

# Utilizing solar power to improve the efficiency of road lighting systems

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## KEYWORDS

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## ABSTRACT

The road lighting system is an important technical infrastructure that ensures safety and security. However, using traditional light sources such as High-Pressure Sodium (HPS) lamps has revealed several limitations in terms of energy efficiency, operational costs, and greenhouse gas emissions, thereby impacting on the environment. This paper focuses on the application of solar-powered LED lighting systems (PV-LED) as a sustainable and efficient alternative for both urban areas and remote regions without access to the electrical grid. The study shows that over a 5-year lifecycle, a 50W PV-LED system can save more than 600 kWh of electricity compared to grid-powered 50W LED lighting. Moreover, PV-LED systems substantially cut greenhouse gas emissions, with total lifecycle emissions reduced by approximately 45% compared to conventional grid-powered LED lighting. Obviously, PV-LED lighting offers both economic and environmental benefits, contributing to the development of sustainable cities.

## 1. Introduction

Public lighting systems are an important component of urban infrastructure, playing an essential role in ensuring traffic safety, preventing crime, and enhancing the city's visual identity [1]. However, current urban lighting systems are facing significant challenges that require a transition toward more sustainable approaches.

Firstly, there is the issue of power consumption and the financial burden on municipal budgets. Traditional lighting systems typically rely on High-Pressure Sodium (HPS) lamps, which have high power consumption, commonly ranging from 150 W to 250 W per lamp [2]. The annual costs of electricity and maintenance for these systems represent a significant financial burden for city authorities [3]. In addition, HPS lamps are highly dependent on voltage; when the voltage is insufficient, they may fail to illuminate properly and only emit a dim reddish glow. In contrast, LED lamps can still operate under low-voltage conditions. Their luminous efficacy can reach up to 150 lm/W. Moreover, LED fixtures are equipped with optical lenses that allow for controlled, narrow beam angles (approximately 110°), resulting in more focused and better-directed lighting. Consequently, more than 85% of the emitted light is effectively utilized to illuminate the road surface [2].

Secondly, there is energy waste due to the lack of intelligent control. In urban settings, the lighting systems continue operating at full brightness throughout the night, even during these periods of extremely low traffic volume, leading to unnecessary energy consumption [4]. To save energy, some areas activated on-off lighting patterns, creating a “zebra” effect resulting in visual fatigue [5].

Thirdly, there are impacts on the environment and sustainable development goals. Dependence on fossil fuel-based power grids for

street lighting is a major source of greenhouse gas emissions, causing global warming [6].

Fourth, there are infrastructure barriers and high investment costs. In new urban areas or suburban regions, expanding the traditional power grid requires expensive installation of copper cables and substations. Although solar LED technology can help address these challenges, the high initial investment cost – including photovoltaic panels, storage batteries, and controllers – remains a major obstacle to large-scale deployment.

Comparative analysis results indicate that although the initial investment cost of solar-powered LED lighting systems (PV LED) is higher than or comparable to that of grid-powered LED systems, over a five-year lifecycle, the total cost of PV LED systems is significantly lower due to the absence of electricity expenses [7].

Therefore, researching and implementing solar-powered LED lighting systems integrated with smart control technology is an urgent necessity.

## 2. Survey of lighting conditions on selected streets in Hanoi

The research team conducted illuminance measurements on Vê Hồ Street and Láng Street in Hà Nội. The measurements were carried out from 6:00 PM to 7:00 PM in December 2026.

Measurements were taken using a UNI-T UT381A lux meter over a period of one week. The measurement positions were located on the road surface, perpendicular to the lighting direction of the luminaires, and at points midway between two consecutive lamps.

On Vê Hồ Street, located along West Lake, the lighting poles have a height of 7 meters with a spacing of 30 meters, using 150 W HPS. The carriageway includes two lanes, HPS lamps installed on one side.

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On Láng Street, the lamp poles also have a height of 7 meters, with a spacing of 35 meters, and use 100 W LED. The carriageway includes three lanes, lighting system installed on one side from 1<sup>st</sup> to 9<sup>th</sup> of measurement position, and from 10<sup>th</sup> to 28<sup>th</sup> of measurement position, LED lamps installed on opposite sides.

The pavement of both streets made of aged asphalt concrete. Assuming a surface reflectance coefficient of 0.4, the luminance (L)

can be calculated from the illuminance (E) according the following formula [5]:

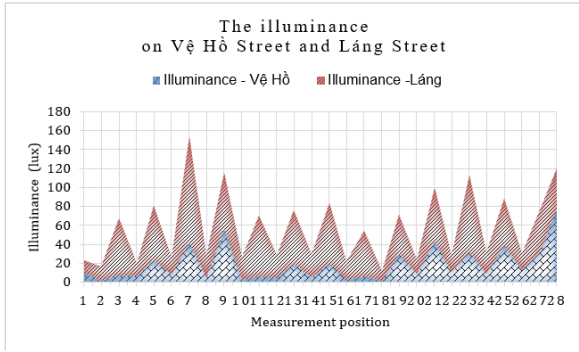
$$L = \frac{\rho E}{\pi} (1-1)$$

The measured illuminance values and the corresponding luminance are presented in Table 1 as follows.

The illuminance of HPS lamps on Vê Hồ Street and Láng Street is shown in Figure 1 below.

**Table 1.** Illuminance and luminance on Vê Hồ Street and Láng Street in Hanoi.

Measurement position	Illuminance –Vê Hồ street (lux)	Luminance Vê Hồ street (cd/m <sup>2</sup> )	Illuminance Láng street (lux)	Luminance Láng street (cd/m <sup>2</sup> )
1	9.88	1.3	13.1	1.67
2	1.93	0.2	14.77	1.88
3	7.61	1.0	59.57	7.59
4	6.4	0.8	14.09	1.79
5	23.38	3.0	57.52	7.33
6	8.58	1.1	18.38	2.34
7	42.09	5.4	110.9	14.13
8	5.7	0.7	22.74	2.90
9	56.47	7.2	58.81	7.49
10	2.81	0.4	23.74	3.02
11	6.32	0.8	63.46	8.08
12	4.78	0.6	23.58	3.00
13	19.38	2.5	56.26	7.17
14	5.65	0.7	23.74	3.02
15	20.12	2.6	63.28	8.06
16	2.29	0.3	20.22	2.58
17	6.32	0.8	48.3	6.15
18	1.97	0.3	10.29	1.31
19	29.83	3.8	41.3	5.26
20	9.52	1.2	14.6	1.86
21	42.48	5.4	57.19	7.29
22	11.38	1.4	17.82	2.27
23	31.33	4.0	81.59	10.39
24	9.16	1.2	22.19	2.83
25	39.36	5.0	48.3	6.15
26	12.87	1.6	18.25	2.32
27	29.83	3.8	44	5.61
28	76.96	9.8	43	5.48



**Figure 1.** The illuminance on Vê Hồ Street and Láng Street.

The results show that the illuminance at the measurement points on Láng Street is higher than that on Vê Hồ Street, along West Lake. Some locations exhibit unusually high illuminance values, which can be attributed to the influence of passing vehicles or lighting from roadside shops at the time of measurement. Nevertheless, these results reflect actual field measurements and provide an overall view of real street lighting conditions.

Although LED luminaires on Láng Street are installed with a spacing of 35 m – greater than the spacing on Vê Hồ Street – the illumination level on Láng Street is higher at all measured points. On Vê Hồ Street, several measurement points have luminance values below the required standard. According to the Vietnamese National Standard TCVN 13608:2023 on artificial outdoor lighting for public works [8], the average luminance for collector roads must satisfy  $L_{ave} \geq 1.5 \text{ cd/m}^2$ .

This demonstrates that the lighting efficiency of LED luminaires is clearly superior to that of HPS lamps. It should also be noted that the power rating of LED lamps is lower than that of HPS lamps, meaning that energy consumption during operation is correspondingly lower.

If PV LED systems are used, the potential for energy savings and greenhouse gas emission reduction would be even greater.

### 3. Effectiveness of pvled in public lighting system

#### 3.1. Configuration of a PV-LED system

A 50 W LED luminaire is considered in this study. The lighting control scenario is defined as follows: the lamp operates continuously for 12 hours per day, from 6:00 PM to 6:00 AM the next morning, under the following assumed schedule:

From 6:00 PM to 10:00 PM (4 hours): 100 % power

From 10:00 PM to 12:00 AM (2 hours): 50 % power

From 12:00 AM to 6:00 AM (6 hours): 30 % power

Lithium battery capacity: PVLED uses charge controller MPPT - Maximum Power Point Tracking following the lighting control scenario above. The total daily energy consumption of a 50 W LED lamp is:

$$E = (4 \times 100 \% \times 50) + (2 \times 50 \% \times 50) + (6 \times 30 \% \times 50) = 340 \text{ Wh/day (1-2)}$$

In Northern Vietnam, due to intermittent solar conditions, a backup capacity of 2 days is selected to ensure reliable system operation

during periods of low sunlight, corresponding to a reserve factor of 2.0. Besides, to ensure system safety, a design factor of 1.25 is applied.

Therefore, the required battery capacity is:

$$340 \times 2 \times 1.25 = 850 \text{ Wh (1-3)}$$

The average solar power yield is approximately 4 kWh/kWp/day.

Solar panel capacity is:

$$850 \text{ Wh} : (4.000 \text{ Wh/kWp}) = 0.2 \text{ kWp (1-4)}$$

The area of the solar panel is:

$$(0.2 \text{ kWp} \times 2 \text{ m}^2) : 0.54 \text{ kWp} = 0.74 \text{ m}^2 \text{ (1-5)}$$

#### 3.2. Greenhouse gas (GHG) emissions of grid powered LED lighting

The average lifespan of LED lamps ranges from approximately 10,000 to 20,000 hours, operational lifespan of around 5 years [2,3]. Therefore, in this study, a 5-year lifecycle is selected to compare energy savings between PV-LED systems and grid-powered LED lighting.

For a grid-powered LED lamp, the total electricity consumption of 50 W LED in 5 years is:

$$(0.05 \text{ kW} \times 4\text{h} + 0.05 \text{ W} \times 50 \% \times 2\text{h} + 0.05 \text{ kW} \times 30 \% \times 6\text{h}) \times 365 \times 5 = 620.5 \text{ kWh (1-6)}$$

Viet Nam's grid emission factor for 2023 is 0.6592 kgCO<sub>2</sub>e/kWh [10].

The greenhouse gas (GHG) emissions during operation are:

$$620.5 \times 0.6592 = 409.03 \text{ kgCO}_2\text{e (1-7)}$$

Greenhouse gas (GHG) emissions from infrastructure construction are calculated as follows:

Power cable: 30 - 80 kgCO<sub>2</sub>e/km [11]

Distribution transformer substation: 50-100 kgCO<sub>2</sub>e range

Thus, we estimate the total greenhouse gas emissions from infrastructure construction to be 120 kgCO<sub>2</sub>e.

Total greenhouse gas emissions of grid powered LED lighting is:

$$409.03 + 120 \approx 530 \text{ kgCO}_2\text{e (1-8)}$$

#### 3.3. Greenhouse gas (GHG) emissions of PVLED lighting

According to the IEA PVPS (International Energy Agency's Photovoltaic Systems Program) and NREL (National Renewable Energy Laboratory), the greenhouse gas emissions from solar panels are approximately 900 kgCO<sub>2</sub>e/kWp.

According to formula (1-4), the solar power of a 50 W PVLED is 0.2 kWp, so the greenhouse gas emissions of a 50 W PVLED solar panel are:

$$0.2 \times 900 = 180 \text{ kgCO}_2\text{e (1-9)}$$

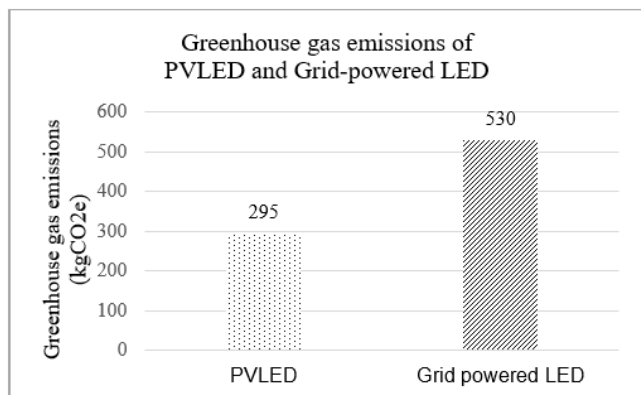
According to IVL Swedish Environmental Research Institute [12], the GHG emissions of Lithium batteries are 100–150 kgCO<sub>2</sub>e/kWh, end-of-life treatment for batteries is about 30 kgCO<sub>2</sub>e.

Thus, the GHG emissions of Lithium batteries for 50W PVLED (battery capacity is 850 Wh) lamps are:

$$0.85 \times 100 = 85 \text{ kgCO}_2\text{e (1-10)}$$

Total greenhouse gas emissions of PVLED lighting is:

$$180 + 30 + 85 = 295 \text{ kgCO}_2\text{e (1-11)}$$



**Figure 2.** Greenhouse gas emissions of 50 W PVLED and Grid-powered 50W LED.

Greenhouse gas emissions of PVLED and Grid-powered LED as shown in Figure 2. Thus, when comparing a 50 W PV-LED system with a grid-powered LED of the same capacity, greenhouse gas emissions are reduced from 530 kgCO<sub>2</sub>e to 295 kgCO<sub>2</sub>e, corresponding to a reduction of approximately 45 %.

#### 4. Conclusion

From an economic perspective, although the initial investment cost of PV-LED systems (including solar panels, energy storage, and control units) is higher than that of grid-powered lighting, the total cost over a 5-year operational lifecycle is significantly lower. The complete elimination of monthly electricity expenses, along with reduced costs for underground cabling and distribution transformer substations, makes PV-LED systems a financially attractive option.

Specifically, the study estimates that each PV-LED unit saves more than 600 kWh over a 5-year lifecycle compared to grid-powered LED lighting. Moreover, using PVLED does not place additional demand on the power grid during peak hours and, notably, is not affected by grid failures.

Notably, when considering the full lifecycle and a 2-day backup requirement, PV-LED systems still result in significantly lower emissions compared to grid-powered LED lighting. However, the increased battery capacity is the primary factor contributing to the higher initial emissions of PV-LED systems.

Overall, PV-LED systems can reduce greenhouse gas emissions by approximately 45 % compared to conventional grid-powered LED lighting, thereby directly contributing to CO<sub>2</sub> reduction targets and climate change mitigation efforts.

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