Integrated Management Model for Photovoltaic Projects: Optimizing Control

Financial, Planning and Execution

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***Abstract* — The management of photovoltaic (PV) projects is characterized by high technical and logistical complexity, coupled with resource volatility. This study addresses the critical fragmentation among planning, execution, and financial control processes, which leads to information silos, administrative burden on project managers, and delayed strategic decisions, ultimately compromising project profitability. The main objective was to develop and propose a conceptual integrated management model for the PV sector, operationalized via a prototype tool in Microsoft Excel, to effectively articulate these three dimensions. A qualitative methodology was employed, centered on a single case study within a sector company.**

Data collection involved documentary analysis (10 projects) and direct observation of project managers' work. The critical literature review reveals that while robust project management frameworks (PMBOK, PRINCE2) and control methodologies (Earned Value Management - EVM) are available, their practical application and integration within the specific PV context remain underexplored, indicating a significant research gap.

The proposed model synthesizes and adapts the principles of PMBOK, EVM metrics, and Balanced Scorecard (BSC) perspectives to the sector's specificities. It is concluded that implementing this integrated model, supported by a real-time monitoring tool, significantly enhances performance visibility, deviation anticipation, and decision-making effectiveness, thereby strengthening the economic sustainability of PV companies.

Success will be evaluated through specific KPIs that reflect the effectiveness of the integration. To ensure sustainability and continuous improvement, the following feedback mechanisms will be implemented:

- **Quarterly Performance Reviews**
- **Lessons Learned Reports**
- **User Satisfaction Surveys**
- **Technological Evolution**

This research contributes an applied conceptual framework and a phased implementation plan, proposing future research lines for the empirical validation of the model in other contexts.

***Keywords* — Photovoltaic Project Management; Integrated Management; Earned Value Management (EVM); Financial Control**

I. INTRODUCTION

The photovoltaic energy sector has experienced exponential growth on a global scale, driven by the energy transition, the reduction in technological costs, and public decarbonization policies (IEA, 2023). In Portugal, strategic instruments such as the National Energy and Climate Plan 2030 reinforce this trajectory, projecting a significant increase in installed capacity. At the same time, the literature recognizes that photovoltaic projects are highly complex, due to their dependence on weather conditions, supply chain volatility, uncertainties in licensing processes, and the need for integration with existing electrical infrastructures (Spertino et al., 2015; Jäger-Waldau, 2020). In this context, effective project management, based on the integration of planning, execution, and financial control, is widely identified as a critical success factor.

Despite these advances, significant gaps remain in the integration of these three dimensions. In particular, there is an observable operational fragmentation between systems and processes, which are often managed independently through distinct tools (e.g., planning software, execution reports, and ERP systems). This lack of integration leads to the creation of information silos, increased administrative burden, and the absence of a real-time, integrated view of project performance, thereby limiting the ability to monitor progress and respond to deviations (Silva et al., 2022). Although well-established frameworks exist, such as PMBOK, Earned Value Management (EVM), and the Balanced Scorecard (BSC), their integrated application—adapted to the specific context of photovoltaic projects—remains insufficiently explored.

Addressing these gaps is critical, given their direct impact on operational efficiency, predictability of outcomes, and the economic sustainability of projects. In this context, the present study aims to develop a conceptual model of integrated management that aligns planning, execution, and financial control, tailored to the photovoltaic sector, and to operationalize it through a decision-support tool prototype. The central contribution of this work lies in the proposal of an Integrated Management Model that overcomes current fragmentation by systematically linking planning, execution, and financial control within the specific context of the photovoltaic sector. This model is operationalized through a prototype that transforms dispersed data (MS Project, ERP systems, and site reports) into real-time management information, enabling the anticipation of deviations and agile decision-making, and thereby contributing significantly to the economic sustainability of projects.

II. Literature Review

Photovoltaic (PV) projects have assumed a central role in the energy transition, reflecting the increasing adoption of renewable energy sources and the reduction in technological costs (IEA, 2023). Initially, the literature focused on the technical and economic feasibility of these systems; however, more recent studies highlight the complexity associated with their implementation, emphasizing operational, logistical, and regulatory challenges (Jäger-Waldau, 2020; Sørensen, 2021). This evolution reflects a paradigm shift in which effective project management emerges as a critical factor in ensuring performance and economic sustainability.

When evaluating a project in this sector, it is essential to consider the specific characteristics of photovoltaic projects. These are marked by high technical complexity, requiring coordination across multiple engineering disciplines and the integration of various components (Spertino et al., 2015). Additionally, dependence on global supply chains exposes projects to logistical and market risks, including delays, price volatility, and material shortages (García-López, 2022). These factors are compounded by often lengthy licensing processes and the need to coordinate with multiple stakeholders, including regulatory bodies, suppliers, and local communities, thereby increasing uncertainty and the need for robust management approaches (Silva et al., 2022).

In terms of evaluation approaches, traditional project management methodologies have been widely adopted. Frameworks such as PMBOK (PMI, 2021) and methodologies such as Earned Value Management (EVM) (Fleming & Koppelman, 2010) are widely recognized for their ability to structure planning and monitor performance in terms of time and cost. In parallel, the Balanced Scorecard (BSC) (Kaplan & Norton, 1996) introduces a multidimensional strategic perspective. However, the literature indicates that these approaches are often applied in isolation and in a generic manner, revealing limitations in their adaptation to complex contexts such as photovoltaic projects, particularly regarding the integration of planning, execution, and financial control (Kerzner, 2017; Ahlemann et al., 2013). This fragmentation contributes to the late identification of deviations and reduces the effectiveness of decision-making (Zwikael, 2009).

In response to the limitations of traditional approaches, more recent perspectives have focused on digitalization and the integration of information systems. The adoption of tools such as ERP systems, planning software, and Business Intelligence (BI) solutions has increased, improving data collection and analysis (Biesenthal & Wilden, 2014). Nevertheless, significant challenges remain, particularly related to system fragmentation and the lack of interoperability, leading to the absence of a "single source of truth" and limiting real-time visibility of project performance (Yeoh & Koronios, 2010). Data integration through dashboards and analytical platforms has emerged as a relevant trend, enabling the transformation of dispersed data into actionable information (Too & Weaver, 2014).

In this context, recent literature highlights the need for integrated project management models that align processes, information, and decision-making (Badewi, 2016). The combination of methodologies such as EVM with strategic frameworks such as the BSC has been suggested as a promising approach to align operational control with strategic objectives (Qureshi et al., 2019).

Thus, a clear gap is identified in the literature: the absence of operationalized models that integrate planning, execution, and financial control, supported by digital tools and empirically validated. This study aims to contribute to the body of knowledge by developing and proposing an integrated conceptual model specifically designed for photovoltaic projects, and by demonstrating its feasibility through a prototype tool and a case study that illustrates its practical application and potential benefits, with a central focus on the integration of planning, execution, and financial control.

The following table summarizes the main limitations of the methodological approaches.

Table 1. Summary of Photovoltaic Project Challenges and Limitations of Current Management Approaches (own elaboration)

Photovoltaic Project Challenges	**Limitations of Traditional Project Management Approaches**
Technical complexity and system integration	Generic frameworks fail to adequately address technical specificities and system interdependencies.
Volatile supply chain management	Limited capability to integrate real-time data from external suppliers into internal systems.
Unpredictable licensing and regulatory processes	Inability to dynamically incorporate regulatory delays into project schedules and budgets.
Multiplicity of stakeholders	Inefficient communication resulting from functional silos and lack of integrated coordination mechanisms.
Exposure to external risks (e.g., weather conditions)	Predominantly reactive approaches, with insufficient use of predictive analytics and scenario simulation.

III. Methodological Approach: Qualitative Case Study

The exploratory and contextual nature of the research problem, focused on gaining an in-depth understanding of integration processes and challenges within a specific organization, justified the adoption of a qualitative approach. This research is structured as a single, intrinsic case study, aimed at analyzing the particularity and complexity of the case under study, prioritizing contextual understanding over statistical generalization.

The research design is both applied and developmental in nature, as it goes beyond merely analyzing the existing reality and seeks to contribute to solving an identified practical problem — namely, the fragmentation between planning, execution, and financial control in photovoltaic projects.

Additionally, the research incorporates elements of the Design Science Research (DSR) methodology. While the case study enabled the diagnosis of the problem and a deeper understanding of organizational needs, the DSR approach guided the design, development, and validation of an artifact — a management tool prototype — ensuring that the proposed solution addresses a relevant problem and is grounded in solid theoretical foundations.

A. Research Context and Case Selection

The study was conducted in a medium-sized Portuguese company dedicated to the development, engineering, and construction (EPC) of medium- and large-scale photovoltaic projects (1 MWp to 150 MWp). The case was selected purposively, based on three key criteria.

First, accessibility, which enabled access to internal data, documentation, and staff, allowing for a detailed analysis of the interactions between planning, execution, and finance. Second, the company's experience, demonstrated by a consolidated portfolio of more than 20 completed projects, which supported a consistent historical analysis of cost and schedule deviations. Finally, representativeness, as the company exhibits typical operational challenges of the sector, namely the lack of integration between planning, execution, and financial control processes, thus constituting an information-rich case that illustrates the research problem.

B. Data Collection Methods

Data collection was based on methodological triangulation (Denzin, 1978), with the aim of enhancing the validity and reliability of the findings.

Document analysis focused on 10 photovoltaic projects completed over the past three years. Project schedules (MS Project), progress and site reports, financial records extracted from the ERP system, and reports on deviations and lessons learned were examined. This analysis made it possible to characterize cost and schedule deviations, identify patterns of inefficiency, and understand the nature of information fragmentation between planning, execution, and financial control.

Additionally, in situ participant observation of project management workflows was conducted. The observation focused on interactions between teams, the use of tools and information systems, and communication and decision-making processes. This method provided a direct and contextualized understanding of organizational practices, enabling the identification of breakdown points in the articulation between the three pillars.

IV. Results and Discussion

A. Foundations of the Proposed Model

The conceptual integrated management model for photovoltaic projects was developed to directly address the gaps identified in the literature and confirmed through the case study. Its architecture is structured around three core pillars.

First, data integration enables the centralization of planning data (e.g., MS Project schedules), execution data (e.g., progress reports), and financial data (e.g., ERP cost records) into a unified platform. This eliminates information silos and establishes a single source of truth, improving the consistency and accessibility of project information.

Second, proactive control is ensured through the application of Earned Value Management (EVM), which provides objective performance indicators and enables the forecasting of cost and schedule deviations. This represents a shift from reactive to predictive project management.

Third, strategic alignment is achieved by incorporating Balanced Scorecard (BSC) perspectives, ensuring that operational performance is aligned with organizational objectives such as profitability, customer satisfaction, and continuous improvement. The combination of EVM and BSC allows performance evaluation from both operational and strategic perspectives.

B. From Fragmentation to Integration: Comparison with Current Practices

The primary contribution of the model lies in transforming the current fragmented management process into an integrated and proactive workflow.

Empirical findings revealed that existing practices rely on disconnected systems (MS Project, ERP, Excel), resulting in delayed identification of deviations and inefficient decision-making. In contrast, the proposed model introduces real-time data integration, automated performance monitoring, and centralized visualization.

This transition significantly enhances transparency, reduces administrative burden, and enables earlier corrective actions, directly addressing the core inefficiencies identified in the case study.

C. Components and Integration Mechanisms

The model is operationalized through a set of interconnected components designed to support data integration and decision-making.

The data input module enables both manual entry and automated import of planning, execution, and cost data, including integration with MS Project (XML) and ERP systems. The analytical module (EVM) functions as the core engine, dynamically calculating key performance metrics (PV, EV, AC, CPI, SPI, EAC, ETC).

The visualization dashboard serves as the main user interface, presenting key performance indicators through S-curves, traffic-light indicators, and forecasting tools. These features enable continuous monitoring of project performance.

Additionally, the alert and reporting module generates automated notifications when performance thresholds are exceeded and supports the generation of structured reports. A document repository ensures centralized access to relevant project documentation.

The central integration mechanism is real-time updating, ensuring that any change in planning or cost data is immediately reflected in performance indicators, thereby enabling proactive management.

D. Performance Measurement System: Integration of EVM and BSC

The model proposes a hybrid performance measurement system combining EVM and BSC.

EVM indicators (CPI, SPI, CV, SV, EAC, ETC) provide objective measures of cost and schedule performance. However, their integration with BSC perspectives extends the analysis to strategic dimensions, including financial performance (e.g., ROI), customer satisfaction, internal processes, and organizational learning.

This integrated approach overcomes the limitations of purely operational metrics, enabling a more holistic evaluation of project performance.

E. Prototype Development and Feasibility

To validate the model, a functional prototype was developed in Microsoft Excel. This choice was driven by accessibility, flexibility, and low implementation cost, making it suitable for small and medium-sized enterprises.

The prototype includes automated EVM calculations, dynamic dashboards, and data import functionalities. It demonstrates the technical feasibility of integrating heterogeneous data sources without requiring complex IT infrastructure.

However, scalability limitations were identified, indicating the need for future development of a dedicated software solution, potentially based on Business Intelligence platforms with ERP integration.

F. Strategic Analysis: SWOT Interpretation

A SWOT analysis was conducted to evaluate the strategic positioning of the model.

The model's main strengths include real-time integrated visibility and proactive deviation detection. Its weaknesses are primarily related to the dependence on manual data input and the inherent limitations of the Excel-based prototype. Opportunities arise from the potential to improve operational efficiency and reduce project deviations, while threats include resistance to change and potential issues related to data quality.

From a strategic perspective, the model's strengths support the exploitation of these opportunities, particularly in enhancing project performance. At the same time, the identified weaknesses highlight the need for technological evolution and the implementation of effective change management strategies.

G. Preliminary Validation of the Prototype

A preliminary validation was carried out through structured feedback sessions with project managers and financial stakeholders. The results (Table 2) indicate that the model is perceived as useful, relevant, and capable of improving decision-making processes.

Although further empirical validation is required, the prototype effectively demonstrates the viability of the conceptual model and supports its potential for practical implementation (APPENDIX).

Table 2. Preliminary validation (own elaboration)

Dimension	Recorded Feedback (Citations/Summary)	Improvement Action / Comment
Visualization (Dashboard)	Traffic-light indicators facilitate immediate understanding, but the S-Curve graph is dense.	Adjust the visual scale of the S-Curve graph.
Data Input	Manual entry of physical progress is the main bottleneck. (Project Manager A)	Identified as a future limitation to be addressed through API integration.
Metrics (EVM)	Automatic calculation of EAC is essential for monthly meetings. (Finance)	Functionality validated and maintained as a priority.

V. PHASED IMPLEMENTATION STRATEGY

The implementation is structured in three phases, covering a period of 9 months, focusing on the progressive integration of the pillars of planning, execution, and financial control.

Table 3. Phases of the Implementation Plan (own elaboration)

Phase	Duration	Main Objective	Key Deliverables
Phase 1: Pre-Implementation	2 Months	Preparation and Customization	Selection of the Pilot Project, Completed Customization, Team Training
Phase 2: Pilot Implementation	3 Months	Testing and Validation in a Real Environment	Pilot Performance Report, Process Adjustments, Prototype Formation
Phase 3: Expansion and Consolidation	4 Months	Integration and Model Sustainability	Expansion to New Projects, Start of ERP/BI Integration, Standard Process Documentation

Monitoring, Evaluation, and Long-Term Sustainability

Success will be evaluated through specific KPIs that reflect the effectiveness of the integration. To ensure sustainability and continuous improvement, the following feedback mechanisms will be implemented:

• Quarterly Performance Reviews: Formal meetings, led by the PMO, to compare the results of projects using the model with reference projects, focusing on cost and schedule variance.

• Lessons Learned Reports: After the completion of each pilot project, a report focused on the effectiveness of the model and dashboard will be mandatory. This report will be the basis for the evolution of the prototype and processes.

• User Satisfaction Surveys: Application of semi-annual surveys to project managers and the finance team to assess the usability, clarity, and perceived value of the information provided by the dashboard.

• Technological Evolution: The Excel prototype will serve as a blueprint for the future migration to a more robust BI solution (e.g., Power BI), ensuring API integration with the ERP.

VI. CONCLUSION

This study demonstrated that information fragmentation constitutes a critical issue in the management of photovoltaic projects within the analyzed company, significantly impacting operational efficiency and project profitability. In response to this gap, a conceptual integrated management model was developed, combining the principles of the Project Management Body of Knowledge (PMBOK), Earned Value Management (EVM), and Balanced Scorecard (BSC). The proposed model provides a robust framework to mitigate fragmentation, as validated through a case study that confirmed its applicability in a real operational context. The findings highlight that data centralization and proactive monitoring through hybrid indicators (EVM+BSC) are essential for optimizing project performance, reinforcing the interdependence and the need for integration between planning, execution, and financial control.

From a theoretical perspective, this research contributes to the literature by synthesizing and adapting established frameworks to the specific context of photovoltaic projects, proposing an integrated model that addresses a recognized gap, particularly regarding the articulation between planning, execution, and financial control. From a practical standpoint, this study provides organizations in the sector with an

applicable model and a functional prototype, developed in Microsoft Excel, which can be readily tested and adapted. This tool acts as a catalyst for continuous improvement in project management processes and supports the enhancement of organizational project management maturity.

Although applied within a private company, the proposed model demonstrates high transferability to the public sector, particularly in public energy companies or municipalities managing photovoltaic assets. The transparency enabled by EVM and the strategic alignment provided by BSC are particularly relevant in ensuring accountability and efficiency in the use of public resources in energy transition projects.

However, this study presents some limitations. The primary limitation lies in the use of a single case study, which restricts the generalizability of the findings. Additionally, the Excel-based prototype may not provide sufficient robustness for large-scale implementation, highlighting the need for more advanced and scalable solutions. Full integration of planning, execution, and financial control will likely require more sophisticated technological infrastructures.

Future research should focus on broader empirical validation of the model across multiple organizations, enabling comparative analysis and refinement, particularly regarding the integration of the three core dimensions. Further developments should include the creation of dedicated software solutions, such as standalone web-based applications with API integration to project management and ERP systems. Additional research avenues include extending the model to other renewable energy sectors (e.g., wind energy) and conducting financial impact assessments to quantify the return on investment (ROI) of integrated project management approaches, thereby demonstrating the value of aligning planning, execution, and financial control.

APPENDIX

Comparing proposal model with other existing models

Existing approac	Main focus	Limitation in PV projects	Proposed model
PMBOK	Project management	Broad/general framework	Adapted to PV context
EVM	Cost & schedule	Mainly operational	Integrated with strategic indicators
BSC	Strategic performance	Less operational/ project-oriented	Combined with EVM
ERP	Financial information	Limited project-performance integration	Integrated financial layer
MS Project	Planning	Limited financial integration	Integrated planning layer
Excel reports	Operational reporting	Fragmented/manual	Centralized dashboard
Proposed model	**Planning + execution + financial control**	—	**Integrated PV management framework**

CONFLICT OF INTEREST

The authors declare no conflict of interest.

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