH
Charging time	6 - 8 hours	6 - 8 hours
Lighting time	5 days	12 - 36 hours
The life	50.000 – 100.000 hours	30.000 - 100.000 hours

Strengths of the technology

The application of a solar traffic light shows advantages for the environment, economy and society. Firstly, the energy source contributes to reducing global emissions as it does not cause greenhouse gas (GHG) emissions, toxic fumes or generate liquid or solid waste products.[7]

Secondly, the cost for installation and operation of solar traffic lights is lower than that of conventional models in many ways. The installation and maintenance cost can be reduced by 25 - 60% with a decentralized system with no transmission line and low operating costs.[3] Further, the integration of LED technology makes the system more feasible in developing countries as it is far more cost-effective than legacy systems. The adoption of solar LED streetlights by can reduce electricity consumption by 60%.[2] In fact, the energy consumption for LED traffic signals can be around 8 - 12W bright and 5 - 7W dim, compared to 50W brightness, and 25W dimming for conventional incandescent signals. This significantly decreases energy consumption and reduces the maintenance requirements without reducing the performance of the lighting system.[2]

Solar PV is the ideal technology for improving infrastructure by increasing light visibility in remote communities with intermittent power supply or coverage. This improves utilities, connects communities, and supports trade between regions, thus improving social life and economic development for local communities.[10–13]

Limitations of the technology

There are some constraints to the widespread application of solar PV technologies including availability, finance, and regulations. Photovoltaic panels can convert sunlight into other forms of energy which is an uncontrollable source and depends on climate and geographic conditions. For this reason, they need an energy storage system to get uninterrupted power supply at other times to ensure continuous support for public traffic and transportation.[14] However, this doubles installation costs and requires suitable designs for utilities such as traffic light poles.10 Although the market price of PV modules has decreased significantly during the last decade, they are still quite expensive for developing countries.[15] Investors and users are still concerned about the price for waste treatment at the end of the panels' life cycle.[10–13,16–20] In addition, lack of consistent policy signals and gaps in renewable energy regulations create uncertainty in markets.[21] Lastly, the lack of standard technical criteria for solar PV applications to instruments, including traffic lights, leads to the inconsistent quality of commercial products.[21]

Case studies

Solar traffic lights have demonstrated their effectiveness in several countries with many benefits and reducing cost.[22] Solar LED lighting technologies proved suitable for highway green rest areas at Lushan West Sea in terms of low energy consumption, green and health, and safety and reliability.[23] The electricity savings reached 248.7 × 103 kWh counting for about $2,900 per year. The energy saving equals the reduction of 99.5-ton standard coal and 248-ton CO_2, 7.5-ton SO_2, 3.7-tons NO_x, and 67.6-ton smoke.[23] These are key examples of technology applications and promise the success of solar traffic light systems globally.

To evaluate solar lights or traditional lights on cost-effectiveness, it is necessary to consider the cost of the lights, the costs incurred during construction, and during installation of the project. The efficiency and long-term life of the project must also be considered. A case study in Vietnam is shown in Annex 3, the initial installation cost of solar lights is 28% cheaper, and the installation and operating costs of solar lights for 10 years are also 38% cheaper than conventional electric lights.[24]

Opportunities

The adoption of solar technology provides business and employment opportunities for local communities. Global employment growth in this sector accounts for a total of 4 million jobs.[25] Within this, China commanded a 39% share of renewable energy jobs worldwide in 2020, followed by Brazil, India, the United States, and members of the European Union.[25] Many other countries are also creating jobs in this sector. Among them are Vietnam and Malaysia, who are key solar PV exporters, and Indonesia and Colombia, which have large agricultural supply chains for biofuels.[25] Tesla and Panasonic are constructing a large solar panel manufacturing plant in Buffalo, New York.[26]

Government and non-governmental organizations create opportunities for this type of energy to grow through income tax exemptions, and funding for individuals and companies to invest in solar energy.[27] For example, Malaysia allows electric power generation from renewable sources and acquires it at a higher fee,[14] and The Indian government has provided 30% of capital subsidy for all solar power projects under the Jawaharlal Nehru Mission Scheme.[28] This support contributes to the expansion of technology application and development. Solar energy technologies are developing quickly and the competition in the technology leads to improved efficiency and cost reduction.[29,30] This creates an opportunity for a large coverage capacity of the technology and shortened payback period.

Threats

The application of solar traffic lights may pose potential risks for humans when it does not seriously consider a number of factors. Firstly, if position and location of installation are not carefully considered, this may cause insufficient lighting for traffic, waste investment, and increase risk of traffic accidents.[10,11] In fact, solar panels only generate electricity in sunny periods; consequently, the efficiency of solar traffic-light systems is highly dependent on weather, climate, and geographic conditions.

Additionally, the disposal of used solar panels in an unsuitable manner can pose threats to human health because they contain unsafe components such as sulphuric acid, hydrogen fluoride, hydrochloric acid, nitric acid, 1,1,1-trichloroethane, and acetone.[31] In developing countries like China and India, the burning of e-waste from solar panel systems to reclaim copper wire for resale has produced toxic fumes that can cause cancer and birth deformity when inhaled.[32] It is approximated that per quadrillion joules of energy produced, 11 to 21 deaths have been identified in conjunction with the solar energy health threats.[32] There is growing concern over the risk of PV waste at the end of their lifetime, which is an estimated stock of 250,000 tons in 2016.[33] Therefore, it is necessary to be prepared in terms of technology and investment in the field of recycling and waste treatment of solar power.

Scenarios

Experts revealed that in urban areas, solar traffic light systems can be used far from centralized lines, which makes this method of generating electricity simply necessary in remote areas, such as railway roads, engineering networks, national parks.[34] These systems can also be constructed on highways, or highway rest areas.[23] In rural, remote or island areas with no grid power or higher levels of power shortage, the use of solar traffic lights is a smart and effective solution to improve transport infrastructure and save costs. Solar traffic lights regions will promote security, economic and social development, both for rural and urban regions.[35]

Solar PV application for traffic light systems will not only play a role in lighting, but can also provide video surveillance. Thus, it can provide both increased light and safety in the absence of communication and a centralized power supply.[36] Solar traffic lights should be designed with storage facilities such as lead acid batteries and for power supply in the absence of sunlight.[37] In addition, hybrid systems between solar and wind energy have also demonstrated their efficient utilization of natural energy sources.[38] This is a promising model amid a current global energy crisis with growing concerns over environmental pollution. In any case, current electricity storage technology does not meet the demand, the suggested hybrid model should be grid electricity and solar energy for traffic light systems.[31]

Recommendations

Solar traffic lights need power storage systems to ensure power supply in periods of sunlight absence. This technology requires further research to improve the quality and the storage capacity of the battery as well as increase its lifespan. The design of the system also needs to be considered to ensure insulation and ventilation for the battery compartment, thereby contributing to the effectiveness of the storage system. In addition, related technologies such as cleaning and monitoring technologies remain for further research to improve the efficiency of the system.

Currently, there is no standard for solar panels, therefore, many different quality panels have appeared on the market. To ensure the uniform quality of commercial panels, it is necessary to identify specifications for solar panels for different contexts. Additionally, pilot projects on solar traffic light systems should be implemented to obtain the necessary parameters in terms of technical considerations, cost, and operation to contribute suitable and realistic policy interventions.[16]

The performance of solar traffic lights depends on lighting intensity; therefore, in order to increase the efficiency of the system, it is necessary to identify a solar radiation map as a basis for determining the appropriate area for technology application.[11] To apply solar energy, a long-term strategy for renewable energy in traffic light systems, as well as incentives and preferential policies for investors (e.g., ecological labeling, the preferential interest rate for investment loans), and creating conditions for the development of highly qualified human resources in this field needs to be considered. At the same time, the government also needs to have mandatory policies for application in certain areas, such as eco-industrial zones, newly formed residential areas and public areas, to improve the landscape.[10]

Most developing countries are not able to build their own solar streetlight infrastructure due to challenges in technology and innovation. The technology can improve industrialization in developing countries, especially improving infrastructure, thereby improving people's quality of life. Therefore, technology transfer from developed countries is very urgent. Consequently, policies to promote relations, cooperation, and technological exchange should be figured for streamlined implementation.

References

1. Subramani C, Surya S, Gowtham J, Chari R, Srinivasan S, Siddharth JP, et al. Energy efficiency and pay-back calculation on street lighting systems. AIP Conf Proc. 2019 Jun 21;2112(1):020082.
2. Green Public Procurement - Street Lighting and Traffic Lights Technical Background Report. [Internet]. European Commission, DG Environment.; 2011 [cited 2021 Dec 15]. Available from: https://ec.europa.eu/environment/gpp/pdf/tbr/street_lighting_tbr.pdf
3. Sustainable urban infrastructure for all: Lessons on solar-powered street lights from Kampala and Jinja, Uganda [Internet]. [cited 2021 Dec 15]. Available from: https://www.researchgate.net/publication/332395708_Sustainable_urban_infrastructure_for_all_Lessons_on_solar-powered_street_lights_from_Kampala_and_Jinja_Uganda
4. Solar PV module prices [Internet]. Solar PV module prices. 2019. Available from: https://ourworldindata.org/grapher/solar-pv-prices
5. Kannan N, Vakeesan D. Solar energy for future world: - A review. Renew Sustain Energy Rev. 2016;62:1092–105.
6. Renewable Energy and Energy Efficiency in Developing Countries: Contributions to Reducing Global Emissions. United Nations Environment Programme.; 2017.
7. Tsoutsos T, Frantzeskaki N, Gekas V. Environmental impacts from the solar energy technologies. Energy Policy. 2005;33(3):289–96.
8. de Oliveira F, Fernandes L, da Fonseca A, Pinto F, de Alencar D. Proposed Use of Photovoltaic Energy in a Traffic Light System. Int J Innov Educ Res [Internet]. [cited 2021 Dec 15]; Available from: https://www.ijier.net/ijier/article/view/1981
9. GIVASOLAR - Công ty điện năng lượng mặt trời SỐ #1 Việt Nam [Internet]. [cited 2021 Dec 15]. Available from: https://givasolar.com/
10. Nguyễn Mộc Đức. Personal Interview. 2021.
11. Huỳnh Thị Minh Thư. Personal Interview. 2021.
12. Huỳnh Tấn Đạt. Personal Interview. 2021.
13. Nguyễn Viết Kiệt. Personal Interview. 2021.
14. Semadeni M. Energy storage as an essential part of sustainable energy systems [Internet]. CEPE Working Paper; 2003 [cited 2021 Dec 15]. Available from: https://www.researchgate.net/publication/46452647_Energy_storage_as_an_essential_part_of_sustainable_energy_systems
15. Technology and Innovation Report 2021. United Nations; 2021.
16. Nguyễn Công Huân. Personal Interview. 2021.
17. Nguyễn Phương Lâm. Personal Interview. 2021.

18. Nguyễn Tấn Khải. Personal Interview. 2021.
19. Nguyễn Trung. Personal Interview. 2021.
20. Phùng Quang Giang. Personal Interview. 2021.
21. Cox S, Walters T, Esterly S, Booth S. Solar power: policy overview and good practices [Internet]. Clean Energy Solutions Center; 2015 [cited 2021 Dec 16]. Available from: https://www.nrel.gov/docs/fy15osti/64178.pdf
22. Solar Generation 6: Solar Photovoltaic Electricity Empowering the world [Internet]. European Photovoltaic Industry Association; 2011 [cited 2021 Dec 16]. Available from: http://pvtrin.eu/assets/media/PDF/Publications/Other%20Publications/36.SolarGeneration6__2011.pdf
23. Qin X, Wei Q, Wang L, Shen Y. Solar Lighting Technologies for Highway Green Rest Areas in China: Energy Saving Economic and Environmental Evaluation. Int J Photoenergy. 2015 Aug 4;2015:e926235.
24. So sánh hiệu quả chiếu sáng giữa đèn NLMT và đèn dùng điện lưới - POSO [Internet]. POSO VIỆT NAM. 2021 [cited 2021 Dec 16]. Available from: https://poso.com.vn/so-sanh-hieu-qua-chieu-sang-giua-den-nang-luong-mat-troi-va-den-dung-dien-luoi/
25. Energy transition: Renewable energy jobs have reached 12 million globally [Internet]. International Labour Organization. 2021 [cited 2021 Dec 16]. Available from: https://www.ilo.org/global/about-the-ilo/newsroom/news/WCMS_823759/lang--en/index.htm.
26. Pyper J. Panasonic Ramps Up Solar Cell Production as Tesla Starts Making Solar Roofs at Gigafactory 2 [Internet]. Greentech Media. 2018 [cited 2021 Dec 16]. Available from: https://www.greentechmedia.com/articles/read/panasonic-ramps-up-solar-cell-production-at-teslas-buffalo-gigafactory
27. Pablo-Romero M. Solar Energy: Incentives to Promote PV in EU27. AIMS Energy. 1:28–47.
28. Guangul F, Chala G. Solar Energy as Renewable Energy Source: SWOT Analysis. In 2019. p. 1–5.
29. Diamandis P. Solar Energy Revolution: A Massive Opportunity [Internet]. Forbes. 2014 [cited 2021 Dec 16]. Available from: https://www.forbes.com/sites/peterdiamandis/2014/09/02/solar-energy-revolution-a-massive-opportunity/?sh=6738aac16c90
30. Kabir E, Kumar P, Kumar S, Adelodun A, Kim K. Solar energy: Potential and future prospects. Renew Sustain Energy Rev. 2018;82:894–900.
31. Nkuissi H, Konan F, Hartiti B, Ndjaka J. Toxic Materials Used in Thin Film Photovoltaics and Their Impacts on Environment. Reliab Ecol Asp Photovolt Modul [Internet]. 2020 [cited 2021 Dec 16]; Available from: https://www.intechopen.com/chapters/68288
32. Ferronato N, Torretta V. Waste Mismanagement in Developing Countries: A Review of Global Issues. Int J Environ Res Public Health. 2019 Jan;16(6):1060.
33. End-of-life management: Solar Photovoltaic Panels [Internet]. International Renewable Energy Agency; 2016 [cited 2021 Dec 16]. Available from: https://www.irena.org/publications/2016/Jun/End-of-life-management-Solar-Photovoltaic-Panels
34. Subbotin A, Larina V, Salmina V, Arzumanyan A. Application of solar energy in various construction industries. E3S Web Conf. 2020 Jan 1;164:13004.
35. Ciriminna R, Pagliaro M, Meneguzzo F, Pecoraino M. Solar energy for Sicily's remote islands: On the route from fossil to renewable energy. Int J Sustain Built Environ. 2016;5(1):132–40.
36. Ansari RA. Concept of Smart Solar Highways Light. Int J Eng Res Technol [Internet]. 2018 Apr 24 [cited 2021 Dec 16];5(10). Available from: https://www.ijert.org/research/concept-of-smart-solar-highways-light-IJERTCONV5IS10044.pdf, https://www.ijert.org/concept-of-smart-solar-highways-light
37. Moghbelli H, Ellithy K, Eslami Z, Vartanian R, Wannous D, Ghamrawy A, et al. Investigation of Solar Energy Applications with Design and Implementation of Photovoltaic Traffic Light Signal System for Qatar. Renew Energy Power Qual J. 2009 Apr 1;1.
38. Wadi M, Shobole A, Tur M, Baysal M. Smart hybrid wind-solar street lighting system fuzzy based approach: Case study Istanbul-Turkey. In 2018 [cited 2021 Dec 16]. Available from: https://www.researchgate.net/publication/326363273_Smart_hybrid_wind-solar_street_lighting_system_fuzzy_based_approach_Case_study_Istanbul-Turkey

Annex

ANNEX 1: Consulted experts

Super Script	Name of Experts	Institution	Position	Interview date	Country
1	Nguyễn Mộc Đức (Mr)	Green power company	Manager	19/11/2021	Viet Nam
2	Huỳnh Thị Minh Thư (Dr).	Van Lang University	Lecturer	17/11/2021	Viet Nam
3	Huỳnh Tấn Đạt (Mr)	Hoang Lien Son Construction Company Limited	Manager	22/11/2021	Viet Nam
4	Nguyễn Viết Kiệt (Mr)	Genergy company	Head of Technical department	24/11/2021	Viet Nam
5	Nguyễn Công Huân (Mr)	Saigon Technology University	Lecturer	2/12/2021	Viet Nam
6	Nguyễn Phương Lâm (Mr)	Long Hau Hau industrial zone Long Hau Joint Stock Company	Director, System Management - Human Resources Administration	1/12/2021	Vietnam
7	Nguyễn Tấn Khải (Mr)	Gotecland company	Project manager	24/11/2021	Viet Nam
8	Nguyễn Trung (Mr).	Hanwha Energy	Technical manager	24/11/2021	Viet Nam
9	Phùng Quang Giang (Mr)	South telecommunication & software JSC.	Head of Technical department	20/11/2021	Viet Nam
10	Erik Velasco (Dr)	Molina Center for Energy and the Environment	Research scientist	26/11/2021	Mexico
11	Ronald. M. Galindo (Dr)	Cebu Technological University	Dean, College of Engineering	25/11/2021	Philippines
12	Soheil Rastan (Dr)	Statistics Canada and UN	Senior R&D officer	26/11/2021	Canada
13	Wilen Melsedec Narvios (Dr)	Cebu Technological University	Chair, Electrical Engineering	29/11/2021	Philippines

ANNEX 2: Methodology

Expert consultation

For this policy brief, 13 experts from a variety of backgrounds including electricity, solar technology, renewable energy were consulted through semi-structured interviews. The meetings were set up virtually; interviews notes were transcribed, and some sessions were recorded.

SWOT analysis

A SWOT analysis is designed to look at the strengths and weaknesses of solar technology then to analyze opportunities and threads of technological application. Based on the results, implied policies were recommended.

ANNEX 3: Cost comparison between fossil fuel energy and solar energy

Type of costs	**Traffic Lights using fossil fuels energy AC 220V – 60W**				**Traffic Lights using Sokoyo – LUMO 60W**			
	Quantity		**Unit Price**	**Total**	**Quantity**		**Unit Price**	**Total**
One off cost (Installed cost)								
Lights	92	item	88,75	**8.165**	92	item	398,57	**36.668,44**
Control Cabinet (2 items) & MCB	**1.132**							
Lamp posts and installed fee	92	item	291,52	**26.819,84**	92	item	289,06	**26.593,52**
Fee of underground cables and installation	**34.155,71**				0			
Fee of underground cable pipe construction	2000	m	8,14	**16.280**				
Earth conductor jacks	**1.356,92**							
Installed cost	**(USD)**				**(USD)**			
Initial installation cost of solar lights is lower than AC	**28%**							
Operation and Maintenance in 10 years								
Electricity Bill	[(60W x 12H/day x 365 days x 10 years x 92 lights)/1000] x 0,075USD/KW			**18.133,200**	0			
System Operation Cost	3650	times	2,50	**9.125**				
Lights Maintenance	92	light	198,02	**18.217,84**	24	time	29,58	**709,92**
Storage battery Replacement	0				92	light	199,28	**18.333,75**
Total cost in 10 years	**(USD)**				**(USD)**			
Installation and operating costs of solar lights for 10 years are lower than AC lights **38%**								

The cost comparison table is based on the construction and installation project of a lighting system for a 1km-long urban streetlight in Ho Chi Minh City. Ho Chi Minh City with 2 lanes in opposite directions, each lane is 5.5m wide, the cost of using for 10 years. Unit: USD. (The data table is for reference only).[24]