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Multi-Criteria Evaluation of Smart Escape and Emergency Lighting Alternatives for Offshore Platforms: Case Study of BorWin5

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Abstract

This study evaluates the feasibility and benefits of adopting the IEC 62034:2012 standard for Automatic Testing Systems (ATS) for emergency and escape lighting on the BorWin5 High Voltage Direct Current (HVDC) offshore converter platform. The system comprises approximately 1800 luminaires from multiple manufacturers that are integrated into an open-architecture 220 VDC emergency network. Life-cycle cost analysis (LCCA) and multi-criteria decision-making (MCDM) approaches were employed to evaluate four configurations, ranging from manual testing to fully automated, centrally powered systems, based on technical, economic, operational, and environmental criteria. The chosen solution, which combines centralized power with automated testing and real-time monitoring, represents a significant advancement in offshore safety infrastructure. Implementing this solution on BorWin5 enhances reliability and maintainability while ensuring compliance with international standards, supporting a projected service life of over 30 years for an emergency and escape lighting system in an extreme marine environment. The findings offer a scalable model for future offshore platforms operating in similarly challenging conditions.

Keywords: escape lighting; emergence lighting; offshore platform; IEC 62034:2012 standard; MCDM

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1. Introduction

Depending on the applicable safety standards and the facility's specific operational requirements, a general lighting system may comprise up to three distinct networks: normal lighting, emergency lighting, and escape lighting. The normal lighting network is powered by the primary electrical supply, the emergency lighting network is activated automatically if the main power fails, and the escape lighting network is designed to guide people safely out of an installation during emergencies. Escape lighting operates independently of the main and emergency networks. It is powered by its own power source—typically battery-based or similar—and activates when both the main and emergency systems fail. It is especially useful when the main power supply cannot be quickly restored, and where emergency lighting cannot be provided without a blackout via diesel generators or similar sources. These generators usually have a latency period between power failure and activation, which can result in a temporary blackout during critical moments. In contrast, battery-powered systems offer immediate activation, ensuring continuous illumination and enhancing safety during evacuation procedures.

Emergency and escape lighting play a crucial role in ensuring safety during critical situations [1]. This type of lighting is essential not only in transportation systems, such as aviation and roadways, but also in public buildings and remote areas where the electricity supply may be irregular or unavailable and blackouts pose a security risk [2]. Emergency and escape lighting is becoming increasingly prevalent in modern society. It remains a mandatory requirement in all onshore buildings intended for public use, including hospitals, educational institutions, shopping centers, factories, warehouses, and numerous other facilities [3]. In the offshore sector—the focus of this work—escape and emergency lighting is a critical safety mechanism designed to protect workers and personnel aboard oil rigs, drilling platforms, wind farms, and service vessels operating in remote marine environments.

Advancements in emergency and escape lighting technology have led to more effective and reliable systems. Current innovations, such as smart emergency lighting solutions that use LEDs [4–6], are designed to provide more energy-efficient and sustainable lighting systems. These systems aim to address issues associated with traditional emergency lighting, such as energy inefficiency and maintenance challenges. Smart emergency and escape lighting systems are characterized by their ability to automatically activate during emergencies and verify proper function, even when they are not switched on. These intelligent systems ensure that escape routes are illuminated in real time, guiding occupants to safety even in challenging visibility conditions. The integration of Internet of Things (IoT) technology is also reshaping the landscape of emergency and escape lighting. IoT-enabled emergency lighting systems can communicate with other safety devices and networks, enabling a coordinated response during emergencies. These systems can collect data on lighting performance, usage patterns, and potential maintenance issues, ensuring that emergency and escape luminaires are always operational when needed. Continuous monitoring and automatic maintenance alerts are critical features that enhance the reliability of emergency lighting [7]. Smart lighting can adapt to different scenarios, for example, adjusting light intensity based on occupancy or time of day, thereby maximizing effectiveness while minimizing energy consumption. This adaptability is especially beneficial in settings where personnel work non-traditional hours, such as night shifts. It enables greater responsiveness to varying operational needs [8,9].

Traditionally, maintenance of emergency and escape lighting involved manual testing, but this is often overlooked today to reduce costs [10,11]. In recent years, the introduction of wireless and automatic checking mechanisms has facilitated easier monitoring of light performance, ensuring that systems are functional when needed [12,13]. In this context, the international standard IEC 62034:2012 [14] represents a significant advancement in emergency escape lighting. This standard defines the performance and safety requirements that automatic test systems must meet, thereby enhancing the reliability of emergency and escape lighting. A key benefit of implementing this standard is the reduction in preventative maintenance costs [15]. The European Standard EN 1838:2024 [16] complements IEC 62034:2012 by providing updated specifications for the luminous requirements of emergency lighting systems. It emphasizes not only minimum illumination levels but also uniformity, glare limitation, and spatial distribution, all of which are crucial for safe evacuation. Another standard, the IEC 60598-2-22 [17], specifies constructional and performance requirements for luminaires used in emergency lighting. These requirements include battery autonomy, light output, and durability under fault conditions. In offshore environments, the DNVGL-OS-A101 Offshore Safety Standard [18] guides the design and implementation of emergency lighting systems.

Automation requires additional infrastructure, such as communication modules, diagnostic software, and integration with building or platform management systems. This increases the initial complexity and cost. However, the operational performance is superior. In this regard, multi-criteria decision-making (MCDM) techniques are useful tools for comparing different alternatives in a decision-making process. MCDM has demonstrated substantial utility in supporting complex evaluations in several fields [19,20], providing structured mechanisms for ranking alternatives based on both quantitative metrics (e.g., life-cycle cost, fault detection time) and qualitative indicators (e.g., system integration capability, human error susceptibility) [21]. Beyond facilitating optimal selection, MCDM enhances the transparency and reproducibility of the decision-making process by explicitly incorporating stakeholder preferences, expert judgment, and context-specific constraints. In this study, the MCDM framework was applied to systematically evaluate and select the most suitable emergency and escape lighting configuration for the BorWin5 high-voltage direct current (HVDC) offshore converter platform. Four technically distinct alternatives were assessed based on a comprehensive set of criteria, including cost, system architecture, operational performance, and environmental sustainability.

2. Materials and Methods

2.1. Case Study

In recent years, the offshore wind energy sector has experienced exponential growth, driving significant transformation in the maritime industry and the broader renewable energy sector. This surge has initiated an unprecedented phase of technological and industrial advancement. The continuous increase in wind power generation capacity, coupled with the relocation of wind farms to greater distances offshore, has rendered the direct transmission of generated energy via low-voltage cables impractical. Offshore electrical substations are being constructed to address this issue by collecting power from wind turbines and transmitting it to onshore grids via HVDC systems. In this context, the BorWin5 platform, depicted in Figure 1, departed the shipyard in mid-March 2025 and is currently being installed in the North Sea.

Figure 1. BorWin5 platform during its transfer to the North Sea.

BorWin5 is an innovative HVDC offshore converter platform designed to improve connectivity between offshore wind farms in the North Sea and the German power grid. Owned by TenneT Offshore GmbH, it was constructed at the Dragados Offshore yard in Cádiz, Spain. With a transmission capacity of around 900 MW, BorWin5 uses voltage-sourced converter (VSC) technology to efficiently and stably convert power between alternating current (AC) and direct current (DC). The platform is part of the BorWin cluster, located off the coast of Germany.

The BorWin5 platform consists of two main elements: the offshore converter platform and the onshore converter station (see Figure 2). The offshore converter transforms the AC power generated by wind turbines into DC, which facilitates the efficient transmission of power over long distances via approximately 120 km of subsea cable. The topsides of the platform weigh approximately 12,000 tons, while the supporting jacket structure weighs approximately 7500 tons. The onshore converter station is located near Emden (Germany). It receives the incoming DC power and converts it back to AC for integration into the national grid. Operating at ±320 kV DC, the system ensures reliable and high-capacity energy transmission.

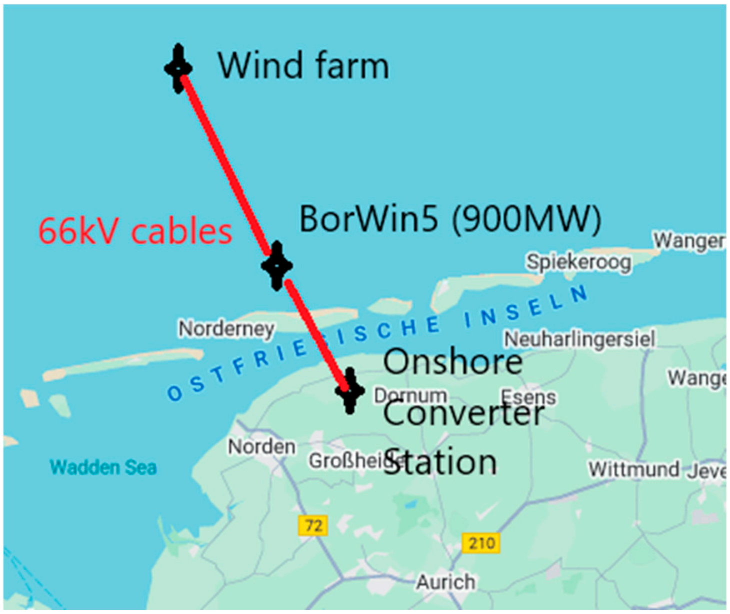

Figure 2. Location of the BorWin5 platform.

BorWin5 not only demonstrates technical excellence in HVDC transmission but also sets a new standard in offshore energy infrastructure. It showcases the ability to integrate large-scale renewable energy sources under challenging environmental and operational conditions. Rigorously engineered and custom-designed to meet the stringent technical, environmental, and safety criteria intrinsic to offshore operations, it constitutes a step forward in sustainable energy system deployment. This makes BorWin5 a pioneering application within the offshore power transmission sector.

2.2. Alternatives for the Emergency and Escape Lighting Test System

The BorWin5 platform's emergency and escape lighting consists of approximately 1800 luminaires from multiple manufacturers. All are powered by a 3 × 400 V + N (main network) and a 220 VDC (emergency network), based on an open architecture design.

Table 1 lists a selection of the standards identified as particularly relevant to the emergency lighting and escape system of the BorWin5 offshore platform.

Table 1. Standards relevant to the emergency and escape lighting system of the BorWin5 offshore platform.

Standard	Title
DIN 4102 [22]	Fire Test to Building Material
DIN EN 12464-1 [23]	Light and lighting—Lighting of workplaces—Part 1: Indoor work places
DIN EN 12464-2 [24]	Light and lighting—Lighting of workplaces—Part 2: Outdoor work places
DIN EN 1838-10 [25]	Lighting applications—Emergency lighting
DIN EN 62034 [26]	Automatic test systems for battery powered emergency escape lighting
DIN EN 50171 [27]	Central safety power supply systems
DIN EN 50172 [28]	Emergency escape lighting systems
DIN VDE 0108-100 [29]	Safety lighting systems
DIN VDE 100-560 [30]	Low-voltage electrical installations
DNVGL-OS-D201 [31]	Electrical Installations
DNVGL-ST-0145 [32]	Standard. Offshore substations
IEC 60079 [33]	Explosive atmospheres
IEC 61000 [34]	Electromagnetic compatibility (EMC)—applicable parts
IEC 61439 [35]	Low-Voltage-Switchgear and control gear assemblies
IEC 61508 [36]	Functional safety of electrical/electronic/programmable electronic safety related systems
IEC 61850 [37]	Design of Electrical substation automation
IEC 61892-2 [38]	Mobile and fixed offshore units—Electrical installations—System design
IEC 61892-6 [39]	Mobile and fixed offshore units—Electrical installations—Installations

There are multiple alternatives available for the testing system, each with distinct features that require thorough evaluation in light of environmental conditions, applicable regulations, and operational demands. The following four alternatives were considered in the present work:

- Alternative 1. Traditional testing of self-contained emergency and escape luminaires. This method involves scheduled manual testing of luminaires equipped with integral batteries. It offers flexibility in terms of installation and is simple to implement; however, it requires continuous human intervention for battery status checks and functional verification, increasing operational workload and the potential for human error.
- Alternative 2. Automatic testing (ATS) of self-contained emergency and escape luminaires. This approach integrates automated testing and monitoring protocols directly into self-contained luminaires. By eliminating the need for manual testing, it significantly reduces maintenance demands and improves overall system reliability. Continuous monitoring ensures timely fault detection and enhances compliance with safety regulations.
- Alternative 3. Traditional testing of centrally powered emergency and escape lighting systems. Under this configuration, a centralized battery system supplies power to multiple luminaires. Manual testing is carried out periodically in accordance with established schedules. Centralized power simplifies battery replacement and lifecycle monitoring, thereby assisting and facilitating maintenance through its centralized structure.
- Alternative 4. Automatic testing (ATS) of centrally powered emergency and escape lighting systems. This solution incorporates automated testing and diagnostics within a centralized power framework. It enables real-time monitoring and streamlined fault identification, offering enhanced system performance. However, it entails greater infrastructure complexity and a higher initial investment compared to other solutions, as well as the need for skilled professionals to maintain the system.

Tables 2–5 present an analysis of the comparative advantages of each of the four aforementioned alternatives in relation to each other.

Table 2. Advantages of alternative 1 (traditional testing of emergency and escape self-contained luminaires) compared to those of the other alternatives.

Advantages	Comparison to the Other Alternatives
Lower initial investment compared to ATS	Unlike ATS (alternatives 2 and 4), traditional testing does not require automated control components, diagnostic systems, or communication modules. This significantly reduces capital expenditure.
Low technical complexity	Unlike centralized systems (alternatives 3 and 4), and automated self-contained luminaires (alternative 2), this approach does not require complex configurations, which makes it easier to install.
Independence and fault containment	Similar to alternative 2 and unlike alternatives 3 and 4, self-contained luminaires function independently. In the event of a failure, the issue is isolated to a single unit, with no impact on other luminaires or circuits.
No dependency on central infrastructure	Unlike alternatives 3 and 4, traditional self-contained luminaires do not rely on centralized battery systems, power distribution panels, or extended cabling. This makes them highly suitable for modular or remote installations.
Ideal for small-scale installations	In installations where the number of luminaires is limited, the simplicity and low cost of manual testing offer a practical and efficient solution compared to more sophisticated (and costly) automated or centralized alternatives.

Table 3. Advantages of alternative 2 (automatic testing of emergency and escape self-contained luminaires) compared to those of the other alternatives.

Advantages	Comparison to the Other Alternatives
Automated compliance and reduced human error	Unlike alternatives 1 and 3, the ATS function automatically performs periodic tests (function and duration) according to pre-defined schedules, minimizing the risk of missed inspections, human oversight, or non-compliance with regulatory requirements.
Enhanced fault detection and reporting	Unlike traditional systems (alternatives 1 and 3), ATS systems automatically detect, log, and report failures of each luminaire in real time. This provides clear and timely diagnostics that support preventive maintenance and reduce downtime.
Retention of luminaire independence	Unlike centrally powered systems (alternatives 3 and 4), self-contained luminaires operate independently. A failure in one luminaire does not compromise the functionality of the overall system, enhancing operational reliability in safety-critical environments.
Simplified infrastructure compared to centralized systems	Unlike alternatives 3 and 4, this solution does not require central battery systems, power distribution battery networks, or additional cabling. This reduces installation complexity and cost, particularly in retrofitting or offshore modular applications.
Lower long-term operational costs	Although the initial investment may be higher than that of traditional testing methods, the reduction in manual labor and increased efficiency in maintenance activities typically result in lower lifecycle costs.
Improved data logging and maintenance planning	Compared to manual systems, ATS provides a continuous log of system performance. This supports maintenance planning, trend analysis, and facilitates documentation for compliance with standards.
Suitable for distributed and isolated installations	Unlike centralized systems (alternatives 3 and 4), ATS-enabled self-contained luminaires are well suited for installations with spatial constraints or segmented layouts, which are common in offshore units, where centralized cabling and control may be impractical.

Table 4. Advantages of alternative 3 (traditional testing of centrally powered emergency and escape lighting systems) compared to those of the other alternatives.

Advantages	Comparison to the Other Alternatives
Lower initial investment compared to ATS	This alternative offers the benefits of centralized power management, while avoiding the additional cost of the automation infrastructure required by alternatives 2 and 4 (ATS). This makes it a more economical solution for projects with budget constraints.
Simplified system architecture compared to self-contained solutions	Unlike alternatives 1 and 2, the central battery system eliminates the need for each luminaire to have its own power source. This centralization can simplify power maintenance and battery replacement logistics over the lifecycle of the system.
Unified battery maintenance	With a centralized power source, battery testing, charging, and replacement are managed at a single location, unlike self-contained systems (alternatives 1 and 2), where batteries must be individually maintained and monitored.
Suitable for high-density lighting installations	In facilities or offshore units with large concentrations of emergency and escape luminaires, a centralized system may offer a more efficient and structured approach to power management than distributed self-contained units.
Lower complexity than ATS systems in terms of software and configuration	Traditional centralized systems, compared to alternatives 2 and 4, do not require automated testing protocols or software-based monitoring, which reduces system setup complexity and potential cybersecurity risks.

Table 5. Advantages of alternative 4 (automatic testing of centrally powered emergency and escape lighting systems) compared to those of the other alternatives.

Advantages	Comparison to the Other Alternatives
Centralized monitoring and management	Unlike self-contained systems (alternatives 1 and 2), centrally powered ATS systems enable centralized supervision, enabling real-time fault detection, test result logging, and streamlined maintenance management from a single control point.
Automated testing without manual intervention	Unlike traditional testing methods (alternatives 1 and 3), ATS systems automatically perform scheduled functional and autonomy tests, ensuring continuous compliance with safety regulations independent of manual inspections.
Reduced long-term operational costs	Automation and centralized battery infrastructure reduce the need for individual inspections and interventions, leading to significant cost savings over the system's lifecycle.
Optimized energy and battery management	Compared to self-contained luminaires (alternatives 1 and 2), centrally powered systems offer more efficient energy distribution and centralized control of battery charging, discharging, and health monitoring.
Scalability and suitability for complex installations	Ideal for large-scale or high-density lighting installations, where managing numerous individual units would be impractical. Centralized systems provide structured and scalable solutions.
Integration with Building Management Systems (BMS) or offshore automation system	Unlike traditional systems, ATS centrally powered solutions can be integrated with BMS or other facility management platforms. This enables remote diagnostics, alarm notifications, and full traceability of system performance. Artificial intelligence protocols can be integrated into the automation system through continuous luminaire monitoring, thereby enabling adaptive and data-driven decision-making.
Architectural and technical design flexibility	Many emergency and escape luminaries, such as projectors, downlights, and recessed fittings with elevated power consumption, are not designed to house an internal battery but also serve architectural or decorative purposes. In such cases, self-contained luminaires (alternatives 1 and 2) would require built-in batteries, which often complicate the luminaire design, increase its size significantly, and negatively impact its aesthetics or architectural integration. A centrally powered system overcomes this limitation by enabling compact, visually refined luminaires without internal batteries, thus preserving both performance and design integrity.

To implement any of the alternatives described above, it is essential that the number of luminaires, their models, and their photometric distributions remain unchanged, ensuring that the illuminance levels produced by each luminaire—and in each area—are not affected. In this context, the BorWin5 platform was equipped with high-quality luminaires from leading offshore-market manufacturers, which can be adapted to any of the four alternatives described above without necessitating any changes to the luminaires' photometric characteristics (e.g., lamp wattage, correlated color temperature, light distribution, luminaire efficacy, luminous flux, color rendering index, among others).

2.3. Life-Cycle Cost Analysis

A life-cycle cost analysis (LCCA) was performed to determine the total cost of each alternative over the course of its entire service life. The analysis encompasses all relevant cost categories, including acquisition, installation, operation, maintenance, component replacement, and end-of-life disposal, as indicated by the following equation [40]:

$$LCC = IC + \sum_{t=1}^{n} \frac{OC_t + MC_t}{(1+r)^t} + \frac{EOLC}{(1+r)^n} - \frac{RV}{(1+r)^n}, \quad (1)$$

where LCC is the total life-cycle cost, IC is the initial cost, OC_t is the operating cost in year t, MC_t is the maintenance cost at year t, $EOLC$ is the end-of-life cost, RV is the residual value, r is the discount rate, and n is the system's lifetime.

When conducting an LCCA, applying a consistent discount factor is crucial to accurately reflect the time value of money over a project's lifespan. Common values of the discount rates are around 3.0% to 4.0% [41]. In the present work, a discount rate of 3.9 was considered. Regarding the system's lifetime, 30 years were considered. The other parameters related to computing the LCC are detailed below.

2.3.1. Initial Costs (IC)

This category includes all initial capital expenditures associated with designing, acquiring, and installing the emergency lighting system. These costs usually include the purchase of luminaires or central battery systems, ATS modules (in alternatives 2 and 4), cables, connectors, control units, installation labor costs, commissioning and functional testing, engineering and project management fees, configuration and programming, and so on.

The investment cost of each alternative was calculated by taking into account the following considerations derived from the actual BorWin5 project:

- Luminaire pricing. An average unit price was considered for both emergency luminaires (such as floodlights, technical luminaires, downlights, wall-mounted fixtures, and similar) and escape route luminaires, based on platform design standards.
- Battery pricing. The cost of the battery was estimated using an average value provided by LIGHTPARTNER, the main supplier of luminaires on this platform, for this type of equipment.
- A 2.5 mm^2 cable section was considered for each luminaire, as is standard for this type of installation. A 3G2.5 cable was used for traditional systems in platforms, and a 5G2.5 cable was used for ATS systems, assuming an average distance of 25 m between luminaires. For centralized systems, it was assumed that the power supply from the battery panels is provided using 35 mm^2 cables over a distance of 60 m. All other auxiliary system cabling (power supplies, heating circuits, and automation signals) was estimated at 10% of the total value of the main cabling.
- It was estimated that the entire emergency and escape lighting system project should be completed within 4 months with a team of three engineers, whereas autonomous systems are expected to require 5 months.
- The cost of the electrical panels was estimated based on information provided by the supplier for the BorWin 5 project, considering a 30% reduction if the system does not include an automatic control system.

- The cost of the central panels includes the inverters, batteries, interconnections, and distribution boxes.
- Illumination software. The involvement of an expert technician in programming was considered for three months.

Figure 3 shows the different values of the initial investment corresponding to each alternative.

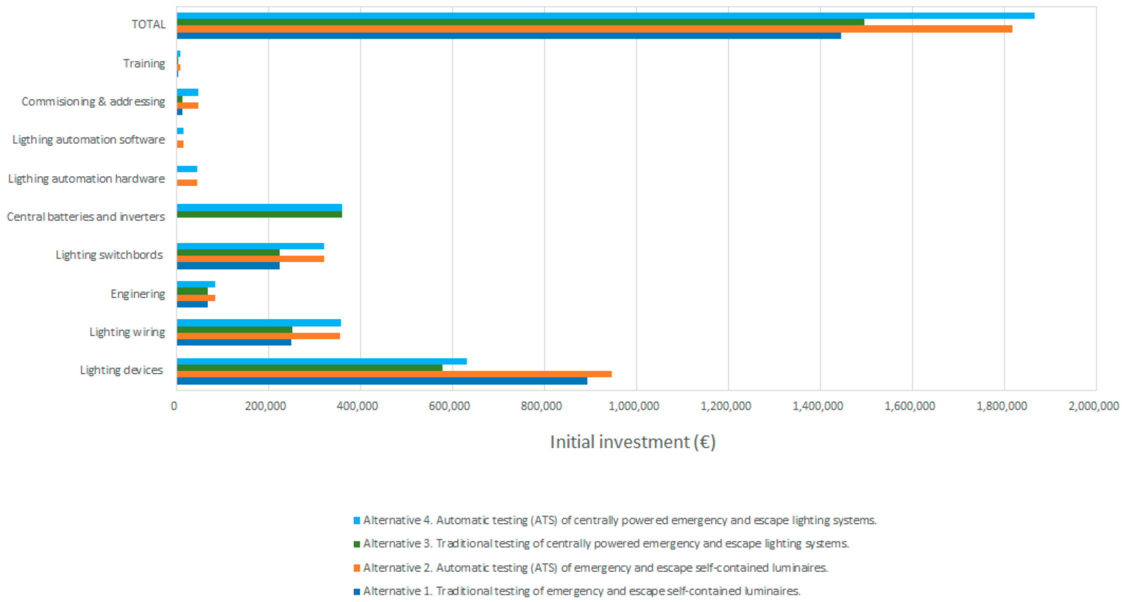

Figure 3. Investment costs of the four analyzed alternatives.

2.3.2. Operation Costs (*OC*)

These are recurring annual costs incurred throughout the system's service life. Operation costs include:

- Periodic power consumption of luminaires and testing systems. The energy consumption of emergency and escape lighting systems comprises three main components:
    1. Standby power to maintain battery charge in each luminaire.
    2. Energy used during routine functional and duration testing cycles.
    3. Power consumption of ancillary devices, such as ATS controllers, gateways, and communication interfaces (where applicable).

       For an installation with 1800 luminaires, the annual energy consumption is estimated to range between 8000 kWh (traditional systems) and 9000 kWh (smart systems), resulting in an annual cost ranging from EUR 1200 to EUR 1500.
- Monitoring system operation costs. This only applies to alternatives 2 and 4, because they include ATS. For alternative 2, the annual monitoring cost is estimated at an average of EUR 2880, which covers software licenses, communication gateways, and periodic updates. For alternative 4, the annual monitoring cost increases to EUR 5940, due to more complex centralized supervision, remote diagnostics, data logging, and potential cloud or server maintenance.
- Utility costs for continuous operation. The utility costs associated with the operation of emergency luminaires are assumed to be identical across all alternatives, as all systems operate with the same number and type of luminaires under similar load profiles. Therefore, utility costs are excluded from the life-cycle cost comparison, as they do not impact the economic performance of the alternatives.

2.3.3. Maintenance Costs (*MC*)

Like operation costs, maintenance costs are also recurring annual costs incurred over the system's service life. Maintenance costs include:

- Battery replacement cost. The annual cost for battery replacement is a significant component of the maintenance costs for emergency and escape lighting systems. For self-contained systems, where each luminaire has an individual battery, the annual cost is approximately EUR 20,250. This estimate is based on replacing 1/4 of the batteries annually, considering the typical replacement cycle of three to six years. In contrast, centralized systems, which use fewer batteries with a longer service life (six to eight years), incur a significantly lower annual replacement cost of approximately EUR 3000. This is based on replacing 1/7 of the batteries annually. Additionally, systems with ATS incur a slight increase in maintenance costs due to additional testing requirements, estimated at 5% of the battery replacement cost.
- Lamp or LED module replacement. The cost for LED lamp replacement is dependent on system configuration, with luminaires operating continuously throughout the year. Given a lifespan of 80,000 h per luminaire, the annual replacement frequency is derived from this operating time. For self-contained systems (alternatives 1 and 2), where each luminaire is replaced individually, the annual replacement cost is estimated at EUR 69,985. For centralized systems (alternatives 3 and 4), the annual replacement cost is lower, at approximately EUR 51,739. The inclusion of ATS does not influence the LED replacement cost, as the frequency is determined solely by the lifespan of the luminaires.
- Labor for manual inspection and testing. Manual inspection and functional testing represent a considerable operational cost for systems without ATS, specifically alternatives 1 and 3. These systems require regular manual verification of luminaire functionality and battery performance, in compliance with regulatory standards such as IEC 62034. For 1800 luminaires, the estimated annual labor requirement is 2160 h, based on 1.2 h per luminaire per year (12 functional tests and one duration test, per luminaire and year). With an average labor rate of EUR 40/h, the resulting annual cost is approximately EUR 86,400. This cost is eliminated in alternatives 2 and 4, where ATS automates the testing and reporting processes.
- Software updates and system calibration. Software updates and system calibration are recurring costs for ATS systems, applicable to alternatives 2 and 4. These systems require periodic firmware updates, cybersecurity patches, and calibration of central control units to maintain compliance with functional and safety standards (e.g., IEC 62034). For a system with 1800 luminaires, the annual technical maintenance—including software updates, diagnostics, and calibration—is estimated at EUR 3400, including 40 h of specialized labor at EUR 60/h and licensing fees of EUR 1000 per year.
- Spare parts and consumables. Spare parts and consumables are another recurring maintenance cost. This includes a fixed annual cost of approximately EUR 600 for general consumables (e.g., mounting accessories, labels, fuses) and the cost of replacing minor components in 1% of the luminaires annually. For self-contained systems, the component replacement cost is estimated at EUR 100 per luminaire, while for centralized systems, it is EUR 50 per luminaire.

2.3.4. End-of-Life Costs (*EOLC*)

These are costs incurred at the end of the system's useful life and may include:

- Dismantling and removal of luminaires, central units, and wiring. The cost of dismantling and removing luminaires, central units, and wiring infrastructure includes labor, transportation, and disposal. For non-centralized systems (alternatives 1 and 2), the primary cost is driven by the removal of 1800 luminaires at EUR 15 per unit, as well as four distribution panels. For centralized systems (alternatives 3 and 4), in addition to the removal of 1800 luminaires, there are eight distribution panels to be removed, and wiring removal costs are estimated at EUR 1500.

- Disposal of hazardous components. The disposal of hazardous components, especially batteries, is a significant cost at the end of the system's life cycle. This cost includes removal, transportation, and recycling fees. For self-contained systems, the cost to dispose of each battery is estimated at EUR 15. Over 30 years, approximately 10,800 batteries will need to be replaced, resulting in a total disposal cost. In contrast, for centralized systems with 20 batteries replaced over 30 years, the total disposal cost is minimal.

2.3.5. Residual Values (*RV*)

The residual value is the value that the components retain at the end of their service life. It is subtracted from the total lifecycle cost and may include the resale or reuse value of equipment, estimated book value of capital assets (accounting-based), materials with recovery value (e.g., copper, other metals), and so on. For self-contained systems (alternatives 1 and 2), the residual value is negligible due to the integrated nature of the components. In contrast, centralized systems (alternatives 3 and 4) may retain some residual value through the reuse or recycling of central units and materials. However, this value is still considered insignificant and is therefore disregarded in the total lifecycle cost calculation.

To summarize, Figure 4 shows the costs mentioned in the last sections, and Table 6 shows the main parameters of the LCCA.

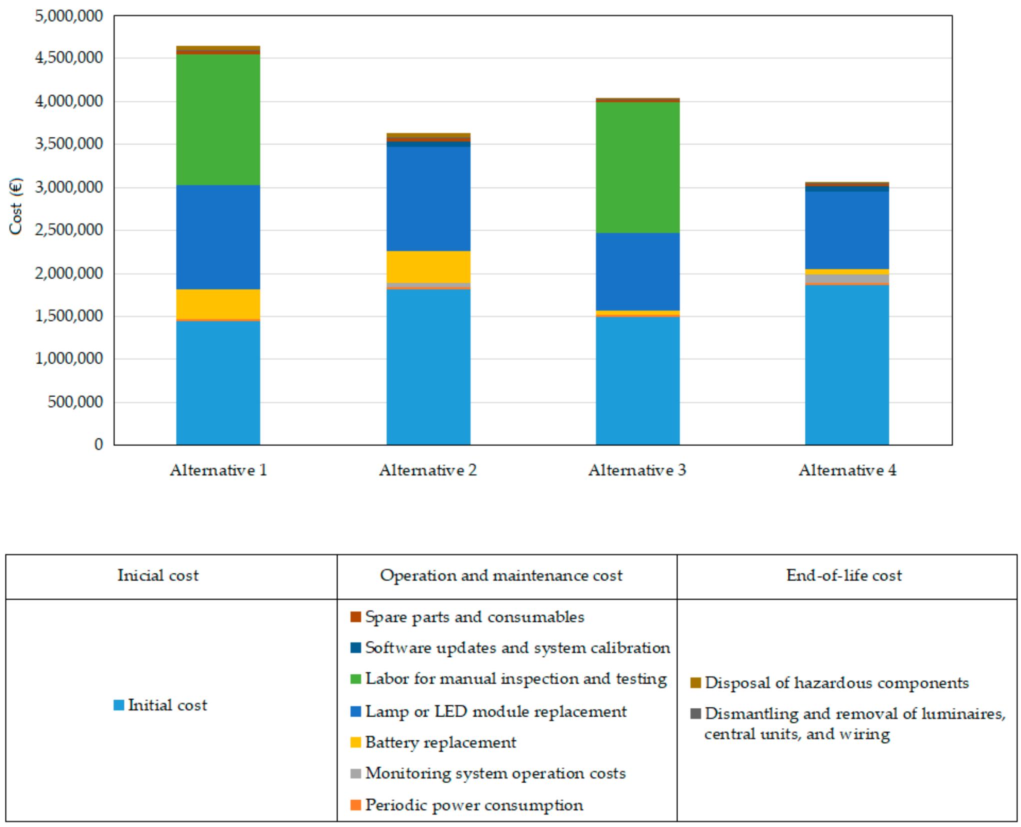

Figure 4. Costs employed in the LCCA.

Table 6. Summary of the main parameters of the LCCA.

Cost (€)	Alternative 1	Alternative 2	Alternative 3	Alternative 4
Initial cost	1,445,240	1,818,310	1,495,663	1,865,945
Operation and maintenance cost	3,137,318	1,755,251	2,517,745	1,174,22
End-of-life cost	62,359	62,359	12,948	12,948
Residual value	0	0	0	0
TOTAL	4,644,917	3,635,920	4,026,355	3,053,035

2.4. Decision Model

An MCDM model was carried out to take into account aspects beyond economic considerations when selecting the most appropriate alternative among the four considered. To facilitate this selection, a decision tree was established (see Table 7). As shown in this table, the model was structured around four primary criteria:

- cost
- system architecture and design optimization
- operational performance
- environmental sustainability

Table 7. Decision tree for the MCDM model.

Criterion	Sub-Criterion	Beneficial
1. Cost	1.1 *LCC*	✘
2. System architecture and device optimization	2.1 Wire cables	✘
	2.2 No dependency on central infrastructure	✘
	2.3 Luminaire weight optimization	✘
	2.4 Suitability for high-density luminaire configurations	✔
	2.5 Reduction of electrical number switchboards	✘
3. Operational performance	3.1 Interface with other systems (BMS, ICMS,. . .)	✔
	3.2 Influence of human error	✔
	3.3 Fault isolation and discrimination	✘
	3.4 Optimized data dogging and maintenance management	✔
	3.5 Reliability of monthly duration test performance	✔
	3.6 Reliability of yearly duration test performance	✔
	3.7 Time of fault detection	✔
4. Environmental sustainability	4.1 LED technology	✔
	4.2 Durability and longevity of enclosures	✔
	4.3 Reduced environmental impact from batteries	✘
	4.4 Number of batteries to be replaced	✘
	4.5 Battery service life	✔

Each of these criteria was further divided into several sub-criteria. Both beneficial and non-beneficial aspects were included. Beneficial are those for which higher values are preferred, while non-beneficial are those for which lower values are desirable. The nature of each sub-criterion is specified in the last column of the table (✔ beneficial, ✘ non-beneficial).

The values corresponding to each sub-criterion are detailed in Table 8. Most of these values were quantified using continuous measurement scales, such as monetary units (€), time durations (hours), and other metrics. For cases where quantitative continuous data could not be obtained, a qualitative assessment was employed using a Likert-type ordinal scale ranging from 1 to 5, where 1 denotes the least favorable performance and 5 the most favorable.

Table 8. Values of each sub-criterion.

Sub-Criterion (*i.j*)	Unit	Alternative 1 (*k* = 1)	Alternative 2 (*k* = 2)	Alternative 3 (*k* = 3)	Alternative 4 (*k* = 4)
1.1	€	4,644,917	3,635,920	4,026,355	3,053,035
2.1	kg	7920	11,880	8202.48	12,162.48
2.2	-	5	3	3	1
2.3	kg	7182	7182	5760	5760
2.4	-	1	4	2	5
2.5	switchboards	4	4	8	8
2.6	-	1	3	4	5
3.1	-	1	5	3	5
3.2	-	1	5	2	5
3.3	-	1	4	3	5
3.4	-	1	5	2	5
3.5	-	1	5	2	5
3.6	-	1	5	2	5
3.7	-	1	5	2	5
4.1	number	1800	1800	1800	1800
4.2	years	25	25	25	25
4.3	kg	1422	1422	240	240
4.4	number	1800	1800	4	4
4.5	years	3–6	3–6	6–8	6–8

To ensure comparability across criteria with different units and scales, a normalization process was applied to all values. Several normalization procedures can be found in the literature [42]. In the present work, the so-called linear max-min normalization was employed. In this method, the normalized values are given by the following equations:

$$V_{i.j,k} = \frac{X_{i.j,k} - X_{k,\min}}{X_{k,\max} - X_{k,\min}} \text{ for beneficial criteria} \tag{2}$$

$$V_{i.j,k} = \frac{X_{k,\max} - X_{i.j,k}}{X_{k,\max} - X_{k,\min}} \text{ for non-beneficial criteria} \tag{3}$$

whereby each $X_{i.j,k}$ represents the value of the sub-criterion *i.j* corresponding to the alternative *k*, $V_{i.j,k}$ the normalized value of $X_{i.j,k}$, $X_{k,max}$ the maximum grades of the alternatives for each sub-criterion *i.j*, and $X_{k,min}$ the minimum grades of the alternatives for each sub-criterion *i.j*.

The linear max-min normalization method transforms all values of a sub-criterion to a [0, 1] range, where a value of 0 corresponds to the least favorable outcome and a value of 1 corresponds to the most favorable outcome. Using this procedure, all values are transformed into a dimensionless scale that facilitates unbiased aggregation and comparison. The normalized values for the present work are shown in Table 9.

Several procedures can be used to evaluate and rank the alternatives. In the present work, the Simple Additive Weighting (SAW) method was employed. The SAW method was selected for this study due to its clarity, ease of implementation, and suitability for problems involving a large number of quantitative and qualitative criteria. Unlike more complex methods such as AHP, TOPSIS, or PROMETHEE, SAW is based on a straightforward aggregation of normalized values. Given the practical engineering context of this work—focused on evaluating real-world alternatives for emergency lighting systems—SAW provides a transparent and replicable framework that supports decision-making without introducing unnecessary computational complexity.

In the SAW method, the overall performance of each alternative is calculated as a weighted sum of its normalized scores across all sub-criteria, Equation (4). Given the hierarchical structure of the model, in which each main criterion comprises multiple sub-criteria, the adequacy index (AI) for each alternative is computed by aggregating the weighted contributions of all sub-criteria, nested within their respective main criteria, as shown in Equation (4). When the SAW method is used with linear max-min normalized values, the adequacy index falls within the [0, 1] range. A value close to 1 indicates a highly suitable alternative, while a value close to 0 indicates a less suitable one.

$$AI_k = \sum_{i=1}^{n} \alpha_i \cdot \left(\sum_{j=1}^{m_i} \beta_{i.j} V_{i.j,k} \right), \quad (4)$$

where AI_k is the adequacy index for alternative k, α_i is the weight (per unit basis) of the i-th main criterion, $\beta_{i.j}$ is the weight (per unit basis) of the j-th sub-criterion under criterion i, $V_{i.j,k}$ is the normalized value of the j-th sub-criterion of criterion i for alternative k, n is the number of main criteria, and m_i is the number of sub-criteria under criterion i.

Table 9. Normalized values of each sub-criterion.

Sub-Criterion (*i.j*)	Alternative 1 (*k* = 1)	Alternative 2 (*k* = 2)	Alternative 3 (*k* = 3)	Alternative 4 (*k* = 4)
1.1	1	0.634	0.389	1
2.1	1	0.067	0.933	0
2.2	1	0.788	0.091	0
2.3	0	0	1	1
2.4	0	0.75	0.25	1
2.5	1	1	0	0
2.6	0	0.5	0.75	1
3.1	0	1	0.5	1
3.2	1	0	0.75	0
3.3	0	0.75	0.5	1
3.4	0	1	0.25	1
3.5	0	1	0.25	1
3.6	0	1	0.25	1
3.7	0	1	0.25	1
4.1	1	1	1	1
4.2	1	1	1	1
4.3	0	0	1	1
4.4	0	0	1	1
4.5	0	0	1	1

3. Results

An important aspect of MCDM is establishing the weights assigned to each criterion and sub-criterion. These weights represent the importance given to each aspect. There are numerous objective methods available in the literature for determining weights using mathematical formulas. However, subjective weighting approaches are more frequently used. Objective methods are especially advisable when there is no consensus among the expert-defined weight sets [43,44]. In the present work, the weights were established based on what is known as expert citation. Twelve experts were consulted to assign weights to the criteria and sub-criteria. All experts have professional backgrounds in electrical engineering, offshore platform design, and safety systems, with direct experience in emergency and escape lighting projects. The weighting process was conducted using individual assessments followed by a consensus-building discussion. Each expert initially proposed weight distributions independently. These were then reviewed collectively, and a consensus-based approach was used to finalize the weights, ensuring that the final values reflected shared professional judgment and practical relevance.

The weights are shown in Table 10. It is important to note that a sensitivity analysis of the assigned weights is provided at the end of this section.

Table 10. Criteria weights.

Criterion	Criterion Weight	Sub-Criterion	Sub-Criterion Weight
1. Cost	α_1 = 40%	1.1 Initial cost	$\beta_{1.1}$ = 100%
2. System architecture and device optimization	α_2 = 20%	2.1 Wire cables 2.2 Independency on central infrastructure 2.3 Luminaire weight optimization 2.4 Suitability for high-density luminaire configurations 2.5 Reduction of electrical number switchboards 2.6 Streamlined luminaire design	$\beta_{2.1}$ = 10% $\beta_{2.2}$ = 20% $\beta_{2.3}$ = 10% $\beta_{2.4}$ = 30% $\beta_{2.5}$ = 15% $\beta_{2.6}$ = 15%
3. Operational performance	α_3 = 20%	3.1 Interface with other systems (BMS, ICMS,. . .) 3.2 Influence of human error 3.3 Fault isolation and discrimination 3.4 Optimized data dogging and maintenance management 3.5 Reliability of monthly functional test performance 3.6 Reliability of yearly duration test performance 3.7 Time of fault detection	$\beta_{3.1}$ = 15% $\beta_{3.2}$ = 15% $\beta_{3.3}$ = 10% $\beta_{3.4}$ = 15% $\beta_{3.5}$ = 15% $\beta_{3.6}$ = 15% $\beta_{3.7}$ = 15%
4. Environmental sustainability	α_4 = 20%	4.1 LED technology 4.2 Durability and longevity of enclosures 4.3 Reduced environmental impact from batteries 4.4 Number of batteries to be replaced 4.5 Battery service life	$\beta_{4.1}$ = 20% $\beta_{4.2}$ = 20% $\beta_{4.3}$ = 20% $\beta_{4.4}$ = 20% $\beta_{4.4}$ = 20%

As Table 10 shows, a weight of 40% was assigned to cost, 20% to system architecture and device optimization, 20% to functionality and operability, and 20% to environmental sustainability. Obviously, the total weight assigned to all criteria must equal 100, i.e., $\sum_{i=1}^{n} \alpha_i = 100$. Similarly, weights were also assigned to the sub-criteria. The sum of the weights of each sub-criterion must also equal 100, i.e., $\sum_{j=1}^{m_i} \beta_{i.j} = 100$. The cost criterion was assigned the highest weight, 40%, due to its critical influence on project feasibility. The system architecture and device optimization criteria were assigned a weight of 20%, reflecting their importance in ensuring modularity, scalability, and ease of integration with existing platform infrastructure. Sub-criteria, such as suitability for high-density luminaire configurations and reduction of switchboards, were emphasized due to their direct impact on engineering design and installation logistics. Operational performance was assigned a weight of 20%, acknowledging the need for real-time fault detection, automated testing, and integration with platform management systems—capabilities that are essential for maintaining safety and reliability in offshore conditions. Sub-criteria such as fault isolation, test reliability, and data logging were considered vital for minimizing human error and ensuring regulatory compliance. Finally, environmental sustainability was assigned a weight of 20%, in line with the growing pressure to reduce environmental footprints.

Based on the application of the SAW method described in the previous section, the *AIs* corresponding to each alternative were computed by aggregating the weighted and normalized scores across all sub-criteria. The results of applying Equation (3) are shown in Table 11.

Table 11. Adequacy indices corresponding to each alternative.

Alternative (*k*)	*AI*
Alternative 1	0.160 (4th)
Alternative 2	0.610 (2nd)
Alternative 3	0.529 (3rd)
Alternative 4	0.920 (1st)

The resulting indices shown in this table provide a quantitative measure of how well each alternative satisfies the defined evaluation criteria. These values, which range between 0 and 1, allow for a straightforward comparison: alternatives with higher adequacy indices are considered more suitable according to the model. The rankings are shown in brackets in the table. The computed results reveal clear differences in performance among the alternatives, thereby supporting an informed and transparent decision-making process. As can be seen, alternative 4 resulted in the best option with the first position, alternative 2 the second-best position, alternative 3 the third-best position, and alternative 1, the least recommended option, achieving the fourth-best and last position in the ranking.

It is worth mentioning that the *AI* calculated using Equation (4) can be broken down into four distinct sub-adequacy indices, each of which corresponds to one of the four key analyzed criteria: cost, system architecture and design optimization, operational performance, and environmental sustainability. Thus, the method enables the assessment of how each alternative contributes to each of these four pillars individually. Thus, it is possible to derive four sub-indices: an economic index (AI_{cost}), a system architecture and design optimization index (AI_{system}), an operational performance index ($AI_{performance}$), and an environmental sustainability index ($AI_{environment}$). These sub-indices are also determined using Equation (4), but by considering only the sub-criteria associated with each specific dimension. Table 12 presents the overall *AI* along with its corresponding sub-indices for the evaluated alternatives. Positions are indicated in brackets. This information is also shown graphically in Figure 5. As can be seen, alternatives 2 and 4 are notably suitable in terms of performance ($AI_{performance}$), alternatives 2 and 4 stand out for their cost (AI_{cost}), and alternative 1 has the lowest values for the four criteria considered (AI_{cost}, AI_{system}, $AI_{performance}$, and $AI_{environment}$).

Table 12. Detailed results and rankings.

Alternative (*k*)	Adequacy Indices				
	AI_{cost}	AI_{system}	$AI_{performance}$	$AI_{environment}$	*AI*
Alternative 1	0.000 (4th)	0.050 (4th)	0.030 (4th)	0.080 (4th)	0.320 (4th)
Alternative 2	0.254 (2nd)	0.111 (2nd)	0.165 (2nd)	0.080 (4th)	0.538 (3rd)
Alternative 3	0.155 (3rd)	0.096 (3rd)	0.078 (3rd)	0.200 (1st)	0.596 (2nd)
Alternative 4	0.400 (1st)	0.150 (1st)	0.170 (1st)	0.200 (1st)	0.760 (1st)

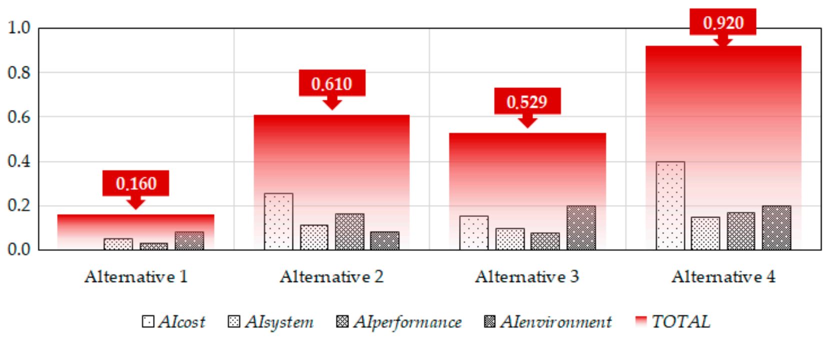

Figure 5. Results of total and partial adequacy indices.

It is important to highlight that MCDM methods are inherently subjective, and SAW is no exception. Subjectivity primarily arises when assigning weights. As a result, applying Equation (4) may yield different outcomes depending on these inputs. However, while the exact numerical results might vary, the overall ranking of alternatives should remain largely consistent, provided that the weights are chosen reasonably. Shifts in ranking are typically limited to alternatives with very similar input values and performance. Similarly, the difference between the adequacy indices of two alternatives may vary with different input assumptions, though the proportional relationship between them tends to remain somewhat consistent. To address these uncertainties, a sensitivity analysis is a recommended approach; one such analysis was carried out in this study. A weight sensitivity analysis was performed by examining six cases with different weight combinations, as shown in Table 13. The results are visually represented in Figure 6. As can be seen, the adequacy indices change slightly according to the different weight distributions. The positions of each alternative remain unchanged. Alternative 4 appears to be the most adequate option in all six cases. This indicates that the model is robust, as small changes in the weights do not significantly affect the results.

Table 13. Adequacy indices derived from the weight sensitivity analysis.

Weights and Adequacy Indices	Cases					
	Case 1	Case 2	Case 3	Case 4	Case 5	Case 6
α_1	40%	35%	35%	45%	45%	45%
α_2	20%	25%	20%	20%	15%	25%
α_3	20%	20%	25%	15%	15%	15%
α_4	20%	20%	20%	20%	25%	15%
AI_1 (alternative 1)	0.160 (4th)	0.173 (4th)	0.168 (4th)	0.153 (4th)	0.160 (4th)	0.145 (4th)
AI_2 (alternative 2)	0.610 (2nd)	0.606 (2nd)	0.619 (2nd)	0.600 (2nd)	0.592 (2nd)	0.608 (2nd)
AI_3 (alternative 3)	0.529 (3rd)	0.534 (3rd)	0.529 (3rd)	0.529 (3rd)	0.555 (3rd)	0.503 (3rd)
AI_4 (alternative 4)	0.920 (1st)	0.908 (1st)	0.913 (1st)	0.982 (1st)	0.940 (1st)	0.915 (1st)

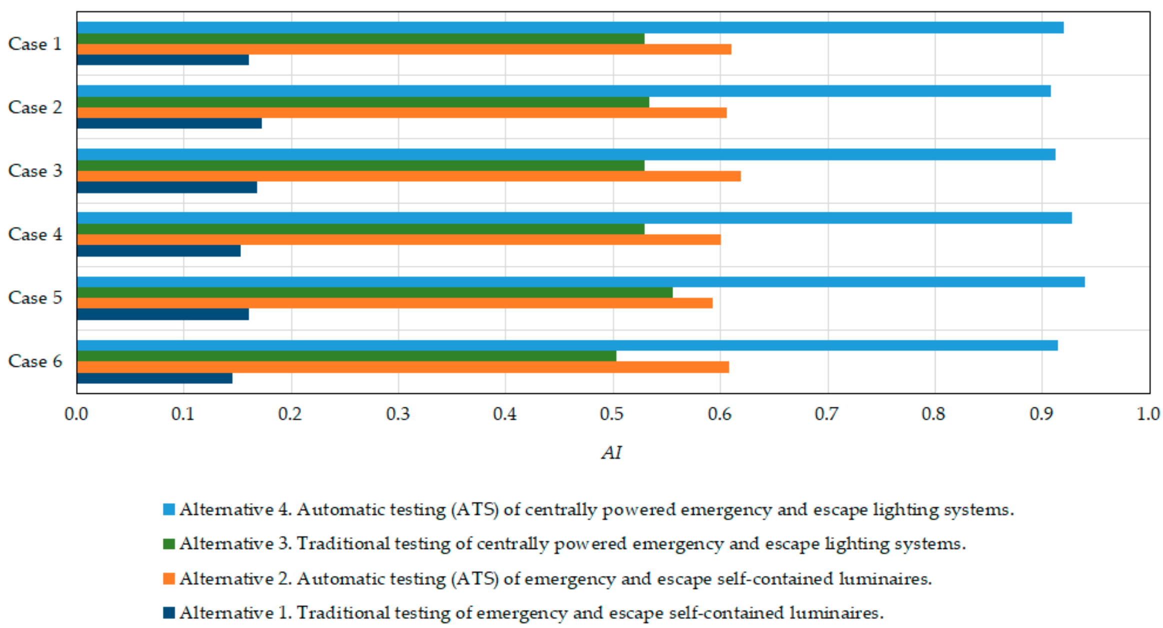

Figure 6. Results of the six cases examined.

4. Discussion

The importance of this work lies in its comprehensive integration of technical, economic, operational, and environmental criteria to evaluate emergency lighting and escape systems for offshore platforms. The LCCA demonstrated the initial capital investment, operating and maintenance costs, and end-of-life expenses. Among the options, alternatives 2 and 4, which are based on ATS automated testing systems, emerged as the most cost-effective solutions. While alternative 4 has the highest initial cost, it reduces operating and ongoing maintenance expenses, resulting in the lowest total life-cycle cost. Its initial cost is slightly higher than alternative 2, but this solution has higher operating and maintenance costs. Alternatives 1 and 3, based on manual testing systems, offer a lower initial investment than alternatives 2 and 4, but lack the automated fault detection, real-time monitoring, and integration capabilities that characterize alternatives 2 and 4. These limitations reduce their responsiveness and reliability in safety-critical marine environments. The LCCA has shown that alternatives 1 and 3 are less cost-effective in the long term due to higher maintenance costs.

Using the LCCA data in the MCDM model, alternatives 2 and 4 also emerged as the most suitable solution for emergency and escape lighting on the BorWin5 offshore platform. Alternative 4 provided better results than alternative 2, as the centralized power supply offers performance advantages. Therefore, alternative 4 was selected and successfully implemented on the BorWin5 platform, proving its effectiveness in addressing the unique technical, environmental, and operational challenges inherent in offshore installations. Details are presented in Appendix A. This safety system has been designed with the most advanced technologies on the market to ensure maximum reliability and performance in critical infrastructure applications.

To the authors' knowledge, offshore platforms constructed to date are equipped with conventional emergency and battery-powered escape lighting techniques, and have not been implemented in accordance with the IEC 62034:2012 regulation (Automatic Test Systems for Battery-Powered Emergency Escape Lighting). Alternatives 1 and 3 have been widely used on platforms all over the world. The offshore wind platform market is a relatively recent development, with typical construction timelines ranging from two to three years. For example, the DolWin6 HVDC platform—delivered in September 2023—featured centralized battery-powered LED emergency lighting without automatic testing capabilities, corresponding to the alternative 3 in this study. In contrast, upcoming platforms such as DolWin4 and BorWin4, which are scheduled for delivery in 2028 and 2029, respectively, will incorporate centrally powered systems with automatic testing (ATS), aligning with alternative 4. This progression reflects a clear industry trend toward smarter, more integrated safety systems in offshore environments. As the technology of intelligent systems constantly advances, alternatives 2 and 4 are expected to be widely implemented in the future.

5. Conclusions

This study demonstrates that the implementation of automatic testing systems for emergency and escape lighting, in accordance with IEC 62034:2012, offers a robust and future-proof solution for offshore platforms operating in demanding environments. Through a comprehensive LCCA and an MCDM analysis, four alternative configurations were evaluated based on cost, system architecture, operational performance, and environmental sustainability. The results clearly identified the automatic testing of centrally powered systems as the most suitable option, offering superior reliability, maintainability, and integration capabilities.

The successful deployment of this solution on the BorWin5 HVDC converter platform validates its technical and economic feasibility. Key innovations—such as the use of a 220 VDC emergency network, open-architecture network, real-time monitoring, and DALI-based interoperability—highlight the system's adaptability and long-term scalability. Moreover, the adoption of an open communication protocol breaks away from vendor lock-in, enabling flexible integration of multi-brand luminaires and enhancing lifecycle sustainability.

This work not only advances the implementation of the IEC 62034:2012 standard on the BorWin5 platform but also provides a replicable framework for future offshore infrastructure projects. The BorWin5 case study serves as a reference for the modernization of emergency and escape lighting systems in critical offshore installations. The implications of this study are multifaceted. Technically, it supports the transition toward intelligent, interoperable lighting systems that enhance safety and reduce maintenance overhead. Economically, it demonstrates that higher initial investments in automation can yield substantial long-term savings. Strategically, it provides a decision-support tool for engineers, designers, and regulators involved in offshore infrastructure planning.

Certain limitations must be acknowledged. The weighting of criteria in the MCDM model, although based on expert consensus, inherently involves subjective judgment. Additionally, the analysis assumes stable operational conditions and does not account for unforeseen events such as system-wide failures, cyberattacks, or extreme weather disruptions that could affect system performance or maintenance schedules. Future work could incorporate probabilistic risk assessment or dynamic modeling to address these uncertainties.

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Appendix A. Emergency and Escape Lighting System of BorWin5

The emergency and escape lighting system of BorWin5 platform was developed in Spain by the company Norispan S.L. The first author of the present work was involved in the project.

The emergency and escape lighting system incorporates a comprehensive testing and monitoring framework capable of reporting the operational status of each installed luminaire. Monitoring can be conducted either locally via a Human-Machine Interface (HMI) or remotely through integration with the platform's automation system, both onshore and offshore. The system is fully compliant with the IEC 62034:2012 standard, which specifies the requirements for automatic testing systems for battery-powered emergency escape lighting.

The system is powered via dual redundant sources: the emergency power supply system at 400 V AC and the 220 V DC battery system. These sources interconnect through a Battery Connection Box incorporating diode isolation to prevent reverse current flow, thereby ensuring uninterrupted power delivery under fault conditions.

In the event of failure of either power source, no less than 30% of the lighting fixtures within each compartment or designated zone maintain full operational functionality. The illumination provided under these conditions does not fall below the minimum required for safe escape and rescue route lighting as stipulated by applicable safety regulations.

The emergency and escape lighting system activates automatically and operates in continuous mode, maintaining constant illumination until normal power is restored and the system is reset.

The emergency lighting system is engineered such that any failure, including fire or other casualty within spaces housing the emergency power sources—such as transformers, converters, or associated electrical equipment—does not result in the loss of illumination provided by the main lighting system. The system guarantees adequate residual illumination levels to satisfy safety requirements during a general lighting outage.

A lighting study was conducted using the DIALux evo software 13.1, with the updated plugins specifically developed for this project by the lighting suppliers. Based on this study, both the onboard luminaire layout drawings and the corresponding wiring diagrams were prepared. The components shown in Table A1 and Figure A1.

Table A1. Components of the emergence and escape lighting.

Distribution panels	Central emergency lighting switchboard Sub-distribution emergency lighting switchboard Central escape lighting switchboard Sub-distribution escape lighting switchboard
220 Vdc/3 × 400 V + N inverters	Emergency inverter Escape inverter
Approximately 1800 luminaires with DALI drivers for the emergency and escape networks	

The Emergency/Escape Subdistribution Boards are supplied from the Central Panels via a single incomer. Under normal operating conditions, the emergency and escape lighting system receives power from the emergency distribution board (via the main switchboard) and remains continuously energized.

The emergency and escape lighting system is designed to supplement the platform's normal lighting, with an approximate ratio of 2:1—meaning that for every emergency and escape luminaire, two normal lighting luminaires are installed, resulting in a total of approximately 1800 luminaires.

All emergency lighting fixtures are LED and comply with platform standards and the applicable regulations of the DNV GL Classification Society [45]. Critical factors in the selection of equipment included key environmental conditions such as humidity, temperature, corrosion resistance, ingress protection, illuminance levels, and a required service life of 30 years.

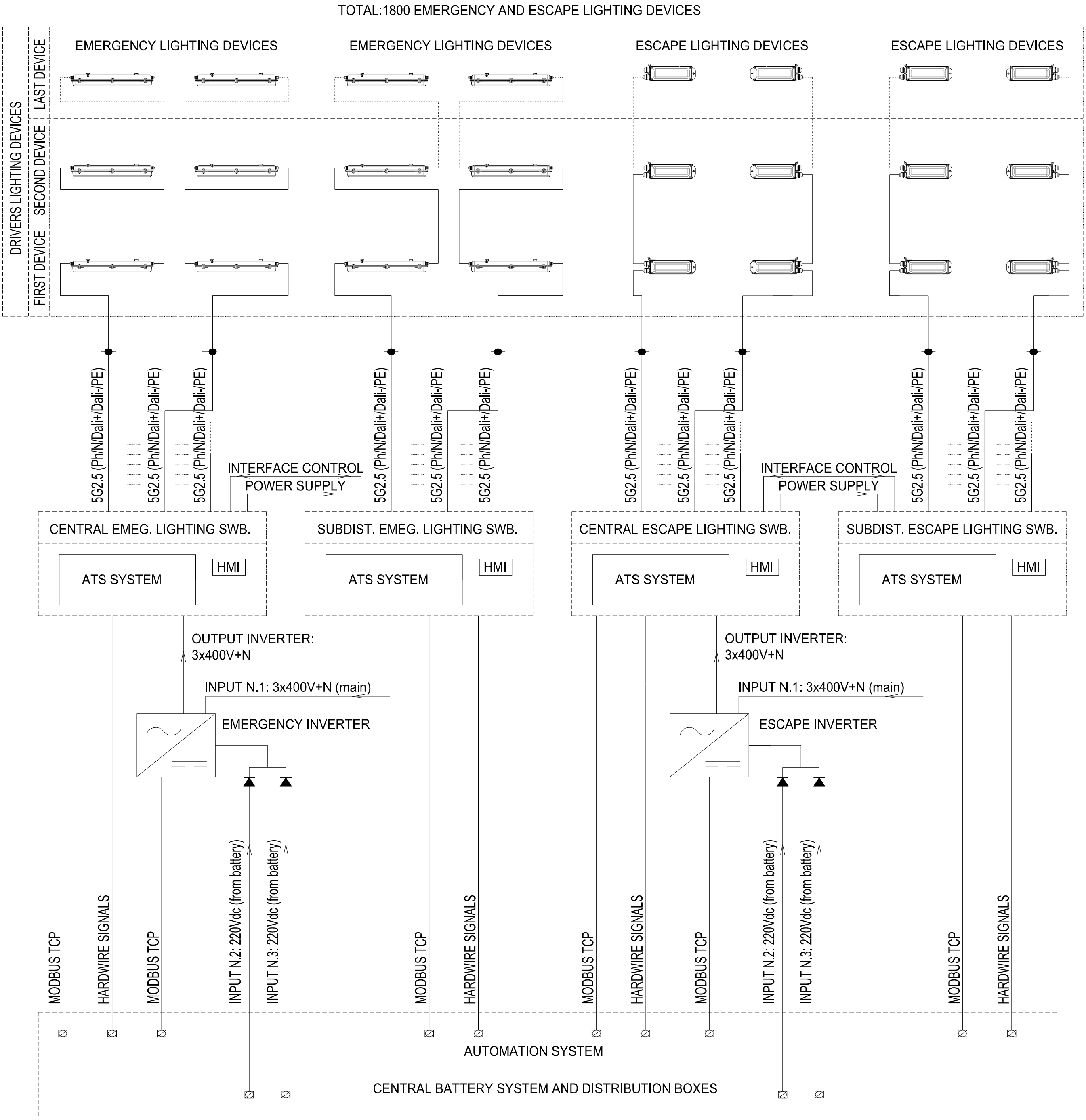

Figure A1. Layout of the emergency and escape lighting.

As previously mentioned, all installed lighting deviced are monitored both through the automation system of the system which is intefaced with the automation system of the platform. For this reason, all luminaires are equipped with DALI-2 drivers. All luminaires are capable of operating at both 230 V AC and 220 V DC via inverter.

One of the main advantages of the developed design is the use of luminaires from multiple marine-grade suppliers, with full interoperability between them—made possible through DALI technology.

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