Energy Consumption Comparison of Halogen and LED Runway Lighting: Case Study at West Java International Airport

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Abstract

The increasing inefficiency and high costs of traditional halogen runway lighting systems have prompted a need for sustainable alternatives. This study investigates the performance, energy efficiency, and both economic and environmental impact of halogen versus LED runway edge lights at West Java International Airport. Utilizing the Constant Current Regulator (CCR) and Cost Benefit Analysis (CBA) methods, the research highlights the advantages of LED lighting systems, including superior energy efficiency, longer lifespan, and faster responsiveness. In addition to financial analysis, the study also evaluates sustainability impacts by estimating potential carbon emission reductions. The findings reveal that adopting LED lights could reduce annual electricity costs by up to 80.48% and decrease CO_2 emissions by approximately 30.349 metric tons per year. These results reinforce the feasibility of LED implementation not only from a financial perspective but also as a strategy for environmental sustainability. Based on these findings, the study provides actionable recommendations for airport management to upgrade to energy-efficient and eco-friendly LED lighting systems.

Keywords: LED Runway Edge Lights, Energy Efficiency, Cost Benefit Analysis (CBA), CO_2 Emission Reduction, Airport Lighting Sustainability.

Abstrak

Meningkatnya inefisiensi dan tingginya biaya sistem penerangan landasan pacu halogen tradisional telah mendorong kebutuhan akan alternatif yang berkelanjutan. Studi ini menyelidiki kinerja, efisiensi energi, dan dampak ekonomi dan lingkungan dari lampu tepi landasan pacu perbandingan halogen dan LED di Bandara Internasional Jawa Barat. Dengan memanfaatkan metode Constant Current Regulator (CCR) dan Cost Benefit Analysis (CBA), penelitian ini menyoroti keunggulan sistem penerangan LED, termasuk efisiensi energi yang unggul, masa pakai yang lebih lama, dan respons yang lebih cepat. Selain analisis finansial, studi ini juga mengevaluasi dampak keberlanjutan dengan memperkirakan potensi pengurangan emisi karbon. Temuan tersebut mengungkapkan bahwa penerapan lampu LED dapat mengurangi biaya listrik tahunan hingga 80,48% dan menurunkan emisi CO_2 sekitar 30,349

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metrik ton per tahun. Hasil ini memperkuat kelayakan penerapan LED tidak hanya dari perspektif finansial tetapi juga sebagai strategi untuk keberlanjutan lingkungan. Berdasarkan temuan ini, studi ini memberikan rekomendasi yang dapat ditindaklanjuti bagi manajemen bandara untuk meningkatkan sistem penerangan LED yang hemat energi dan ramah lingkungan.

Kata kunci: Lampu LED di Tepi Landasan Pacu, Efisiensi Energi, Analisis Biaya Manfaat (CBA), Pengurangan Emisi CO_2, Keberlanjutan Pencahayaan Bandara.

1. Introduction

Kertajati Airport, located in Majalengka Regency, encompasses Kertajati Village, Bantarjati Village, Kertasari Village, and Sukamulya Village in Kertajati District. The development of the airport is a collaborative effort between the Ministry of Transportation and the West Java Provincial Government, supported by private investors. The Ministry of Transportation oversees airside infrastructure such as runways, aprons, taxiways, and security barriers. Meanwhile, PT. BIJB, a joint venture between the West Java Provincial Government (51%) and private investors (49%), manages the land-side development, including the main passenger terminal and supporting facilities. Covering an area of 1,000 hectares with plans for expansion to 1,800 hectares, Kertajati Airport operates under the supervision of the West Java Provincial Government [1].

The efficiency and reliability of runway lighting systems are critical for ensuring safe and effective aircraft operations [2], particularly during low-visibility conditions [3]. Traditional halogen lighting systems [4], commonly used in airports worldwide [5], have increasingly been associated with high energy consumption [6], shorter lifespan, and costly maintenance requirements [7]. In response to these challenges, airports are exploring the adoption of more sustainable lighting technologies, such as LED (Light Emitting Diode) systems [8]. This study focuses on Kertajati Airport, officially known as West Java International Airport, where halogen lights are still in use for runway 14. The research aims to assess the potential benefits of transitioning to LED lighting systems, highlighting their efficiency, operational cost savings, and environmental advantages.

Previous studies on airport lighting systems have emphasized the importance of energy efficiency and operational sustainability [9]. For instance, research conducted at international airports has shown that LED systems consume significantly less power [10], reduce carbon emissions [11], and offer a longer service life compared to halogen systems [12]. However, these studies often focus on general observations without conducting detailed cost-benefit analyses specific to a particular airport's infrastructure and operational needs. Unlike prior research [13], this study employs both the Constant Current Regulator (CCR) and Cost Benefit Analysis (CBA) methodologies to provide a comprehensive evaluation of LED versus halogen runway edge lights specifically at Kertajati Airport.

This research emerges in response to the increasing global focus on sustainability and energy efficiency within the aviation sector. As one of Indonesia's newest and largest airports, Kertajati Airport holds a strategic position to lead in adopting environmentally sustainable technologies. Implementing LED lighting systems is a strategic step not only for minimizing operational and maintenance expenditures but also for aligning with international benchmarks for energy-efficient and eco-conscious airport operations. The study offers essential recommendations and analytical perspectives to guide airport authorities in adopting greener infrastructure practices, while simultaneously ensuring safety, operational efficiency, and cost-effectiveness.

At the time this study was conducted, the runway edge lighting system at West Java International Airport (Kertajati) was still entirely dependent on halogen lamps. Direct field observations and consultations with the assigned supervisor at PT Angkasa Pura II confirmed that runway 14 and its adjoining taxiways exclusively utilize halogen-based lighting, in accordance with ICAO and FAA regulations. As such, the present research does not evaluate an ongoing LED implementation, but instead serves as a rational academic simulation designed to project the technical and economic potential of a future LED transition. Through detailed analysis of energy consumption, long-term cost benefits, and operational advantages, this study aims to provide evidence-based guidance for future policy and infrastructure decisions in airport lighting modernization.

2. Research Methods

The research conducted a comprehensive review of various sources, including books, journals, and websites, to gather relevant information. Key references were sourced from the On The Job Training report produced by PT. Angkasa Pura II, which provided valuable insights into the subject matter. Additionally, the author explored both national and international journals available online to further support the findings of the study. In parallel, the researchers conducted direct observations at the research site, ensuring that the data collected was based on real-time conditions. The methodology employed in this research comprises several stages, starting with the Preliminary Study, which involves testing theories and conducting initial research to establish a foundation for the study. The next step, the Literary Method, focuses on gathering and analyzing information from various literature sources, such as books, journals, lecture notes, and other relevant materials related to runway edge lighting systems. Following this, the Field Study was carried out to identify the existing issues by collecting data through direct observation of the current conditions at the site. Lastly, the research utilized the Interview Method, where field officers were interviewed to gather additional information through a question-and-answer format. The systematic flow of this research process is depicted in the accompanying flowchart.

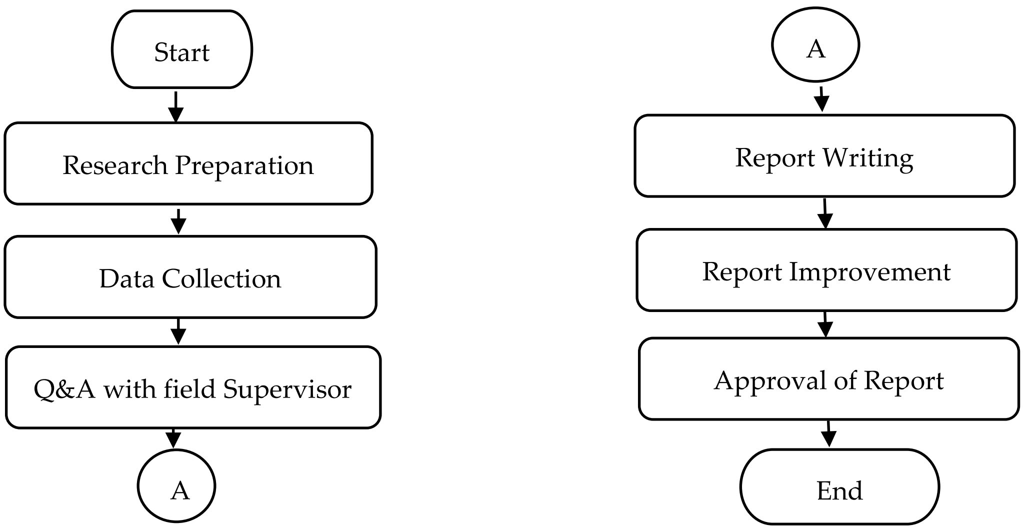


Figure 1. Data Collection Flows

The following flow diagram of this research flow is as follows:

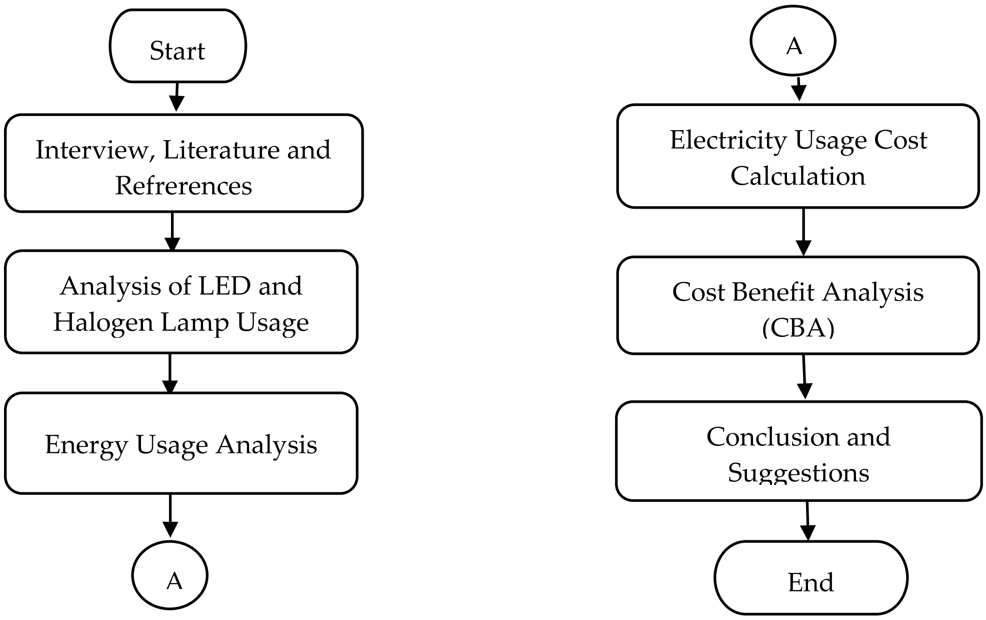


Figure 2. Research Methods Flows

This study employs a cost benefit analysis (CBA) approach to compare the costs and benefits of two types of runway edge lights: LED and Halogen. The research utilizes both primary and secondary data sources to conduct the analysis. The Constant Current Regulator (CCR) is a standard component in airfield lighting systems used to maintain a constant current (typically 6.6A) despite load variations, ensuring uniform brightness across all luminaires. CCRs play a critical role in stabilizing the electrical supply for both halogen and LED runway lighting systems [14]. Cost Benefit Analysis (CBA) is an analytical tool used to evaluate the financial feasibility of a project by comparing its total expected costs against the anticipated benefits. It is widely used in infrastructure planning to support rational decision-making [15].

2.1. Methodology: Constant Current Regulator (CCR) and Cost Benefit Analysis (CBA)

The study is conducted based on field data from the current halogen system at West Java International Airport. Since LED lights have not yet been implemented, the LED data used in this research is based on standardized technical specifications, datasheets, and unit pricing from Indonesia's e-Catalogue procurement system. The comparison between halogen and LED systems in this study is therefore hypothetical but grounded in realistic, practical data, allowing for rational cost-benefit evaluation under equivalent operational conditions.

In this study, two primary methods were employed: Constant Current Regulator (CCR) and Cost Benefit Analysis (CBA). The Constant Current Regulator (CCR) is an essential component in airfield lighting systems, especially in series circuits where voltage may vary depending on load. CCRs maintain a constant output current (typically 6.6 Amps) regardless of changes in the number or type of lights operating on the circuit. This ensures uniform brightness and operational stability for all connected luminaires. In this research, the CCR serves a dual purpose. First, it standardizes the electrical environment in which both halogen and LED runway edge lights are tested, allowing for a fair and consistent performance comparison. Second, it ensures that both lighting systems operate under identical current conditions, so that variations in energy efficiency and power consumption can be attributed solely to the lamp technology and not external electrical fluctuations. During field observations at West Java International Airport, the CCR system was observed and its parameters measured to verify that both halogen and LED lights operated at the same current levels (2.8–6.6 A range). This setup was critical in generating reliable data for cost calculation, energy analysis, and lifespan estimation. By integrating CCR into the research framework, the study simulates real-world operational scenarios, thereby enhancing the accuracy and applicability of the findings. CCR typically regulate current at 6.6 Amps and are widely adopted in airport lighting systems per FAA and ICAO standards [16] [17].

Meanwhile, the Cost Benefit Analysis (CBA) method is used to evaluate the financial feasibility of transitioning from halogen to LED runway lights. CBA compares the initial investment, operational energy costs, maintenance expenses, and expected lifespan of each lighting system. This helps determine long-term economic efficiency and return on investment. In this study, the CBA is carried out by calculating and comparing the total cost of ownership (TCO) for both lighting systems over a projected lifespan of 25 years. The investment cost for LED includes unit price, installation, and potential replacement of spare parts, which are obtained from the national e-Catalogue (LKPP) to ensure market relevance. Operating costs are estimated using electricity consumption calculations based on daily usage of 6 hours per day, multiplied by the local electricity tariff. Maintenance costs consider the replacement frequency of lamps based on their rated lifespans—halogen (1,000 hours) versus LED (56,000 hours) [18]. Additionally, the study computes the Return on Investment (ROI) using the formula:

$$ROI = \frac{Total\ Net\ Savings\ over\ 25\ years}{Total\ Initial\ Investment} \times 100\% \quad (1)$$

One key aspect of the analysis involves calculating the daily electricity consumption cost for each lighting system using the formula:

Electricity Consumption Cost per Day=Electricity Price per kWh×Power×Usage Hours (2)

The operational energy cost is calculated using the basic energy consumption formula, which multiplies unit power consumption with electricity price and duration of use [19]. This calculation helps quantify the operational energy costs for both LED and halogen runway edge lights, serving as a critical component in comparing their economic efficiency [20]. Through these methods, the research aims to provide actionable recommendations for adopting a more energy-efficient and cost-effective lighting system at West Java International Airport.

3. Results and Discussion

The layout of Runway Edge Lights in figure 3 at West Java International Airport is designed to ensure optimal guidance for pilots during aircraft alignment and operations under varying conditions, including daylight, adverse weather, and nighttime. Strategically placed along the edges of the runway, these lights are critical for ensuring safety and efficiency.

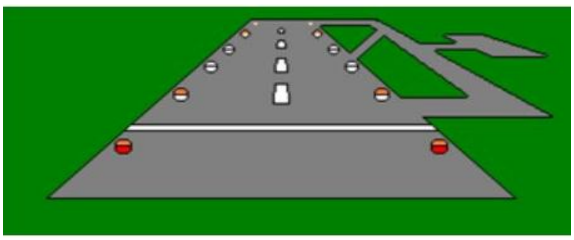


Figure 3. Runway edge light layout

The current system at the airport primarily utilizes halogen runway edge lights, which consume 210 Watts of electricity at 6.6 Amps, providing a lifespan exceeding 1,000 hours. These halogen lights meet both FAA and ICAO standards, ensuring durability against jet blasts and extreme weather conditions. However, LED runway edge lights are emerging as a superior alternative due to their advanced features, including integrated intelligence and fail-open technology, which enhance compatibility with Safegate ASP and 2A systems.

Figure 4. Halogen lights on Runway 14 of Kertajati International Airport, West Java

The LED lights are equipped with all-in-one electronics, offering surge and lightning protection, while providing long-lasting illumination with significantly lower power consumption. Constructed with anodized aluminum housing, tempered glass, and stainless steel fasteners, the LED systems meet IP67 standards, ensuring resistance to environmental factors. Operated using a Constant Current Regulator (CCR), LED lights also minimize visual flicker, providing an efficient and sustainable lighting solution compared to traditional halogen systems. This research underscores the need for transitioning to LED technology to enhance runway lighting efficiency.

3.1. Lamp Specifications and Performance

The lamp specification Table 1 highlights significant differences between Halogen and LED runway edge lights in terms of power consumption, lifespan, and operational current range. Halogen lamps consume 210 Watts of power, while LED lamps are far more energy-efficient, requiring only 41 Watts. This substantial reduction in power consumption demonstrates the clear advantage of LED technology in minimizing energy costs. Additionally, the lifespan of LED lamps is an outstanding 56,000 hours, significantly surpassing the 1,000-hour lifespan of Halogen lamps. Halogen lamps are a type of incandescent lamp that produce light through the heating of a tungsten filament enclosed in a halogen gas-filled bulb. These lamps typically operate at high temperatures and have moderate luminous efficacy (around 15–25 lumens per watt). While halogen lights offer consistent brightness, they have relatively short lifespans (typically 1,000–2,000 hours) and consume more energy compared to modern alternatives [13].

Table 1. Comparative Specifications of Halogen and LED Runway Edge Lights

Type of Lamp	Specification		
	Lamp Power (Watt)	Lifetime (Hours)	Current Operate (A)
Halogen	210	1000	2,8 – 6,6
LED	41	56000	2,8 – 6,6

LED lamps, on the other hand, are solid-state devices that emit light when an electric current passes through a semiconductor. They offer several advantages, including higher luminous efficacy (often exceeding 100 lumens per watt), longer operational lifespans (typically 25,000–50,000 hours), and lower energy consumption [13]. Additionally, LEDs provide instant full brightness and generate significantly less heat compared to halogen lamps. This extended lifespan not only reduces the frequency of replacements but also lowers maintenance costs and operational disruptions. Both lamp types operate within a similar current range of 2.8 A to 6.6 A, ensuring compatibility with existing Constant Current Regulator (CCR) systems. The LED's remarkable longevity and efficiency provide a more sustainable and cost-effective solution for runway lighting compared to Halogen lamps. These differences emphasize the practicality and long-term benefits of transitioning to LED lighting systems in airport runway applications, where reliability, durability, and energy efficiency are critical. The table 1 serves as strong evidence supporting the adoption of LED lamps for improving operational efficiency and reducing overall costs at airports.

3.2. Energy Efficiency and Power Consumption Analysis

To find out the lifetime of the runway edge light at West Java International Airport, you must calculate the number of flights per day

a. Runway Edge Light Halogen lamps, with a rated lifetime of 1,000 hours based on the datasheet and operating hours of 6 hours per day, then:

$$\frac{Rated\ lifetime}{Operating\ hours\ \times 365\,\frac{days}{year}} = \frac{1000\ hours}{6\,\frac{hours}{days} \times\ 365\,\frac{days}{year}} = \frac{1000\ hours}{2.190\,\frac{hours}{year}} = 4.5\ months$$

b. LED Runway Edge Light, with a rated lifetime of 56,000 hours based on the datasheet and operating hours of 6 hours per day, then:

$$\frac{Rated\ lifetime}{Operating\ hours\ \times 365\ \frac{days}{year}} = \frac{56000\ hours}{6\ \frac{hours}{days}\ \times\ 365\ \frac{days}{year}} = \frac{56000\ hours}{2.190\,\frac{hours}{year}} = 25.5\ years$$

Table 2. Cost of electricity consumption per hour

Type of Lamp	Cost of electricity consumption per hour		
	Lamp Power (Watt)	Price per kWh	Total cost
Halogen	21000	Rp 1.114,74	Rp 23.409,5
LED	4.100	Rp 1.114,74	Rp 4.570,4

West Java International Airport uses a price per kWh WBP of Rp 1.114,74. The airport uses 100 runway edge lights. So, the costs of electricity consumption per day, per month to per year are as follows:

a. Electricity consumption costs for halogen runway edge lights per day

$$\text{Rp } 23.409{,}5\ \times 6\text{ hours} = \text{Rp } 140.457$$

b. Electricity consumption costs for halogen runway edge lights per month

$$Rp\ 140.457\ \times 30\ \text{days} = \text{Rp}\ 4.213.710$$

c. Electricity consumption costs for halogen runway edge lights per year

$$\text{Rp}\ 140.457\ \times 365\ \text{days} = \text{Rp}\ 51.266.805$$

The electricity consumption costs for led runway edge lights per day, one month and one year

a. Electricity consumption of LED lights per day

$$\text{Rp}\ 4.570{,}4\ \times 6\ \text{hours} = \text{Rp}\ 27.422{,}4$$

b. Electricity consumption of LED lights per month

$$\text{Rp}\ 27.422{,}4 \times 30\ \text{days} = \text{Rp}\ 822.672$$

c. Electricity consumption of LED lights per year

$$\text{Rp}\ 27.422{,}4 \times 365\ \text{days} = \text{Rp}\ 10.009.176$$

The savings in electricity costs due to switching from halogen lamps to LEDs can therefore be calculated as follows

$$Cost\ savings\ = \text{Rp}\ 51.266.805 - \text{Rp}.\ 10.009.176 = \text{Rp}\ 41.257.629 \qquad (3)$$

Thus, the use of LED lights can save electricity costs of IDR 41,257,629 per year compared to halogen lights. To find out the savings percentage, the following calculation is carried out:

$$\frac{Cost\ Savings}{Halogen\ Electricity\ Consumption\ Costs} = \frac{41.257.629}{51.266.805} \times 100\% = 80.48\%$$

These results show that the use of LED lights can save electricity costs by up to 80.48% compared to halogen lights, thereby reducing airport operational costs, increasing energy efficiency, and supporting reduced power consumption and longer lamp life.

3.3. Economic Analysis of Investment Costs

The prices of LED lights and Halogen Inset Runway Lights have quite significant differences. Based on LKPP e-Catalog data, the price of the LED Inset Runway Lamp is recorded at Rp 75.457.800.00 per unit, while the Halogen Inset Runway Lamp is priced at Rp 29.670.300.00 per unit, along with a detailed table of spare parts procurement.

The following is an analysis of the cost efficiency and benefits of using LED Runway Light compared to Halogen over a 25 year period using the Cost-Benefit Analysis (CBA) method. The main focus of the calculation includes initial investment, electricity consumption, maintenance costs, as well as benefits from energy savings and lamp life.

Table 3. Spare Parts Procurement Details

Type of Lamp	ADB Safegate brand		
	Price Unit	Amount	E-Catalog
Runway Light Inset Halogen	Rp 29.670.300,00	Rp 29.670.300,00	https://e-katalog.lkpp.go.id/katalog/produk/detail/67953581
Runway Light Inset LED	Rp 75.457.800,00	Rp 75.457.800,00	https://e-katalog.lkpp.go.id/katalog/produk/detail/81998884?lang=id&type=general

Table 4. Comparison of Halogen and LED

LED Usage Costs	Cost of Using Halogen
Initial Investment Cost = Rp 75.457.800,00 Annual Electricity Consumption Cost = Rp 10.009.176 Total Electricity Consumption 25 Years = 10.009.176 × 25 = Rp 250.229.400 Total Cost of Using LEDs = 250.229.400 + 75.457.800,00 = Rp 325.687.200	Initial Investment Cost = Rp 29.670.300 Annual Electricity Consumption Cost = Rp 51.266.805 Total Electricity Consumption for 25 Years = 51.266.805 × 25 = Rp 1.281.670.125 Total Halogen Cost = 1.281.670.125 + 29.670.300 = Rp 1.311.340.425

Based on Equation (3), the total benefits of using LED runway lights over a 25-year period can be calculated as follows:

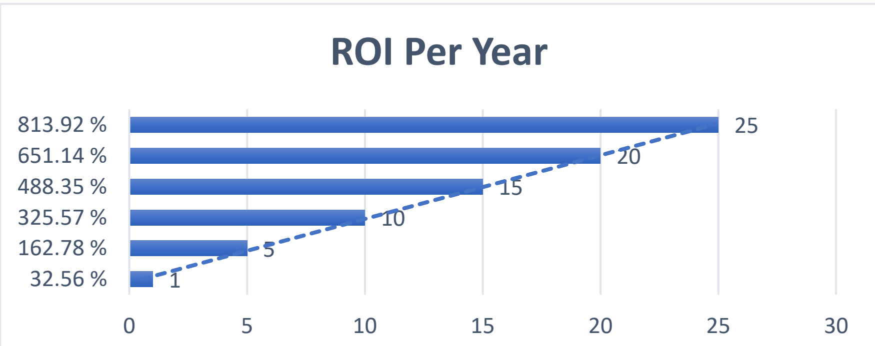
$$Total\ benefit = \text{Rp } 41.257.629 \times 25 = \text{Rp } 1.031.440.725$$

From Table 4, the net benefit of using LED runway lights can be calculated as follows

$$\begin{aligned} Net\ benefit &= Total\ benefit - Total\ Costs \\ &= \text{Rp. } 1.031.440.725 - \text{Rp. } 325.687.200 \\ &= \text{Rp } 705.753.525 \end{aligned}$$

Taking into account the total savings in electricity and maintenance, the ROI of LEDs is achieved in less than 3 years, after which the use of LEDs only provides benefits. Then the following are the results of ROI calculations for the 1st year, 5th year, 10th year, 15th year, 20th year and 25th year in Figure 5.

Investments in LED Runway Lights demonstrate increasing cost efficiencies over time. In the first year, the ROI was 32.56%, indicating that although the investment has not been fully returned, operational cost savings have begun to be felt. These savings continue to grow until the 5th year, where the ROI reaches 162.78%, meaning the initial investment has returned and is starting to provide returns of more than 1.5 times the capital invested. As time goes by, the efficiency of using LEDs becomes increasingly visible. In the 10th year, the ROI increased to 325.57%, indicating that the cost savings had reached more than 3 times the initial investment. This positive trend continued into the 15th year with an ROI of 488.35%, making it clear that LED-based lighting systems provide far greater benefits than halogen lamps.



	32.56 %	162.78 %	325.57 %	488.35 %	651.14 %	813.92 %
Year	1	5	10	15	20	25

Figure 5. ROI results

In the 20th year, the ROI value reached 651.14%, indicating that the total savings obtained were more than 6 times the initial investment. The peak occurred in the 25th year, where the ROI reached 813.92%, proving that the use of LEDs not only provides a quick return on investment but also produces very significant cost savings in the long term. Based on these results, it can be concluded that investing in LED Runway Lights is a very efficient and economical option compared to halogen lights. With a relatively short payback period of less than 3 years, and an ever-increasing rate of return on investment, the use of LEDs provides great benefits for energy efficiency and reduced airport operational costs in the long term.

3.4. Environmental Impact and CO_2 Emission Reduction Analysis

In line with the sustainability goal mentioned in the introduction, this study also analyzes the potential reduction in carbon dioxide (CO_2) emissions resulting from the transition from halogen to LED lighting systems. Electricity generation in Indonesia, especially in the Java-Bali region, remains dominated by fossil fuels such as coal. According to the Directorate General of Electricity, Ministry of Energy and Mineral Resources (ESDM), the average CO_2 emission factor for the Java-Bali grid is 0.82 kg CO_2 per kWh generated [21]. This value is used to estimate the annual carbon emissions associated with the operation of both lighting systems.

a. Energy Consumption:
   Halogen: 21kW × 6 hours/day × 365 days = 45,990kWh/year
   LED: 4.1kW × 6 hours/day × 365 days = 8,979kWh/year
b. CO_2 Emissions:
   Halogen CO_2 Emissions: 45,990 × 0.82 = 37,712 kg CO_2/year
   LED CO_2 Emissions: 8,979 × 0.82 = 7,363 kg CO_2/year
   LED CO_2 Emissions: 8,979 × 0.82 = 7,363kg CO_2/year
c. Emission Reduction:
   37,712 − 7,363 = 30,349 kg CO_2/year

Based on the calculation of annual energy consumption and carbon emissions, there is a significant difference between halogen and LED lighting systems. Assuming the use of 100 lamps for 6 hours per day throughout the year, the total energy consumption of the halogen system reaches 45,990 kWh per year, while LED is only 8,979 kWh. Referring to the emission factor of 0.82 kg CO_2/kWh applicable in the Java-Bali electricity network, halogen produces annual emissions of 37,712 kg CO_2, while LED only contributes 7,363 kg CO_2. The difference in emissions of 30,349 kg CO_2 per year reflects the potential for emission reductions of more than 80% if there is a transition to LED. These results indicate that the efficiency of LED power consumption has a direct impact on reducing annual carbon emissions on a significant scale. The notable decrease in emissions illustrates the technical superiority of LED systems in reducing energy consumption and related carbon output when operated under the same conditions. Although this analysis does not present a conclusive recommendation, the significant difference in calculated emissions serves as a solid quantitative reference for evaluating the potential of adopting LED technology. From a data-driven perspective, the shift to LED lighting presents meaningful environmental advantages that may contribute to wider sustainability initiatives in airport infrastructure development and energy efficiency planning.

Command Window Output: Annual CO_2 Emission and Reduction Estimation This output displays the annual energy consumption (in kWh) and CO_2 emissions (in kilograms) for both halogen and LED runway lighting systems, as well as the calculated annual emission reduction. It also shows the cumulative emission reduction over a 25-year operational period.

Table 5. Parameters and Calculation of Annual CO_2 Emissions from Halogen and LED Lighting Systems

Component	Halogen	LED
Power per 100 lamps	21,000 Watts	4.100 Watts
Hours of use per day	6 hours	6 hours
Days of the year	365 days	365 days
CO_2 emission factor	0.82 kg/kWh	0.82 kg/kWh
Annual CO_2 Emissions (kg)	37,712	7,363
Annual CO_2 Reduction (kg)	-	30,349

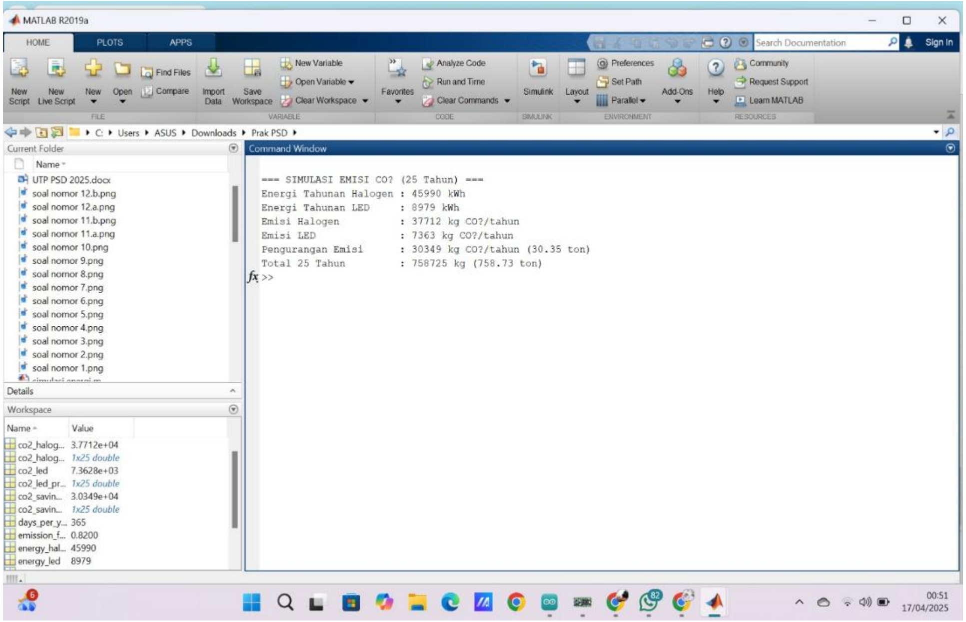


Figure 6. Matlab Command Window Output Image

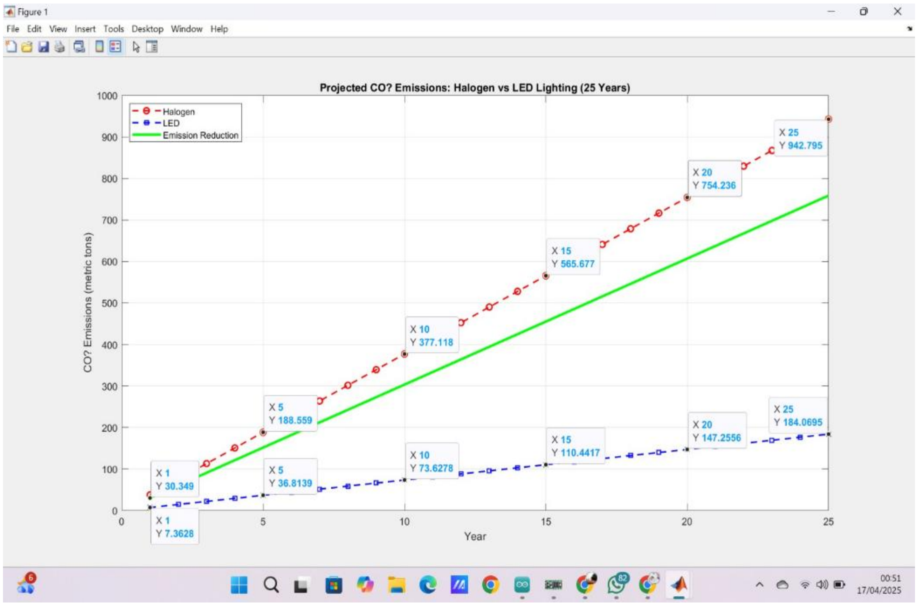


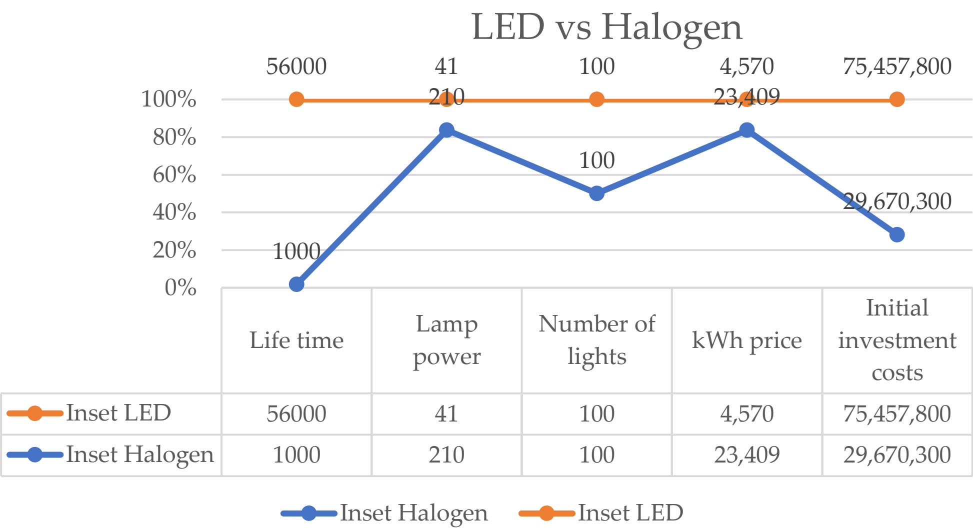
Figure 7. Projected CO_2 Emissions: Halogen vs LED Lighting (25 Years)

Figure 7 shows the projected cumulative CO_2 emissions for halogen and LED lighting systems over a 25-year period. The red line represents halogen lighting emissions, the blue line represents LED lighting emissions, and the green line indicates the amount of CO_2 saved each year through the transition to LED technology. The simulation shows that replacing halogen lights with LEDs could reduce carbon emissions by approximately 30.349 metric tons annually, resulting in a total reduction of 758.7 metric tons over 25 years. The results of the CO_2 emission simulation using MATLAB show that the transition from halogen to LED runway edge lights can significantly reduce annual carbon emissions. Based on operational parameters and an emission factor of 0.82 kg CO_2/kWh (as per the Java-Bali grid), halogen systems were estimated to emit 37,712 kg CO_2 annually, while LED systems emit only 7,363 kg CO_2. This leads to an annual reduction of 30,349 kg CO_2, equivalent to approximately 30.35 metric tons. Over a projected operational lifespan of 25 years, this transition results in a cumulative emission reduction of 758.7 metric tons of CO_2. This finding reinforces the environmental sustainability aspect of the proposed LED implementation.

To ensure the accuracy of this simulation and the fairness of the comparison, both halogen and LED systems were tested under controlled electrical conditions using a Constant Current Regulator (CCR). Field observations confirmed that the CCR maintained a stable output current of 6.6 Amps across both systems, minimizing external electrical variables and ensuring that all performance and emission differences originated solely from the lighting technologies themselves. This reinforces the validity of the simulation results, making the analysis more reliable from both a technical and environmental perspective.

3.5. Recommendations for Transition to LED Systems

To illustrate the advantages of transitioning to LED runway lighting, a comparative operational cost analysis is presented in the form of a graphical representation. The graph highlights the significant cost savings, energy efficiency, and long-term benefits of using LED systems over halogen lighting.



	Life time	Lamp power	Number of lights	kWh price	Initial investment costs
Inset LED	56000	41	100	4,570	75,457,800
Inset Halogen	1000	210	100	23,409	29,670,300

Figure 8. LED and Halogen comparison chart

Based on the comparison between ADB SAFEGATE Runway Light Inset LED and Halogen, the use of LED systems offers greater advantages in terms of energy efficiency, operational costs, and longer lifespan. Therefore, transitioning from halogen lighting to LED is highly recommended to improve efficiency and reduce long-term expenses. In terms of energy consumption, LED lights require only 41 watts per unit, significantly lower than halogen lights, which consume 210 watts per unit. With the installation of 100 lighting units, the total electricity consumption for LED is only 4.1 kWh per hour, whereas halogen reaches 21 kWh per hour. Additionally, the electricity tariff for LED is lower at Rp 4.570/kWh, compared to Rp 23.409/kWh for halogen. This clearly demonstrates that using LED can significantly reduce operational electricity costs compared to the halogen system.

Beyond energy efficiency, LED also offers a much longer lifespan. LED lights have a lifespan of up to 50,000 hours, whereas halogen lights last only about 1,000 hours. Assuming an average usage of 6 hours per day, halogen bulbs need to be replaced every 166 days, while LED lights can last for more than 8 years without requiring replacement. This significantly reduces the frequency of spare part replacements and maintenance costs, enhancing the reliability of airport lighting systems. Although the initial investment cost for LED is higher (Rp 75.457.800 compared to Rp 29.670.300 for halogen), in the long run, savings in electricity consumption and maintenance costs make LED systems far more economical. Return on Investment (ROI) analysis indicates that LED systems can reach the break-even point in a relatively short time, after which their use will generate significant financial benefits.

From a technical perspective, LED lights offer better durability with an IP68 rating, compared to halogen lights with an IP67 rating. This makes LED lights more resistant to extreme environmental conditions, such as low temperatures down to -60°C and humidity levels up to 100%. Considering all these factors, migrating to an LED lighting system is highly recommended. Its implementation not only reduces electricity consumption and operational costs but also enhances the reliability, sustainability, and efficiency of airport runway lighting systems in the long term.

4. Conclusion

This research concludes that LED lighting systems are superior to halogen in terms of energy efficiency, lifespan, and both economic and environmental impact. Based on the Cost Benefit Analysis (CBA), LED systems significantly reduce operational and maintenance costs, achieving up to 80.48% in electricity cost savings. In addition, environmental analysis using Indonesia's national emission factor shows that replacing halogen with LED lights can reduce CO_2 emissions by approximately 30,349 kg (30.35 metric tons) per year. This not only improves airport sustainability but also aligns with global efforts to lower carbon footprints in aviation infrastructure. Although LED lights have a higher initial investment cost, the long-term financial savings and emission reductions make them a highly recommended alternative. The study supports the transition to LED as both a cost-effective and environmentally responsible lighting solution for airports.

References

[1] A. Andiyan and A. Rachmat, "Telaahan Kerjasama Pemerintah Swasta Dalam Pembangunan Bandara Kertajati Di Jawa Barat," *Aksara J. Ilmu Pendidik. Nonform.*, vol. 7, no. 2, p. 413, May 2021, doi: 10.37905/aksara.7.2.413-424.2021.

[2] T. Li, A. Liu, Y. Li, and J. Zhang, "Research on the construction of low-current Airfield Groud Lighting system for civil airports in China," *J. Phys. Conf. Ser.*, vol. 2840, no. 1, p. 012029, Sep. 2024, doi: 10.1088/1742-6596/2840/1/012029.

[3] J. Pitter and Junaid Iqbal, "Systematic Review of Airport Sustainability Through Life Cycle Assessments," 2024, *Unpublished*. doi: 10.13140/RG.2.2.21650.06088.

[4] A. P. Mukhtar and N. Desryanto, "Penggantian Halogen ke LED pada Runway Edge Lights Bandara Ahmad Yani Sebagai Efesiensi Energi Listrik," *Aviat. Sci. Technol. J.*, vol. 1, no. 01, pp. 37–47, Feb. 2024, doi: 10.54147/astj.v1i01.1025.

[5] Y. C. Kurniawan and D. Supardam, "Optimizing the Safety and Efficiency of Ngurah Rai Airport Runway, Bali through the Implementation of Stopbar Light," *Proceeding Int. Conf. Artif. Intell. Navig. Eng. Aviat. Technol. ICANEAT*, vol. 1, no. 1, Art. no. 1, Jan. 2024, doi: 10.61306/icaneat.v1i1.167.

[6] D. E. J. Chukwuka, "Effect of Air Safety Operations on Performance of Air transport Business in Nigeria," no. 75, 2023. Accessed: Jan. 25, 2025. [Online]. Available: https://www.journal-innovations.com/

[7] O. O. E. Ajibola, M. M. Jimoh, M. B. Shitta, S. M. Abolarin, and L. Lagrange, "Economics of deploying LED lamps as energy efficiency measure in the Senate building of the University of Lagos using time series analysis," *Mater. Today Proc.*, vol. 105, pp. 110–118, Jan. 2024, doi: 10.1016/j.matpr.2023.08.019.

[8] "LED Airport Lighting Behavior in Real-World Conditions." Accessed: Jan. 25, 2025. [Online]. Available: https://rosap.ntl.bts.gov/view/dot/55248

[9] A. Manea, G. Dolci, and M. Grosso, "Life cycle assessment and cost analysis of an innovative automatic system for sorting municipal solid waste: A case study at Milan Malpensa airport," *Waste Manag.*, vol. 183, pp. 63–73, Jun. 2024, doi: 10.1016/j.wasman.2024.04.049.

[10] N. M. Alsharari, "The impact of low-cost carriers on high-quality producers in the aviation industry: cost-benefit analysis," *J. Money Bus.*, vol. 4, no. 1, pp. 107–120, Aug. 2024, doi: 10.1108/JMB-11-2023-0064.

[11] "Potential Energy Generation of Photovoltaics With Acceptable Risk at Korean Airports - Kim - 2025 - International Journal of Energy Research - Wiley Online Library." Accessed: Jan. 25, 2025. [Online]. Available: https://onlinelibrary.wiley.com/doi/full/10.1155/er/7288954

[12] A. Nazir *et al.*, "Impact of halogens modifications on physical characteristics of lead-free hybrid double perovskites compounds Cs2YCuX6 (X=Cl, Br, and I) for energy storage applications: First principles investigations," *Chem. Phys.*, vol. 588, p. 112449, Jan. 2025, doi: 10.1016/j.chemphys.2024.112449.

[13] R. Bloudicek, S. Perina, S. Rydlo, and P. Makula, "Degradation of Photometric Characteristics of Phosphor Layers in LED Based Airfield Lights," in *2024 AIAA DATC/IEEE 43rd Digital Avionics Systems Conference (DASC)*, Sep. 2024, pp. 1–7. doi: 10.1109/DASC62030.2024.10748720.

[14] F. A. Administration, *Advisory Circular*, no. January. 2016. [Online]. Available: https://www.faa.gov/documentLibrary/media/Advisory_Circular/draft-150-5340-30J.pdf

[15] A. E. Boardman, et. al., Cost–Benefit Analysis: Concepts and Practice, 5th Ed., Cambridge University Press, New York, 2018, doi: 0.1017/9781108235594

[16] Hartono, R. I. Sudjoko, S. Hariyadi, and D. A. Kumalawati, "Design of Constant Constant Current Regulator Control System of NBF 1200 Using Programmable Logic

Controller at the Airport," *J. Phys. Conf. Ser.*, vol. 1845, no. 1, pp. 0–8, 2021, doi: 10.1088/1742-6596/1845/1/012077.

[17]"Full article: Dosimetry Assessment of Potential Hazard from Visible Light, Especially Blue Light, Emitted by Screen of Devices in Daily Use." Accessed: Jan. 25, 2025. [Online]. Available: https://www.tandfonline.com/doi/full/10.2147/CCID.S490977

[18]M. Asir and A. I. Asir, "Cost Benefit Analysis of Key Actors in The Cocoa Beans Marketing," *J. Manaj. dan Agribisnis*, vol. 20, no. 1, pp. 102–111, 2023, doi: 10.17358/jma.20.1.102.

[19]Ten, C.-W., & Hou, Y., Modern Power System Analysis, 3rd Ed.. CRC Press, Boca Raton, 2024. https://doi.org/10.1201/9781003129769

[20]I. Choir, S. Anisa, and Rahmaniar, "Design and Construction of Runway Centreline Light Module Module Type LED Using Arduino Uno (Studi Case: West Java International Airport)," *Int. Conferance Digit. Sci. Eng. Technol.*, vol. 1, no. 1, Art. no. 1, Oct. 2024. Accessed: Jan. 25, 2025. [Online]. Available: https://proceeding.pancabudi.ac.id/index.php/ICDSET/article/view/215

[21]Ditjen Ketenagalistrikan ESDM Indonesia, "Faktor Emisi Gas Rumah Kaca Sistem Ketenagalistrikan 2019," *Direktorat Jenderal Ketenagalistrikan*, no. 5, pp. 1–7, 2019, [Online]. Available: https://gatrik.esdm.go.id/assets/uploads/download_index/files/96d7c-nilai-fe-grk-sistem-ketenagalistrikan-tahun-2019.pdf

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