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Integrated Energy Management System of Bicol Airport

Engr. Homer O. Principe
University of Santo Tomas–Legazpi, Legazpi City, Albay, Philippines
engr.hop@gmail.com

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ABSTRACT

This study assessed energy consumption and supply at Bicol Airport in Daraga, Albay, examined implementation of energy reduction measures mandated by the Civil Aviation Authority of the Philippines, and proposed an integrated energy management system (EnMS). The study employed documentary analysis, interviews involving 20 chiefs of office and 70 airport employees, thematic analysis, and an independent energy audit mechanism. Historical electricity and fuel records covered January 2024 through June 2026. The findings identified terminal facilities, heating, ventilation and air conditioning, and lighting as electricity consumers, while powerplant generators dominated recorded fuel use. Limited submetering restricted equipment-level assessment. Interview findings emphasized resource availability, organizational policies, management commitment, employee participation, technical competencies, and dedicated funding as conditions for effective implementation. The proposed system combines energy monitoring, conservation measures, renewable energy integration, and organizational accountability. The consolidated preliminary solar photovoltaic design for seven facilities specifies 1,212.9 kWp of capacity and modeled annual generation of 1,429,948.47 kWh. At an assumed electricity tariff of PHP 11 per kWh, estimated gross annual savings amount to PHP 15,729,433.17 against estimated capital expenditure of PHP 94,487,550.30, yielding a gross simple payback of 6.01 years. These projections are conditional on actual onsite utilization, system performance, and tariff arrangements and do not represent realized savings. Electric vehicle replacement was also examined as a fuel conservation option. The study recommends systematic monitoring, qualified energy management personnel, financing, and validation of technical designs before implementation. The proposed framework supports regulatory compliance, operational efficiency, energy resilience, and continuous improvement in airport energy performance.

Keywords: *energy management system, airport operations, solar photovoltaic, energy efficiency, energy audit, renewable energy, ISO 50001, Philippines*

INTRODUCTION

Airports are energy-intensive infrastructures because terminal buildings, airfield lighting, cooling, security, baggage handling, communications, and emergency systems require reliable energy. Growing passenger traffic increases the need for efficient resource management while maintaining safety and service quality (Ortega Alba & Mañana, 2016). Bicol Airport, located in Daraga, Albay, is managed by the Civil Aviation Authority of the Philippines (CAAP). Its passenger traffic has grown since inauguration in 2021, increasing the importance of energy planning and operational resilience.

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Republic Act No. 11285 establishes the national energy efficiency and conservation framework. The source classifies Bicol Airport as a Type 2 designated establishment based on estimated annual electricity consumption of 3 million kWh. ISO 50001:2018 provides a framework for energy performance monitoring and continual improvement through the Plan–Do–Check–Act cycle. The airport lacks a fully integrated real-time energy management approach, particularly for detailed monitoring, coordinated conservation, and renewable energy integration.

Theoretical and Conceptual Framework

The study combines Systems Theory, the Technology Acceptance Model, the Plan–Do–Check–Act cycle, and RA 11285. Systems Theory treats airport facilities, technology, personnel, and energy flows as interconnected. The Technology Acceptance Model emphasizes perceived usefulness and ease of use in adopting energy-efficient practices. PDCA provides a continuous improvement process, while RA 11285 establishes the regulatory context.

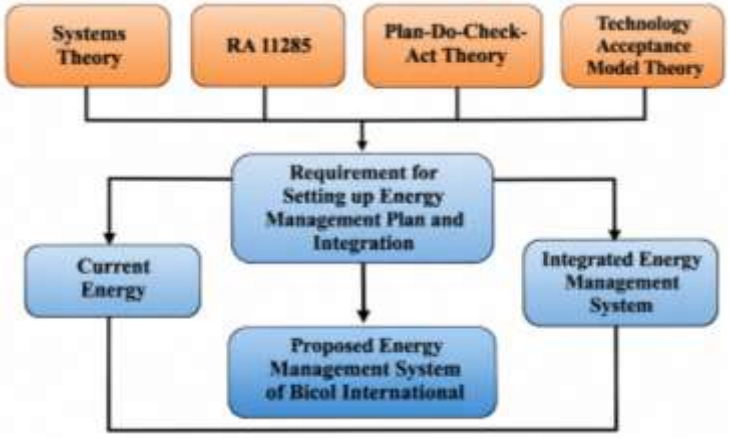

Figure 1. *Theoretical and conceptual framework*

Objectives of the Study

The study sought to (1) assess current energy consumption and supply; (2) determine implementation of CAAP-mandated energy reduction in technical, operational, organizational and management, and financial dimensions; and (3) propose an Integrated Energy Management System addressing electricity and fuel costs.

METHODS

Research Design

The study assessed documented evidence concerning the airport engineering plans, equipment design, energy-related data, and employee awareness of energy efficiency and conservation at Bicol Airport. A documentary analysis and qualitative research approach were employed, involving the systematic collection and examination of official reports, engineering plans, energy consumption records, technical and equipment documents, organizational publications, and other credible materials to identify existing energy efficiency and conservation practices, policies, programs, and measures. In addition, interviews with selected employees were conducted and analyzed to determine their awareness and perceptions regarding workplace energy conservation practices. The findings from the documentary analysis and interviews were integrated to provide a comprehensive understanding of the airport's existing energy efficiency and conservation efforts, identify existing gaps and practices, and serve as a basis for proposing feasible and

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practical recommendations that considered the airport's engineering plans, equipment, operational practices, energy consumption patterns, and employee awareness.

In this research, data were gathered through various methods, incorporating interviews through Focus Group Discussions (FGDs), thematic analysis, documentary analysis, an energy audit, and a review of electricity consumption based on available records. The empirical data collected were examined using document analysis. Document analysis, which is commonly employed in case studies, focused on gathering and examining information from formal documents and organizational records. The documents collected for the study were evaluated based on four criteria: authenticity, credibility, representativeness, and meaning. Before conducting the formal analysis of the collected documents, the context in which they were created was established, and their authenticity was assessed.

An innovative aspect of the study involved the incorporation of an independent energy audit mechanism. This mechanism was aligned with the documents and procedures utilized by the Department of Energy in conducting independent energy audits of public buildings and institutions. The audit report also served as a basis for examining and evaluating relevant agency documents that supported the implementation of energy efficiency and conservation measures.

Respondents and Sampling

The target population of the study consisted of personnel of Bicol Airport community, Chiefs of Office and Airport Employees including technical staffs who were selected through purposive sampling.

The total number of the Chiefs of Office (20) and the Airport Employees (70) were taken because they were only few could be accessed. Only samples of the airport Chiefs of Office (20 out of 20) and airport employees (70 out of 175) will be interviewed. Table 1 shows the number of respondents of the study.

Furthermore, the research employed purposive sampling, a non-probability sampling technique in which participants were deliberately selected based on their specific characteristics, knowledge, experiences, and qualifications relevant to the study. This approach enabled the researcher to identify individuals with direct knowledge and practical experience of Bicol Airport's existing energy management practices, ensuring that the information gathered was relevant, reliable, and meaningful to the research objectives.

The selection of participants was guided by specific criteria, particularly their work experience, current position, and familiarity with the subject matter. The identified participants included the Chiefs of Office of the Civil Aviation Authority of the Philippines (CAAP)–Bicol Airport and selected airport employees whose roles and responsibilities provided them with relevant knowledge and insights into the airport's energy consumption, operational activities, and existing energy management practices.

Table 1. Respondents of the study

Respondents	Target Population	Sample
Airports Managers and Chiefs of Office	20	20
Airport Employees including Technical Personnel	175	70
TOTAL	195	90

The employee sample was allocated equally between ancillary buildings and the passenger terminal building (35 each). The source describes both purposive selection and facility-based allocation.

Instruments and Data Collection

The research sought the assistance of Subject Matter Experts (SMEs) with substantial expertise relevant to the study to validate the interview guide developed for data collection. The SMEs evaluated the interview guide to ensure that the questions were appropriate, relevant, clear, and aligned with the objectives

of the study. Certificates of validation issued by the SMEs were included in the appendices of the paper as supporting documentation.

A copy of the Interview Questionnaire used in the study was included in Appendix C. In conducting the key informant interviews, the researcher manually encoded the responses and identified the words and phrases used to establish connections among themes, which were subsequently tabulated.

The study on energy management practices at Bicol Airport employed a structured and multi-method approach to ensure a comprehensive understanding of energy usage, compliance, and potential improvements.

For the first objective, which assessed the current energy usage patterns of energy consumption and supply at Bicol Airport, the research primarily utilized documentary analysis. This involved examining existing records, such as electricity bills, fuel consumption reports, and operational data, to establish baseline energy usage patterns. In addition, an independent energy audit was conducted to validate the findings and identify discrepancies between recorded data and actual energy performance, particularly in systems and facilities that contributed to excessive energy consumption.

For the second objective, which determined the level of compliance of Bicol Airport with the requirements of an Energy Management System (EnMS), the study employed interviews with key stakeholders, including chiefs of offices, airport employees, and technical personnel involved in energy management and airport operations. The assessment focused on four dimensions of EnMS compliance: technical, operational, organizational and management, and financial. Through these interviews, the researcher gathered relevant information on the extent to which energy management policies, procedures, and practices were implemented in the airport's day-to-day operations. The interviews also explored the participants' experiences, observations, and perspectives regarding existing energy management practices, challenges encountered during implementation, and potential measures to improve energy efficiency and reduce the airport's overall energy consumption.

The interview data were analyzed using thematic analysis, a qualitative research method that involved identifying, organizing, and interpreting recurring patterns or themes in the participants' responses. This approach enabled the research to identify common issues, strengths, gaps, and challenges related to EnMS compliance across the four dimensions. The findings provided a deeper understanding of Bicol Airport's existing energy management practices and served as a basis for identifying opportunities for improvement and recommending appropriate measures to strengthen EnMS implementation and promote more efficient energy use.

Finally, the third objective focused on proposing an Integrated Energy Management System for Bicol Airport operations by evaluating three key areas: energy inefficiency, electricity costs, and fuel consumption costs. The study analyzed these areas to establish a basis for comparing historical energy expenses with current energy consumption and costs. Furthermore, it assessed the potential cost reductions resulting from the proposed improvements and determined their impact on the overall energy efficiency, operational expenses, and energy management practices of Bicol Airport.

Ethical Considerations

The research recognized the importance of observing proper ethical standards, demonstrating respect and courtesy, and complying with the provisions of the Data Privacy Act of 2012. All data collected throughout the study were used exclusively for academic and research purposes. These measures were undertaken to protect the rights, privacy, and confidentiality of all individuals who voluntarily participated in the study and generously shared their time, knowledge, and insights in the hope that the findings would contribute to the improvement of their lives and well-being.

Furthermore, all research assistants and data tabulators were instructed to observe ethical standards and maintain strict confidentiality regarding all information gathered during the study. These measures

aimed to protect participants' privacy, particularly those involved in the key informant interviews, and preserve the integrity of the research.

The researcher declared no personal, financial, or professional conflicts of interest that could influence the study's conduct or findings. The research was conducted solely for academic purposes, with the objective of providing valuable insights into energy utilization, conservation, and sustainability. The researcher remained committed to maintaining objectivity, presenting findings accurately, and promoting responsible and efficient energy consumption.

Data Analysis

Documentary records and the independent audit were used to establish energy baselines and identify significant energy uses. Interview responses were manually encoded and grouped into recurring themes. Preliminary PV sizing used average daily consumption, 3.8 peak sun hours, and assumed system efficiency of 85%. Annual PV generation was estimated as installed capacity multiplied by peak sun hours, 365 days, and system efficiency. Gross savings used ₱11/kWh; simple payback divided capital cost by gross annual savings. Annual operation and maintenance (O&M) was assumed to equal 1% of capital cost. EV replacement was evaluated using fuel records and illustrative fuel economy, charging consumption, and price assumptions.

RESULTS

Current Energy Consumption and Supply

electricity bills, utility meter readings, equipment operating schedules, and the energy consumption patterns of major electrical and mechanical systems. These data were essential in establishing the airport's energy baseline, identifying Significant Energy Uses (SEUs), and determining Energy Performance Indicators (EnPIs) in accordance with ISO 50001 requirements. Although energy monitoring was conducted through the main electrical metering system, the limited availability of sub-metering made it difficult to determine the specific energy consumption of individual equipment and operational areas. This limitation affected the identification of energy inefficiencies and the evaluation of existing energy-saving measures.

Monitoring monthly and annual electricity consumption trends helped identify variations in energy demand and possible equipment inefficiencies. HVAC systems, lighting, and other essential airport facilities were identified as major contributors to overall electricity consumption. The assessment emphasized the importance of continuous monitoring, regular energy evaluations, and improved metering systems to identify energy-saving opportunities, reduce operating costs, and improve energy efficiency. These measures also supported the proposed implementation of an ISO 50001-compliant Energy Management System and promoted the long-term sustainability of Bicol Airport.

The graph shows fluctuations in monthly electricity usage, ranging from approximately 220,000 to 315,000 kWh. Both electricity consumption and utility expenses peaked in June, reaching approximately ₱4 million, while March recorded the lowest consumption and January the lowest utility cost. Overall, the data show a general relationship between energy consumption and electricity expenses, highlighting the importance of monitoring energy usage and implementing conservation measures to improve efficiency and reduce utility costs.

The graph shows fluctuations in monthly electricity usage, ranging from approximately 260,000 to 325,000 kWh. Consumption peaked in May and gradually decreased before increasing again toward December. Similarly, the monthly utility cost generally followed the same trend, with its highest level recorded in May. Overall, the data highlight the need for continuous monitoring of electricity consumption and the implementation of energy conservation measures to improve efficiency and manage utility expenses.

The graph shows fluctuations in electricity usage and monthly expenses from January to June. Electricity consumption was highest in January and February at approximately 285,000 kWh and decreased

in March before stabilizing at around 255,000 kWh from April to June. Meanwhile, the monthly electricity bill generally increased, reaching its highest level in June at approximately ₱2.8 million. Overall, the data indicate that electricity costs continued to rise despite relatively stable energy consumption, highlighting the need for continuous monitoring and effective energy management to improve efficiency and control utility expenses.

The table shows the monthly fuel consumption of four facilities: Aerodrome Rescue and Fire Fighter (ARFF), Maintenance (MD), Air Navigation Service (ANS), and Powerplant (PP). Among the four facilities, Powerplant recorded the highest fuel consumption throughout the year, significantly contributing to the overall monthly totals. The highest total consumption was recorded in April at 20,694.87, while the lowest was in July at 5,909.00. Overall, the report indicates fluctuations in monthly fuel consumption, highlighting the need for continuous monitoring and efficient fuel management to ensure proper utilization of resources.

The table presents the monthly figures of the four airport facilities for the year 2025; Powerplant consistently recorded the highest figures among the four facilities, making it the largest contributor to the overall monthly totals. Maintenance also showed significant contributions, while ARFF and ANS recorded comparatively lower figures throughout the year. The highest combined monthly total was recorded in April at 10,755.80, mainly due to the substantial Powerplant figure of 8,887.37. On the other hand, September registered the lowest combined total at 3,515.85. Overall, the monthly figures fluctuated throughout the year, indicating variations in the recorded performance of each facility.

The table shows the monthly expenses of four airport facilities from January to June 2026. Powerplant (PP) consistently recorded the highest expenses, particularly in May (16,516.10) and June (14,628.40), making it the largest contributor to the overall expenditures. Maintenance (MD) also accounted for significant expenses, while ARFF and ANS recorded comparatively lower amounts. The highest total monthly expenditure was recorded in May at 18,787.61, while February had the lowest at 2,518.13. Overall, the data reflect fluctuations in facility expenses,

distribution utility (Albay Electric Cooperative, Inc- ALECO) through the national power grid. This electrical supply serves all major airport facilities, including the passenger terminal building, administration offices, control and communication systems, security facilities, lighting systems, heating, ventilation, and air-conditioning (HVAC) systems, water supply and pumping stations, baggage handling equipment, and other operational support systems. The availability of a stable utility power supply is essential to maintaining normal airport operations and ensuring passenger safety and comfort.

To enhance operational reliability, the airport is equipped with emergency standby generator sets that automatically provide backup power during utility outages or interruptions. These generators are designed to supply electricity to critical loads such as runway and airfield lighting, navigational aids, communication equipment, security systems, emergency lighting, and other mission-critical facilities. The presence of standby power systems minimizes operational disruptions and ensures compliance with aviation safety requirements during unforeseen power failures.

The airport has also started implementing the use of solar-powered lighting systems along its perimeter and access roads as part of its efforts to promote energy efficiency and environmental sustainability. These solar lights harness energy from sunlight during the day and store it in batteries for use at night, reducing the airport's reliance on conventional electricity. This initiative helps lower electricity consumption and operational costs while providing adequate illumination to enhance visibility and safety for motorists, airport personnel, passengers, and security teams. See in Figure 8.

Although the existing energy supply system provides sufficient electrical power to support airport operations, the airport remains highly dependent on grid-supplied electricity. This dependence exposes operations to risks associated with fluctuations in electricity prices, grid disturbances, and external power interruptions. Furthermore, the current energy supply relies predominantly on conventional electricity

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sources, with limited integration of renewable energy technologies such as solar photovoltaic (PV) systems or other alternative energy sources that could improve energy resilience and sustainability.

Table 2. *Average consumption and preliminary PV sizing by metered facility*

Facility	30-Month Avg. (kWh/mo)	Avg. Daily (kWh/day)	Calculated PV (kWp)	Preliminary PV Capacity (kWp)
Administration Building	4,245.67	141.52	43.81	45
DPPH –Cluster	9,489.67	316.32	97.93	100
DPWR – Water Reservoir	2,880.47	96.02	29.73	30
MDP–PT1	38,196.67	1,273.22	394.19	400
MDP–PT2	60,480.00	2,016.00	624.15	625

The DPPH meter covers three buildings. The source uses an equal allocation as a preliminary estimate, not independently measured building consumption.

Table 3. *Estimated allocation of DPPH consumption*

DPPH Component	Estimated Avg. (kWh/mo)	Estimated Daily (kWh/day)	Calculated PV (kWp)	Rounded PV (kWp)
DPPH cluster	9,489.67	316.32	97.93	100
Maintenance Building*	3,163.22	105.44	32.64	35
CAAP–DOTR Quarters*	3,163.22	105.44	32.64	35
CFR Building*	3,163.22	105.44	32.64	35

Implementation of CAAP Energy Reduction Measures

Technical

The findings revealed that the implementation of the Energy Management System (EnMS) at Bicol Airport primarily focuses on monitoring and analyzing energy consumption to establish a baseline and identify opportunities for improvement. Most respondents emphasized the importance of reviewing current consumption patterns and conducting monthly monitoring to determine trends, identify variances, and recognize areas where energy efficiency can be improved. This suggests that Bicol Airport uses energy consumption data as a basis for evaluating its energy performance and guiding energy management decisions.

The findings revealed that resource availability and adequacy emerged as the most influential factor in the implementation of the Energy Management System at Bicol Airport, as reported by all respondents. This indicated that adequate financial resources, personnel, equipment, technology, and time are considered essential for carrying out energy-efficiency initiatives. Without sufficient resources, the organization may encounter difficulties in implementing energy conservation measures, maintaining energy monitoring systems, and sustaining improvements in energy performance.

The second most frequently identified factor is the presence of clear organizational policies and procedures. This suggested that well-defined energy policies, procedures, responsibilities, and documentation are important in providing direction and consistency in EnMS implementation. Clear organizational guidelines help establish accountability, clarify employee responsibilities, and support the systematic implementation and maintenance of energy management practices.

The main theme is the energy data collection and monitoring, emphasizes the importance of gathering electricity and fuel bills, meter readings, and consumption records on a regular basis. Monthly data collection provides a basis for tracking energy use, establishing consumption patterns, and identifying

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changes over time. This suggests that Bicol Airport recognizes the importance of reliable energy data in supporting informed decisions and monitoring overall energy performance.

The subtheme is the comparative energy performance assessment. This involves comparing current energy consumption with historical records, similar buildings, or established energy-efficiency targets. It also includes identifying the systems, areas, and equipment responsible for the largest share of energy consumption. The result suggests that a substantial majority of respondents recognize the value of comparison and evaluation in determining whether energy use is reasonable and identifying priority areas for improvement. However, the lower percentage compared with data collection indicates that this analytical practice may not be as consistently applied.

The main theme indicates that respondents strongly recognize the potential of renewable energy and energy-efficient technologies to reduce Bicol Airport's energy expenses. Three indicators—renewable energy integration, transitioning from Ordinary to Electric Vehicles, and upgrading runway lighting systems—were reported by all respondents. These results suggested broad agreement on the importance of investing in technologies that reduce electricity demand and reliance on conventional energy sources.

The subtheme focuses on the adoption of energy-efficient equipment. Using technologies such as LED lighting, inverter-type air-conditioning units, high-efficiency motors, and energy-efficient office equipment can help reduce electricity consumption while maintaining good operational performance. It also emphasizes the importance of properly operating and maintaining existing equipment. Regular inspections, preventive maintenance, and proper equipment settings can prevent unnecessary energy use, extend equipment lifespan, and reduce repair costs.

Operational

The main themes are the reduction of operating expenses, lower electricity and fuel consumption can reduce utility bills and other operating expenses, potentially freeing up funds for essential airport requirements, such as equipment maintenance, facility improvements, and operational support. This finding suggested that energy conservation can contribute to more efficient financial management and help the airport allocate its resources according to operational priorities.

The main themes are the implementation and improvement of energy policies. This indicates that most respondents recognize the implementation of existing energy policies while acknowledging the need for improvement in information dissemination, operational practices, and energy conservation measures. The finding suggested that the existence of policies alone may not be sufficient to ensure consistent implementation. Clear communication of responsibilities, regular reminders, and monitoring of compliance could help ensure that workers and stakeholders understand and apply the policies in their respective activities.

The findings highlighted two subthemes: employee participation in energy conservation and promotion of renewable energy projects. Employees contribute to energy efficiency through responsible energy practices, supported by reminders from the Energy Management Team. Meanwhile, respondents unanimously support exploring renewable energy initiatives, such as solar photovoltaic installations and shifting of some to electric vehicles to reduce conventional energy consumption and promote long-term sustainability.

The main themes are the Renewable Energy Integration and Energy Efficiency Improvements, focuses on reducing the airport's dependence on grid electricity, minimizing energy consumption, and promoting more sustainable airport operations. This initiative may include three key strategies: the installation of Solar Photovoltaic (PV) Systems, the transition to Electric Vehicles (EVs), and the replacement of conventional lighting with energy-efficient LED lights.

The subtheme focuses on Employee engagement and energy conservation play an important role in reducing an airport's overall energy consumption. This can be achieved by conducting regular energy-awareness training, encouraging employees to switch off unused lights and equipment, and establishing

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energy-saving policies for airport tenants and commercial establishments. Additionally, introducing incentives for departments that meet or exceed energy-reduction targets can encourage active participation, while conducting regular energy audits helps identify areas of energy waste and opportunities for further improvement. Through these initiatives, airports can develop a culture of energy

Organizational and Management

The main theme focused on the coordination and continual improvement of the Energy Management System (EnMS). This responsibility involves coordinating EnMS activities, identifying Significant Energy Uses (SEUs), establishing Energy Performance Indicators (EnPIs) and energy baselines, and monitoring energy performance. The high percentage of responses suggests that most respondents recognize the importance of having an organized energy management system and ensuring its continual improvement, including the hiring of an Energy Manager in the agency. These activities help ensure that energy-saving initiatives are guided by measurable objectives and that the organization can effectively assess its progress over time.

The subtheme focused on employee participation and energy awareness. This indicates unanimous recognition of the importance of involving employees in energy management activities and keeping them informed about ongoing initiatives. Employee participation encourages responsible energy use, strengthens compliance with energy conservation policies, and promotes shared accountability across departments. Furthermore, regular communication about energy-saving practices helps integrate energy conservation into employees' routine workplace activities, fostering a culture of energy

The main theme is the formal communication of energy policies. The issuance of an energy conservation memorandum serves as a formal mechanism for communicating the organization's policies, objectives, and required practices to personnel. This finding suggests that formal documentation is an established approach at Bicol Airport for informing employees about energy conservation expectations. However, the issuance of a memorandum alone does not necessarily establish that all personnel fully understand or consistently follow the policies.

The main themes are management support and resource allocation. This indicates unanimous recognition of management's role in providing necessary resources, issuing energy conservation policies and directives, and establishing an Energy Conservation Team. These actions provide the organizational foundation for implementing the EnMS by defining expectations, assigning responsibilities, and supporting energy management activities. The result suggests that management commitment is visibly demonstrated through formal policies and institutional arrangements.

The subtheme is the review of energy performance and implementation of energy-saving measures. This indicates that a substantial majority of respondents recognize management's involvement in reviewing monthly energy performance reports and supporting energy-saving initiatives. Reviewing energy data enables management to identify consumption trends, evaluate progress toward energy targets, and determine areas where corrective or improvement measures may be needed. The lower percentage compared with management support and resource allocation suggests an opportunity to strengthen the visibility and consistency of management's involvement in translating performance findings into practical interventions.

dissemination. This highlighted the importance of informing employees about energy-saving practices through orientations, workplace briefings, and the Energy Conservation Team. These activities help employees understand their responsibilities and practice energy conservation in their daily work. It also emphasized the need for the agency to have at least one (1) Certified Energy Manager responsible for overseeing and implementing energy conservation efforts.

The subtheme is the operational guidance for equipment operators. Equipment operators are specifically reminded of proper operating procedures, energy-reduction methods, and the importance of avoiding unnecessary energy use. This finding suggested that Bicol Airport recognizes the importance of

providing practical guidance to personnel whose daily activities directly influence energy consumption. More structured, equipment-specific training could further help operators apply energy-saving procedures without compromising operational requirements, equipment reliability, or safety.

Financial

Most respondents estimated that energy resources account for 10% to 15% of Bicol Airport's monthly expenses. Although this finding indicates a perceived opportunity for cost savings through energy management, financial records are necessary to establish the actual expenditure share and quantify potential savings.

The main theme is the integration into the regular budget process. This indicated unanimous recognition that funding for the implementation, maintenance, improvement, and expansion of the EnMS is planned through the agency's established budgeting procedures. Integrating energy management requirements into the regular budget process can help ensure that these activities are considered alongside other operational priorities. It also provided a formal mechanism for requesting and programming funds for energy conservation initiatives.

The subthemes are the identification and prioritization of energy management activities. This involves the Energy Conservation Team identifying priority initiatives and proposing the corresponding budget requirements for inclusion in the annual budget. Such planning can help the agency focus its limited resources on activities with the greatest potential benefits, including energy-efficiency improvements, equipment upgrades, and monitoring initiatives. The lower percentage compared with the first theme suggests an opportunity to strengthen the visibility and consistency of the team's role in developing specific budget proposals.

The main theme is the dedicated budget allocation for EnMS activities. This indicates unanimous agreement on the importance of establishing a dedicated or clearly identified budget for energy management activities. Such funding can support energy monitoring, energy audits, personnel training and certification, and awareness programs. A clearly defined budget can help ensure that essential EnMS activities are included in annual financial planning rather than depending on occasional or unplanned funding. It can also support compliance-related documentation and the continued development of personnel responsible for energy management.

The subtheme is investment in cost-effective energy-efficiency projects. This finding suggests that most respondents recognize the importance of evaluating energy-efficiency projects according to their expected financial returns. Improvements to lighting, air-conditioning systems, and other energy-consuming equipment may reduce electricity demand and operating expenses. Assessing project costs alongside expected savings and equipment life can help Bicol Airport identify investments that offer the greatest financial and operational benefits. Such assessments are particularly relevant when electricity and fuel prices are increasing.

Energy Audit and Existing Practices

The Energy Audit of Bicol Airport aimed to examine and determine the airport's overall energy consumption, electrical infrastructure, and energy efficiency. The study primarily focused on identifying the major facilities and equipment that contribute to the airport's energy demand, such as heating, ventilation, and air-conditioning (HVAC) systems, lighting fixtures, electrical distribution networks, standby generators, and other essential operational equipment. It also involved gathering and evaluating electricity bills, historical energy consumption data, electrical load profiles, equipment specifications, and operating schedules to identify inefficient energy utilization and potential sources of energy wastage. Furthermore, the audit sought to assess the operational performance of existing electrical systems and identify possible energy-saving opportunities through the adoption of energy conservation measures.

Overall, the assessment indicated that the primary areas of energy inefficiency were associated with HVAC operation, lighting systems, limited energy monitoring, and the need for advanced energy

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management technologies. To address these concerns, Bicol Airport implemented and continued to strengthen various energy conservation measures, including equipment upgrades, improved operational controls, enhanced energy monitoring, regular preventive maintenance, and staff awareness programs. The airport also continued to pursue the implementation of an ISO 50001-compliant Energy Management System to further improve energy management practices.

Existing practices include LED lighting, preventive maintenance, consumption monitoring, government conservation policies, backup generation, and solar-powered outdoor lighting. The audit identifies opportunities for improved HVAC and lighting controls, metering, equipment scheduling, and benchmarking. Detailed audit computations are referenced in the source but are not reproduced in the supplied document.

Proposed Integrated Energy Management System

The creation of an Energy Management System for Bicol Airport should focus on energy efficiency, fuel management, renewable energy integration, operational reliability, and environmental sustainability. Major areas such as HVAC systems, lighting, fuel consumption, building automation, and renewable energy should be prioritized because they have a significant impact on the airport's energy consumption and operating costs. By effectively managing these areas, the airport can reduce operational expenses, improve energy efficiency, minimize its environmental impact, and ensure safe, reliable, and sustainable airport operations.

The implementation of the Energy Management System (EnMS) at Bicol Airport is a shared responsibility under the supervision of the Civil Aviation Authority of the Philippines (CAAP). The Airport Manager leads and supervises the program, while the Energy Manager or EnMS Officer monitors energy consumption and identifies ways to save energy. The Engineering and Maintenance Team maintains airport facilities and equipment, while the Airport Operations Department ensures the efficient use of energy in daily activities. Meanwhile, CAAP provides guidance, approves major projects, and ensures compliance with government energy policies. Together, they aim to reduce energy consumption and costs, improve efficiency, and promote environmental sustainability.

The energy policy in running the Energy Management System (EnMS) in Bicol Airport serves as a guiding framework for ensuring that airport operations are conducted in an energy-efficient and environmentally responsible manner. It emphasizes the commitment to reduce electricity and fuel consumption, minimize greenhouse gas emissions, and promote sustainable use of resources in all airport activities. Through this policy, the airport prioritizes the use of energy-efficient systems such as LED lighting, optimized HVAC operations, and renewable energy sources like solar power to lessen environmental impact. It also supports proper monitoring and continuous improvement of energy performance to ensure that resources are used responsibly and efficiently. In addition, the policy encourages compliance with national environmental regulations and standards set by the Civil Aviation Authority of the Philippines, ensuring that all airport operations align with government sustainability goals. Staff participation is also emphasized through awareness programs and training to promote environmentally responsible behavior. Overall, the environmental policy ensures that the EnMS not only improves operational efficiency but also protects the environment and supports long-term sustainability of airport operations.

The implementation of the Energy Management System (EnMS) in Bicol Airport involves clearly defined organizational roles, responsibilities, and authorities to ensure effective coordination and accountability. The Airport Manager holds the highest authority at the airport level and is responsible for approving EMS policies, setting energy efficiency goals, allocating resources, and overseeing overall implementation. Supporting this role is the EMS or Energy Manager, who directly coordinates the system by monitoring electricity and fuel consumption, analyzing energy data, identifying areas for improvement, and preparing performance reports for management. The Engineering and Maintenance Department is

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responsible for the technical side of EnMS implementation, including the maintenance and upgrading of HVAC systems, lighting, electrical equipment, and other airport facilities to ensure energy efficiency. Meanwhile, the Airport Operations Department ensures that daily airport activities follow energy-saving procedures, particularly in the use of lighting, equipment, and fuel for vehicles and fire trucks. The Finance and Administration unit supports the EnMS by managing budgets and evaluating cost savings from energy efficiency initiatives, while the Safety, Environment, and Quality unit ensures compliance with environmental regulations and sustainability standards. Together, these roles work collaboratively to ensure that the EnMS is effectively implemented, properly maintained, and continuously improved to support efficient, reliable, and sustainable airport operations.

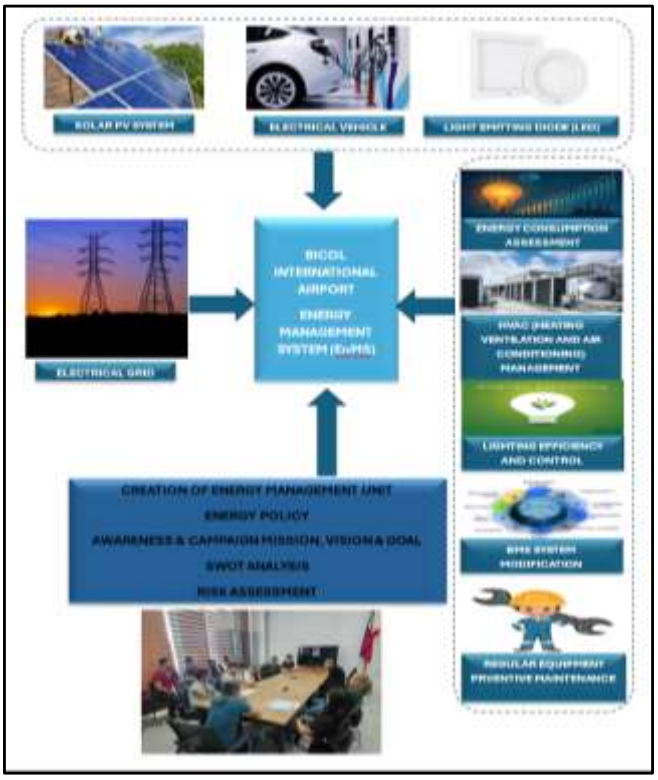

Figure 2. Integrated Energy Management System

Solar Photovoltaic Design and Economic Screening

For preliminary PV sizing, the average daily energy requirement is obtained from the 30-month average monthly consumption. A 30-day representative month is used for the conversion from monthly to daily energy. The solar resource is represented by an average Peak Sun Hours (PSH) of 3.8 hours/day, and a 15% aggregate system loss is applied. Therefore, the net system efficiency factor is 85%.

Equal-allocation preliminary estimate only. Actual component-level PV sizing shall be recalculated after installation of submeters or acquisition of reliable building-specific billing/energy-monitoring records. The three preliminary component capacities collectively approximate the calculated PV capacity requirement of the DPPH cluster.

Important methodological note: the PV capacities in this section are energy-offset sizing results, not final electrical design capacities. The final design must verify actual PV production against the airport's temporal load profile, available installation area, module characteristics, inverter limits, grid-interconnection requirements, and applicable Philippine Electrical Code and airport engineering standards.

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Table 4. *Consolidated PV design and gross financial projections*

Building / Facility	PV Capacity (kWp)	Annual PV Production (kWh/year)	Annual Gross Savings (₱/year)	Project Cost (₱)	Gross Payback (years)
Administration Building	45.5	53,642.23	₱ 590,064.53	₱ 3,548,645.10	6.01
Maintenance Building (DPPH)	33.8	39,848.51	₱ 438,333.61	₱ 2,599,740.00	5.93
CAAP-DOTR Quarters (DPPH)	33.8	39,848.51	₱ 438,333.61	₱ 2,599,740.00	5.93
CFR Building (DPPH)	33.8	39,848.51	₱ 438,333.61	₱ 2,599,740.00	5.93
Pump House / Water Filtration (DPWR)	32.5	38,315.88	₱ 421,474.68	₱ 2,534,746.50	6.02
MDP-PT1 Passenger Terminal	403.0	475,116.85	₱ 5,226,285.35	₱ 31,430,856.60	6.01
MDP-PT2 Passenger Terminal	630.5	743,327.98	₱ 8,176,607.78	₱49,174,082.10	6.01
TOTAL	1,212.9	1,429,948.47	₱ 15,729,433.17	₱ 94,487,550.30	6.01

Table 5. *Annual O&M and net benefit*

Building	Annual O&M = 1% CAPEX (o&m)	Net Annual Benefit (snet)
Administration Building	₱35,486.45	₱554,578.08
Maintenance Building (DPPH)	₱25,997.40	₱412,336.21
CAAP-DOTR Quarters (DPPH)	₱25,997.40	₱412,336.21
CFR Building (DPPH)	₱25,997.40	₱412,336.21
Pump House / Water Filtration System (DPWR)	₱25,347.47	₱396,127.21
MDP-PT1 (Passenger Terminal Building)	₱314,308.57	₱4,911,976.78
MDP-PT2 (Passenger Terminal Building)	₱491,740.82	₱7,684,866.96
TOTAL	₱944,875.50	₱14,784,557.67

The source reports approximately 2,400 kWh of battery storage. Hybrid configurations with and without battery backup were considered. The proposed capacity is preliminary and requires structural, electrical, load-profile, and safety validation. The gross generation estimate is not equivalent to verified grid displacement.

Simple annual ROI does not show the full value generated over the asset life. For a 25-year PV life, the cumulative gross return can be expressed as total undiscounted savings less initial capital, divided by initial capital.

25-year cumulative gross ROI: [(25 × ₱15,729,433.17) − ₱94,487,550.30] / ₱94,487,550.30 × 100 = 316.18%.

25-year cumulative net ROI after 1% O&M: [(25 × ₱14,784,557.67) − ₱94,487,550.30] / ₱94,487,550.30 × 100 = 291.18%.

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Fuel Cost and Electric Vehicle Replacement

Table 6. *Candidate service vehicle fuel baseline*

Candidate vehicle	2024 L/mo	2025 L/mo	2026 L/mo	Ave. fuel L/mo	Ave. Fuel x ₱ 85.00	Annual Fuel Cost
ARFF Pick Up	22.18	63.41	41.66	42.41	₱ 3,604.85	₱ 43,258.20
Maintenance Isuzu Dmax	13.09	244.41	225.25	160.92	₱ 13,678.20	₱ 164,138.40
Maintenance Mitsubishi Strada	120.99	106.42	95.40	107.61	₱ 9,146.85	₱ 109,762.20
Maintenance Toyota Hiace Van 1	235.86	34.84	0.00	90.23	₱ 7,669.55	₱ 92,034.60
Maintenance Toyota Hiace Van 2	250.18	314.33	275.40	279.97	₱ 23,797.45	₱ 285,569.40
ANS Isuzu Dmax	61.49	53.22	75.56	63.43	₱ 5,391.55	₱ 64698.60
TOTAL	703.79	816.63	713.27	744.57	₱ 63,288.45	₱ 759,461.40

Table 7. *EV screening assumptions*

Model input	Value	Basis / interpretation
Fuel price	₱85.00/L	Value used in source Table 1; verify current delivered price.
Conventional vehicle fuel economy	8.0 km/L	Screening assumption for mixed pickup/van fleet; replace with vehicle logs.
EV energy consumption	0.20 kWh/km	Illustrative traction-energy assumption.
Charging losses	10%	Grid energy = traction energy × 1.10.
Grid electricity tariff	₱12.00/kWh	Illustrative blended rate; replace with Bicol Airport billing tariff and demand charges if applicable.
2026 Candidate Fuel Baseline	744.57 L/month	Sum of yellow rows in Table 28.
Estimated Distance Equivalent	5,706 km/month	713.27 L/month × 8 km/L.
EV grid energy	1,255.36 kWh/month	5,706 km/month × 0.22 kWh/km.
Estimated EV charging cost	₱15,064.26/month	1,255.36 kWh/month × ₱12/kWh.

Table 8. EV capital and annualized cost screening

Capital-cost item	Amount	Calculation / note
Total assumed EV purchase price	₱15,128,000.00	Sum of six EV prices shown in Table 29
Assumed disposal proceeds	₱3,600,000.00	Sum of six estimated selling values; not verified.
Net incremental capital outlay	₱11,528,000.00	EV purchase price less assumed disposal proceeds; excludes chargers, electrical upgrades, taxes, financing, and downtime.

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Capital-cost item	Amount	Calculation / note
Annualized energy-cost reduction	₱546,764.25	Fuel savings less estimated charging electricity cost; excludes maintenance savings.

The source EV model uses inconsistent fuel baselines and annualized costs; its reported savings should be treated as provisional rather than a validated business case. Charging infrastructure, electrical upgrades, and actual maintenance costs require further assessment.

Implementation Plan

Strong leadership and long-term commitment are essential for the successful implementation of the Energy Management System (EnMS) at Bicol Airport. The Airport Manager and CAAP officials are responsible for setting energy-saving goals, approving projects and budgets, and ensuring compliance with energy regulations. Management must also provide sufficient resources, such as funding, skilled personnel, equipment, and staff training, to support energy efficiency. Regular monitoring of energy consumption helps identify problems and improve energy-saving practices. Furthermore, airport employees should be encouraged to participate by turning off unused lights and equipment, reporting energy waste, and following energy-saving policies. Through strong leadership, proper resource allocation, and employee participation, the airport can reduce energy consumption and costs while promoting environmental sustainability.

The proposed budget for implementing the Energy Management System (EnMS) at Bicol Airport is divided into seven key areas to improve energy efficiency and reduce operating costs. The largest allocation of 25% is for HVAC System Optimization to improve air-conditioning performance and reduce electricity use. 20% is allocated to Renewable Energy Integration, such as installing solar panels to reduce dependence on grid electricity. 15% is assigned to LED and Smart Lighting Systems to replace traditional lights with energy-efficient lighting. The remaining 40% is divided equally among four components, with 10% each for Energy Audit and Assessment, Fuel Management System, Building Automation and Monitoring System, and Training, Maintenance, and Awareness Programs. These activities will help identify energy-saving opportunities, reduce fuel waste, monitor energy consumption, maintain equipment, and educate employees about energy conservation. Overall, this resource allocation aims to reduce energy consumption and costs, improve airport operations, and promote environmental sustainability.

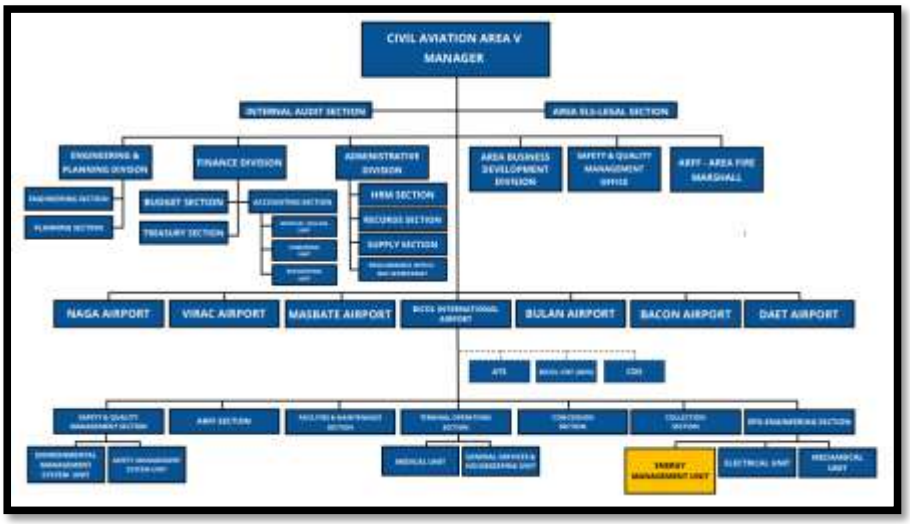

Figure 3. Proposed organizational structure

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The proposed implementation sequence comprises orientation of the EnMS unit, evaluation of existing practices, strategic planning, review by the CAAP managing head, and implementation. Priority actions include energy audits, HVAC optimization, lighting control, renewable energy integration, fuel management, building automation, and personnel training. The proposed budget allocation is indicative rather than an approved appropriation.

DISCUSSION

The findings indicated that Bicol Airport implements its Energy Management System (EnMS) through regular energy consumption monitoring, departmental conservation activities, and inspections of building systems. Resource adequacy, organizational policies and procedures, and information dissemination were identified as the main factors affecting its implementation. To further improve energy efficiency, Bicol Airport should strengthen energy performance monitoring, use historical data, and evaluate energy-saving measures. The findings also emphasized the importance of investing in renewable energy, electric vehicles, upgraded runway lighting, and energy-efficient equipment, supported by proper maintenance and regular inspections to reduce energy consumption and costs.

In terms of Operational aspects, reducing energy consumption at Bicol Airport is essential to improving operational efficiency, reducing costs, and promoting sustainable airport operations. The findings emphasized the importance of strengthening energy policies, encouraging employee participation, and implementing renewable energy and energy-efficient technologies, such as solar PV systems, LED runway lighting, and electric vehicles. Additionally, strengthening the Energy Management Team through regular inspections, monitoring, and departmental reporting can improve policy compliance and accountability. These initiatives support the continuous improvement of the Energy Management System (EnMS) and contribute to the airport's long-term sustainability, resilience, and service quality.

The findings indicated that Bicol Airport has established a foundation for an effective Energy Management System (EnMS) through management commitment, coordination, employee participation, and existing communication mechanisms. However, further improvements are needed in appointing a qualified Energy Manager, strengthening employee awareness and technical competencies, improving communication of energy policies and targets, and regularly monitoring energy performance. Sustained management support, specialized training, systematic performance reviews, and follow-up actions will enhance accountability, ensure compliance, and promote the continual improvement of energy efficiency throughout the agency.

The findings indicated that Bicol Airport recognizes the importance of energy management in reducing operational expenses, with most respondents estimating that energy costs account for 10%–15% of monthly expenditures. Effective implementation of the EnMS requires integrating its funding into the regular budget process, strengthening the Energy Conservation Team's role in identifying and prioritizing initiatives, and allocating dedicated funds for energy monitoring, audits, training, and awareness programs. Prioritizing cost-effective energy-efficiency projects based on potential savings and long-term benefits will further support sustainable resource allocation, improve energy

For Bicol Airport, these studies supported the assessment of major electrical and mechanical equipment, particularly HVAC systems and lighting. Equipment inspections, maintenance records, and electricity consumption data helped determine which systems required further evaluation. However, the presence of inefficient equipment was established through actual assessments rather than assumptions based on findings from other airports. Furthermore, the data gathered during inspections were submitted to management to support decision-making regarding necessary adjustments, repairs, and procurement of materials to improve equipment condition, functionality, and overall operational efficiency.

For Bicol Airport, operational inefficiencies were assessed by comparing equipment operating schedules with actual operational requirements and passenger activity. Site observations and interviews with facilities personnel helped identify practices that contributed to unnecessary electricity consumption.

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The assessment also determined whether improvements in operating schedules, temperature controls, and employee energy conservation practices were necessary.

For Bicol Airport, the assessment included reviewing electricity bills, meter readings, maintenance records, and available energy audit reports. The study also determined whether energy consumption was monitored by individual building, department, or equipment category. These findings helped establish whether existing monitoring practices provided sufficient information to identify and manage potential energy inefficiencies.

These studies were relevant to Bicol Airport because the energy performance of HVAC and lighting systems was influenced by terminal occupancy, local weather conditions, equipment condition, and operating schedules. The study examined lighting controls, air-conditioning schedules, temperature settings, and available equipment performance records to identify areas for improvement. Potential inefficiencies were assessed through site observations and available measurements. Furthermore, the procurement of additional sub-meters, improvements to the Building Management System (BMS) for lighting, elevators, and escalators, and other energy monitoring devices were requested to enhance energy monitoring, improve operational control, and support more efficient energy management at the airport.

Similar study conducted by Sukumaran and Sudhakar (2017), entitled Fully Solar Powered Airport: A Case Study of Cochin International Airport, provided a relevant example of how solar photovoltaic (PV) technology can reduce the electrical expenses of airport operations. The researchers examined the actual operational performance of a 12 MWp grid-connected solar PV power plant installed at Cochin International Airport (CIAL) in Kerala, India. The study highlighted that airports are among the major consumers of electricity because of their continuous operational requirements, including terminal lighting, air-conditioning and ventilation systems, runway lighting, navigation equipment, and other airport facilities. These electricity requirements result in substantial operating expenses, particularly when airports depend heavily on conventional electricity supplied by external utility providers.

The findings indicate that energy management requires coordinated institutional and technical measures rather than renewable generation alone. The concentration of demand in terminal facilities supports prioritizing HVAC, lighting, and detailed metering. The proposed EnMS integrates management accountability, employee engagement, maintenance, and investment planning. The economic projections indicate potential savings, but they depend on actual self-consumption, tariffs, equipment performance, and project costs.

Limitations

The study concerns a single airport and records from January 2024 to June 2026. Interview findings reflect selected personnel perceptions, not independently verified compliance scores. Limited submetering prevents precise allocation of DPPH loads. The source reports differing electricity peaks (315,000 and 325,000 kWh) and does not reconcile airport-wide consumption with the selected-facility PV baseline. Its assumed 15% system loss differs from the sum of listed component losses (20%). The 95% grid-offset scenario retains gross savings despite lower displaced energy; therefore the 80–95% offset claim is not established. The 25-year returns are undiscounted projections, not observed outcomes, and do not establish lifecycle profitability. The EV model also contains inconsistent monthly and annual fuel figures. Greenhouse gas emissions were outside the study scope. These discrepancies require author verification before publication.

CONCLUSION

Assessing Bicol Airport's energy consumption and supply is important in understanding the electricity and fuel needed for its daily operations. Electricity is supplied by the local power distributor, while fuel is obtained from a nearby station through a contractual agreement. The airport also has designated personnel responsible for operating, monitoring, and maintaining its equipment and facilities. Evaluating energy consumption, operating hours, passenger volume, building conditions, and equipment performance

can help identify areas for improvement, reduce energy costs, and promote more efficient energy management.

Strengthen Bicol Airport's EnMS implementation through management commitment, appointment of a qualified Energy Manager, employee participation and training, effective communication of energy policies, regular monitoring, inspections, and performance evaluation to ensure accountability and continuous improvement. And prioritize sustainable energy initiatives by allocating dedicated budgets, investing in renewable energy and energy-efficient technologies, and implementing cost-effective projects to reduce energy consumption, operational expenses, and support the airport's long-term sustainability.

Hence, the proposed Integrated Energy Management System (EnMS) for Airport Operations at Bicol Airport aimed to provide a systematic approach to monitoring and managing electricity and fuel consumption, addressing areas of inefficiency, reducing energy expenses, improving operational efficiency, and promoting sustainable airport operations.

Based on the findings and conclusions of the study, it is recommended that Bicol Airport review and realign its existing Energy Policy in accordance with Republic Act No. 11285, or the Energy Efficiency and Conservation Act, and its applicable implementing rules and regulations. Section 6 of the Act requires government agencies to ensure the efficient use of energy in their offices, facilities, and transportation units. Accordingly, the airport should strengthen its energy management policies, establish appropriate energy efficiency targets, and implement measures that promote energy conservation and the efficient use of resources.

Bicol Airport is recommended to establish and implement an Energy Management Program through regular energy audits, systematic monitoring of electricity and fuel consumption, and strengthened preventive maintenance of equipment and facilities. It should also consider adopting energy-efficient technologies, exploring renewable energy sources, and assigning designated personnel to monitor and manage energy use.

It is recommended that Bicol Airport dedicate sufficient financial resources to renewable energy projects and energy-efficient technologies, while setting clear energy performance objectives and implementing regular monitoring and evaluation. Furthermore, Bicol Airport should enhance its Energy Management System (EnMS) by strengthening management commitment, appointing a competent Energy Manager, and encouraging active employee involvement and awareness. These measures will contribute to reducing energy consumption and operational costs, improving energy efficiency, and ensuring the airport's long-term sustainability through continuous improvement.

Hence, it was recommended that the Integrated Energy Management System (EnMS) be adopted by Bicol Airport to address identified energy inefficiencies, optimize electricity and fuel utilization, and improve overall operational efficiency. This initiative could also serve as a model for other airports and large establishments by demonstrating effective energy management and the integration of renewable energy technologies based on successful local and international practices.

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