

## Sun Charge: Transforming Solar Streetlights into EV Power Hubs

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### Abstract

The fundamental objective of this project is to harvest excess energy generated by solar-powered streetlights. It accomplishes this by installing solar panels on existing streetlights and implementing a centralized control system. Excess energy is intelligently redirected to a shared battery, which is then used to power electric vehicle (EV) charging stations. The project emphasizes sustainable energy methods, urban expansion, and transportation electrification. It has numerous benefits, including the efficient use of renewable energy, enhanced urban sustainability, cost-efficiency, and a substantial decrease in greenhouse gas emissions. Furthermore, the project is scalable, with a chance to expand the network of EV charging infrastructure, making it a crucial part of the moving forward global transition to sustainable energy solutions.

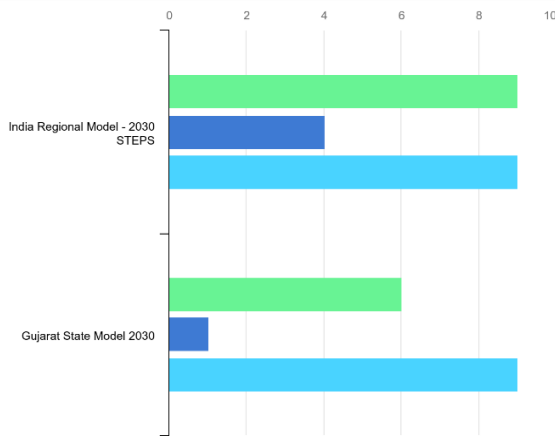
**Keywords:** Solar Retrofit; Centralized Control; Surplus Energy; EV Charging; Sustainability.

### 1. Introduction

In the modern era, sustainable energy measures are approaching a tipping point, mandating the efficient utilization of abundant solar energy. Energy is the most fundamental and comprehensive measure of all the labour that is done by humans and the environment as a whole combined [1]. India is endowed with abundant solar energy, which is capable of producing 5,000 trillion kilowatts of clean energy. Country is blessed with around 300 sunny days in a year and solar insolation of 4-7kWh per Sq. m per day. If this energy is harnessed efficiently, it can easily reduce our energy deficit scenario and that to with no carbon emission [2]. Despite major advances in solar energy usage, a substantial amount of this precious asset goes untapped, culminating in economic and ecological consequences. This investigation proposes an innovative project with the goal of addressing this urgent issue. It proposes enhancing existing lights with solar panels and integrating a central control system. The goals of the project are firmly established in the pressing need of our times: enabling sustainability, minimizing carbon emissions, and boosting energy efficiency. The main aim is to optimize the use of renewable energy sources. The key objective is to optimize the use of renewable energy sources while tackling the

challenges brought by increasing demand for energy. Within India's present energy scenery, this project shines out as a timely and essential answer (Figure 1). It not only raises sustainability but also contributes to urban expansion and transportation electrification by expressing surplus sunlight to fuelling electric vehicle (EV) charging stations. India unveiled 'National Electric Mobility Mission Plan (NEMMP) 2020' in 2013 to address the issues of National energy security, vehicular pollution and growth of domestic manufacturing capabilities. Reiterating its commitment to the Paris Agreement, the Government of India has plans to make a major shift to electric vehicles by 2030[3]. The effort illustrates the promise of a more environmentally conscious and sustainable future, with solar energy playing an essential part in India's energy mix, as we stand at the forefront of the globally migration to sustainable energy solutions. Increasing power system flexibility reduces curtailment, leading to lower operating costs and CO2 emissions, as illustrated in the bar chart. Despite the must-run status of renewables in India, states like Tamil Nadu and Karnataka experience curtailment, impacting investor confidence and overall power sector investment, particularly in solar and wind. Discussions on the must-run status and compensation

policies for curtailment are crucial for mitigating risks and attracting future investments [5].



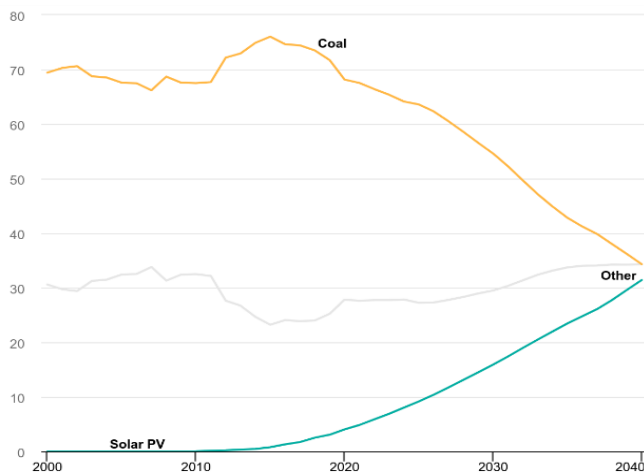
**Figure 1 Reduction in Curtailment CO2 Emissions and Operating Costs Due to Combined Flexibility Options in India and Gujarat [4]**

## 2. Literature Survey

Fares S. El-Faouri et al. [6] describe a prototype for a smart street-lighting system that uses a photovoltaic (PV) source to power an array of DC street lights. A battery is used to store extra energy from the solar panel, which can subsequently be retrieved at night or whenever sunlight is impeded by clouds or other types of shielding. A charge controller shields the battery from overcharging while additionally controlling the overall system operation. The system is also enhanced with a motion sensor circuit and a dust-cleaning loop. The final product is a smart yet effective street lighting system that may be used independently or in partnership with the rest of the grid. Wang Fei et al. [7] principally look into and evaluate the design arrives at of energy-saving solar LED illumination based on microcontrollers. The solar street lamp is made up of several sections, such as a solar panel, controller, pole, LED lamp base, and storage batteries. Microcontrollers, for instance, effectively regulate the controlling mechanism. Liew et al. [8] give a smart control system for streetlights which employs LED lamps. The system was designed to be readily incorporated into existing infrastructures. It uses wireless communication technologies, lowering the initial investment costs substantially when compared to conventional wired

systems, which demand expensive underground cabling and civil engineering work. Furthermore, the proposed solution involves environmental awareness, allowing it to intelligently modify its surroundings. This adaptability is achieved by the system's ability to learn from its environment and apply dynamic rules. Additionally, the system collects real-time data on lighting specifications, taking into account the street's immediate usage. The data gathered is used to propose practical solutions that minimize energy consumption in accordance with the specific contextual needs. Manuel Tobias Danner, et al [9] introduces an innovative solar-powered street light, emphasizing software design, highly efficient electronics (charge controller and LED driver), and an IP65 housing with a passive cooling concept. Furthermore, it presents the results of prototype testing involving 30 lamps under various climatic conditions worldwide, along with an evaluation of the system's overall performance based on data extracted from built-in dataloggers. The thesis concludes with recommendations for initiating the initial serial production and managing the supply chain. Recent advancements in lithium-ion batteries, light emitting diodes (LEDs), and photovoltaic (PV) modules have substantially reduced the cost of off-grid solar systems. Lithium-iron phosphate (LiFePO4) batteries, which are widely utilized in electric vehicles, offer exceptional features, including an extended cycle life and higher energy storage density. These characteristics make them ideal for stand-alone solar applications, particularly solar street lights. The connection between energy and achieving the Millennium Development Goals (MDGs) is widely recognized and supported by the global community [10]. The UN Millennium Project estimates that reaching one billion people by 2015 will be a significant step toward achieving the MDGs by reducing the proportion of the global population without access to basic power and who cook with traditional solid fuels. Our energy vision aims to provide about 1.5 billion people with improved access to contemporary energy, which is consistent with these objectives. The Global Network on Energy for Sustainable Development (GNESD, 2007) states that improvements in reducing poverty, health, and education depend on the supply of affordable energy.

Roughly 1.6 billion people do not have access to electricity globally; most of these people live in rural parts of developing countries in South Asia, Central America, and South America (Figure 2). The importance of energy was brought to light at the Ninth session of the Commission for Sustainable Development (CSD-9) in 2001, which stated that energy is essential to reaching sustainable development goals [11]. Manuela Franz and colleagues et al. [12] states that the main factors behind the growth of energy-efficient and environmentally friendly sources of illumination are growing worries regarding limited resources, dangerous materials, and climate change. The India Energy Outlook 2021 published by IEA states that India is gradually moving away from coal as its primary source of energy, turning more towards renewables and other alternatives. This shift is driven by factors like environmental concerns, changing energy demands, and the increasing competitiveness of renewable energy technologies [13].



**Figure 2 Changes-in-Share-of-Power-Generation-in-India-in-the-Shared-Policies-Scenario-2010-2040 [14]**

As coal demand drops, our solar streetlight retrofitting idea shines brighter. By tapping into renewable energy, we reduce reliance on fossil fuels, aligning with sustainability goals and driving a greener future. This research paper offers a summary of the global illumination market as well as the LED lamp technological advances landscape. It follows with a thorough review and comparison of various published life cycle assessment studies related to

lighting technologies [15]. This work addresses factors that influence end-user well-being, such as glare and health, as opposed to the environmental factors usually addressed in life cycle assessments. A critical analysis of these studies' assumptions and findings is presented, highlighting areas where uncertainties stay and demonstrating the need for additional analysis in forthcoming studies [16].

### 3. Proposed Solution

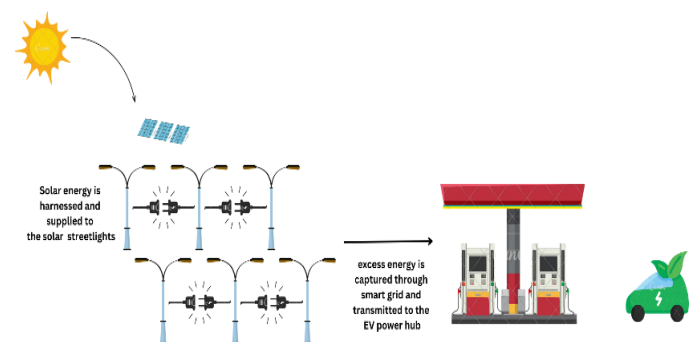
#### 3.1. Solar Energy Panel Retrofitting of Streetlights

Introducing the innovative integration of solar panels on top of streetlights, which represents a major advancement in sustainability. These panels, which are arranged strategically atop poles, collect sunlight from dawn to sunset, converting streetlights into solar energy sources. The lights are continuously powered by the electricity generated from the sunlight that has been gathered. This strategy reduces reliance on outside resources, which increases efficiency while also supporting renewable energy (Figure 3).

#### 3.2. System of Centralized Control

An Artificial Intelligence based centralized control system that acts as an energy orchestrator complements this solar infrastructure [17]. Excess power is efficiently sent to a common battery, maximizing its use for a range of applications, including street lighting, EVs, and urban growth. Our mission is to promote sustainability by reducing the grid's dependency on fossil fuels. Surplus energy's role, it'll deftly embrace, A greener future, we fervently chase.

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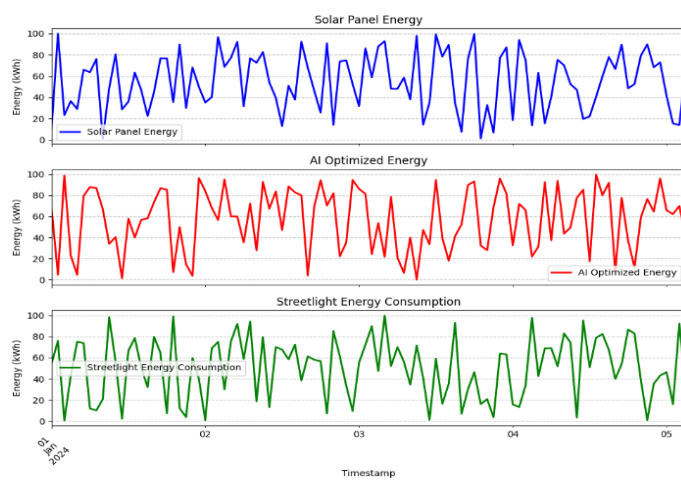


**Figure 3 Sunlight Change**

## 4. Methodology

### 4.1. Energy Management

AI algorithms become essential instruments for maximizing effectiveness in the field of energy management for solar-powered streetlights (Figure 4). These algorithms modulate the flow and storage of electricity from solar panels to streetlights dynamically by analysing weather patterns, historical data, and the present demand for energy [18]. This clever analysis guarantees a precisely calibrated balance, maximising energy use and reducing waste. AI helps to adapt energy flow under various scenarios by using its predictive skills, which supports resource- and eco-efficient metropolitan lighting infrastructure.



**Figure 4 Graph**

The graph, based on assumed real-time data, portrays fluctuations in solar panel energy, the impact of AI optimization, and streetlight consumption trends, guiding potential strategies for sustainable energy management [19].

### 4.2. Smart Grid

Artificial intelligence (AI)-driven smart grid integration transforms streetlight systems by increasing their efficiency and integrating them with the larger electrical grid. AI plays a key role in this integration because it makes it possible to analyse trends in energy supply and demand, which is essential for balancing the load on the grid. In this case, AI's capacity to control high demand times is a major advantage. Artificial intelligence (AI)

algorithms enable streetlight systems to dynamically modify energy usage based on real-time data, reducing grid stress during periods of high demand [20]. This improves overall grid stability and increases energy efficiency. Additionally, by anticipating patterns in energy consumption, AI enhances the performance of streetlight systems. Because of this foresight, lighting schedules and intensity levels can be adjusted pro-actively, reducing energy waste and operating expenses [21].

### 4.3. Autonomous Operation

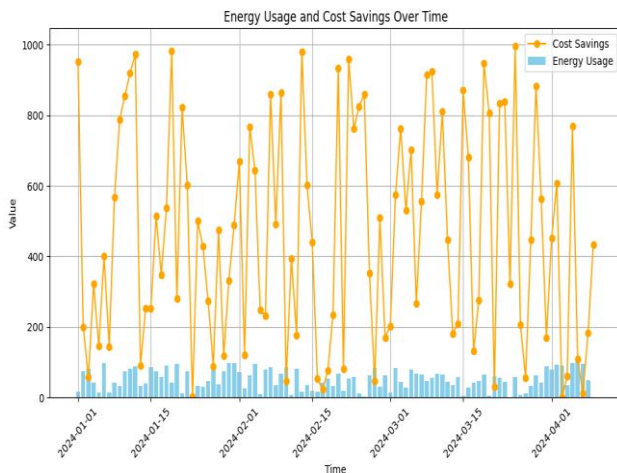
When streetlight systems are able to operate autonomously, it means that artificial intelligence (AI) algorithms are being used to determine the appropriate brightness levels without the need for human interaction [22]. To ascertain the ideal brightness for every light, these algorithms examine real-time data, including ambient light levels, weather, and pedestrian traffic patterns. For instance, the system can boost brightness to enhance safety and visibility when there is a lot of foot traffic. On the other hand, the system can lower the lights to save energy when there aren't enough pedestrians. Artificial intelligence (AI)-enabled streetlight systems can maintain optimal visibility while consuming little energy by dynamically altering brightness levels based on real-time considerations. By lowering the total energy consumption, this lowers power prices while simultaneously promoting environmental sustainability [23].

### 4.4. Data Analytics for Sustainability

Data analytics, especially when combined with artificial intelligence (AI), is essential for improving sustainability initiatives in urban settings. The examination of enormous datasets produced by streetlight systems scattered throughout cities makes this clear. Thousands of lights make up these systems, which offer a wealth of data on the state of the environment, the status of operations, and the amount of energy used. With the use of AI algorithms, this data can be used to spot patterns in energy usage, leading to more effective streetlight management. Artificial Intelligence helps lower energy expenses and consumption by anticipating peak demand times and modifying lighting plans accordingly. Furthermore, AI's capacity to assess environmental effects strengthens its contribution to the promotion



of sustainable urban behaviours [24]. The simplified graph based on assumed data contrasts streetlight energy usage depicted as bars with cost savings represented as a line, offering a straightforward comparison of both metrics across time (Figure 5).



**Figure 5 Energy Usage Graph**

#### 4.5. Predictive Maintenance

This project's implementation of AI-powered predictive maintenance guarantees the smooth running of the solar-powered streetlight system [25]. Artificial Intelligence is able to forecast any problems or breakdowns in solar panels and control systems by evaluating real-time performance data. In the end, this proactive maintenance strategy helps the project achieve its objective of continuous and sustainable street lighting by reducing downtime and improving system reliability.

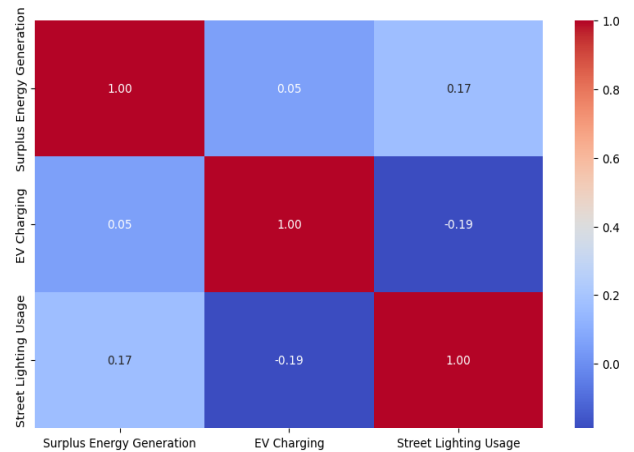
#### 4.6. Traffic and Environmental Monitoring

When streetlights are equipped with AI-powered sensors, they become dynamic urban dynamics monitors. With their skilful tracking of air quality, traffic patterns, and environmental variables, these sensors provide useful information for maximizing traffic flow and identifying pollution levels. Informed modifications, such as improving traffic signals and dynamically adjusting streetlight brightness to reflect the current conditions, are made possible by the intelligent analysis of this data. This integrated method adapts wisely to the changing needs of the city, improving urban efficiency while simultaneously promoting sustainability.

### 5. Results and Discussion

We have a chance to show the outcomes of our efforts, including our knowledge and connections, and a tale that we are eager to tell. We strive for the transformation of excess electricity. We believed to deliver our innovative solution, EV charging. Enhancements for city safety, an important victory, advancement toward sustainability, and an environmental refrain. Our ultimate objective is to make the world healthier through reductions in emissions that can reduce costs and be helpful to the world's economy in the long run. These results indicate the basic principles of our strategy, the value of surplus power, and its relatively easy resolution. The urging evolution of urban safety and long-term viability in addition to cost and emission reductions, as effectively as an environmental revolution. The expected results based on the evaluation of surplus energy generation and how it is utilized to the charging of electric automobiles (EVs) are shown in this section. The nine-day period of simulated data delivers insights into the possible effects of the recommended solution (Figure 6).

Correlation Heatmap: Surplus Energy Generation, EV Charging, and Street Lighting Usage



**Figure 6 Surplus Energy, EV Charging**

The heatmap, based on assumed data, offers insights into the interrelationships among surplus energy generation, EV charging, and street lighting usage. It suggests potential avenues for leveraging surplus energy for EV charging and potentially for street lighting. However, a more in-depth analysis and exploration of actual data may be necessary to comprehensively understand the dynamics.

## Future Use

EV charging has grown a growing trend. Global EVs will be prepared to ride in the system. Our guide is advanced technology for storage and reliability. Efficiency and progress live together. We become allies in smart grids. These grids comprise real-time data. Solar power's pride, scaling to regions. V. Shukla et al. [13] states the dominance of the automotive sector in the Indian market, a notable rise in electric vehicle (EV) exports could significantly bolster the country's economy by helping to reduce the trade deficit. The promotion and export of electric vehicles have the potential to positively impact India's economy by creating jobs, reducing the trade deficit, promoting sustainable technology, and positioning India as a key player in the global automotive industry. We acknowledge to local adaptability on a worldwide basis. Our stride is data analytics and maintenance. Improving energy forecasts, where progress will be gradual. In our pursuit of an improved sustainable, cleaner tide, the system's future is a beacon for all to see.

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