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Ανάλυση και Διαχείριση Κινδύνων σε φωτοβολταϊκά πάρκα με τη μέθοδο Monte Carlo

Risk Analysis in Photovoltaic Parks using the Monte Carlo Method

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ΜΕΤΑΠΤΥΧΙΑΚΗ ΔΙΠΛΩΜΑΤΙΚΗ ΕΡΓΑΣΙΑ
MASTER'S THESIS

ΜΕ ΤΗΝ ΥΠΟΣΤΗΡΙΞΗ ΚΑΙ ΤΗΝ
ΑΠΟΚΛΕΙΣΤΙΚΗ ΧΡΗΜΑΤΟΔΟΤΗΣΗ ΤΗΣ

ΓΕΚ ΤΕΡΝΑ
ΟΜΙΛΟΣ ΕΤΑΙΡΕΙΩΝ

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Υπεύθυνη δήλωση για λογοκλοπή και για κλοπή πνευματικής ιδιοκτησίας:

Έχω διαβάσει και κατανοήσει τους κανόνες για τη λογοκλοπή και τον τρόπο σωστής αναφοράς των πηγών που περιέχονται στον οδηγό συγγραφής Διπλωματικών Εργασιών. Δηλώνω ότι, από όσα γνωρίζω, το περιεχόμενο της παρούσας Διπλωματικής Εργασίας είναι προϊόν δικής μου εργασίας και υπάρχουν αναφορές σε όλες τις πηγές που χρησιμοποίησα.

Αλέξανδρος Σηφάκης

Οι απόψεις και τα συμπεράσματα που περιέχονται σε αυτή τη Διπλωματική εργασία είναι του συγγραφέα και δεν πρέπει να ερμηνευθεί ότι αντιπροσωπεύουν τις επίσημες θέσεις του Εθνικού Μετσόβιου Πολυτεχνείου.

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Abstract

Significant risks and uncertainties are introduced by the quick growth of photovoltaic (PV) parks as a sustainable energy source, which has an impact on their long-term profitability, operational effectiveness, and financial stability. This thesis focuses on risk analysis and management in PV parks using the Monte Carlo method, a probabilistic approach that models risks and assesses their influence on renewable energy investments. A theoretical review of PV park construction, risk management concepts, and the foundations of the Monte Carlo approach are covered at the outset of the study. The risks are then divided into Project Management, Technical, Environmental, Financial, Regulatory and Compliance, Operational, Social and Community and Cyber security risk categories in a thorough risk breakdown structure.

The construction of a 1 MW PV park in Prochoma, Thessaloniki, Greece, is Photovoltaic Park on which the risks are evaluated. Risk sheets and risk tables, which provide a methodical technique for detecting, evaluating, and managing risks, are an essential tool in this study. Each risk is thoroughly described on a risk sheet, along with information on its likelihood of happening, effects on the project, and suggested mitigation techniques. A quantitative risk assessment is conducted using the Monte Carlo method, considering variables including equipment failures, material price volatility, quality control failures, severe weather events and soil stability issues. A statistical assessment of risk impacts is made possible by simulating thousands of conceivable events, which yields a clear distribution of probable outcomes.

The use of the Monte Carlo method as a tool for decision-making that facilitates the creation of risk-reduction plans based on probabilistic models is given particular attention. The study's conclusions demonstrate how applying such approaches might improve PV parks' ability to withstand unforeseen events and offer insightful information to investors, project developers, and legislators involved in the solar energy industry. This study adds to the body of knowledge in risk management by connecting theoretical risk analysis with real-world applications. It also suggests a methodological framework that can be applied to maximize the sustainability and performance of renewable energy projects.

Evidence, such as that derived from this thesis, can be considered highly relevant by construction companies specializing in the field of renewable energy sources, as well as by policy makers in this sector. Each investor receives specific information as to the areas where measures should be taken immediately to be prepared for the main difficulties that they are going to face with this project. By understanding these and anticipating risks such as those discussed, the safest possible condition for the construction of such a project is achieved.

Key words: Risk Analysis, Risk Management, Photovoltaic Park, Mitigation Strategies, Risk Score

Περίληψη

Η ταχεία ανάπτυξη των φωτοβολταϊκών (ΦΒ) πάρκων, τα οποία αποτελούν μέρος των ανανεώσιμων πηγών ενέργειας, συνοδεύεται από σημαντικούς κινδύνους και αβεβαιότητες που επηρεάζουν τη χρηματοοικονομική σταθερότητα, την επιχειρησιακή αποδοτικότητα και τη μακροπρόθεσμη βιωσιμότητά τους. Η παρούσα διπλωματική εργασία εστιάζει στην ανάλυση και διαχείριση κινδύνων κατά την κατασκευή φωτοβολταϊκών πάρκων, χρησιμοποιώντας τη μέθοδο Monte Carlo, η οποία επιτρέπει τη μοντελοποίηση κινδύνων και την εκτίμηση των επιπτώσεών τους.

Η μελέτη ξεκινά με μια θεωρητική ανασκόπηση της ανάπτυξης των ΦΒ πάρκων, των αρχών διαχείρισης κινδύνων και των θεμελιωδών στοιχείων της μεθόδου Monte Carlo. Στη συνέχεια, καταγράφεται μια λεπτομερής δομή ανάλυσης κινδύνων, όπου οι κίνδυνοι ταξινομούνται σε κατηγορίες όπως: διαχείρισης, περιβάλλοντος, χρηματοοικονομικών, κανονιστικούς, επιχειρησιακών, κοινωνικών και κυβερνοασφάλειας.

Σκοπός της εργασίας είναι να διερευνηθούν και να αξιολογηθούν πιθανοί κίνδυνοι που ενδέχεται να παρουσιαστούν κατά την κατασκευή ενός φωτοβολταϊκού πάρκου. Οι κίνδυνοι αυτοί, αφού αξιολογηθούν και κατανεμηθούν στην αντίστοιχη κατηγορία με βάση την επικινδυνότητά τους, διερευνώνται εις βάθος ως προς τους τρόπους αντιμετώπισής τους. Έτσι, η εργασία αποσκοπεί επίσης στο να διαπιστωθεί κατά πόσο μια επένδυση στον τομέα αυτό είναι ελκυστική ή αν οι κίνδυνοι την καθιστούν μη συμφέρουσα.

Για την καλύτερη κατανόηση του τομέα των φωτοβολταϊκών πάρκων, παρατίθενται αρχικά βασικά θεωρητικά στοιχεία. Η κατανόηση των ιστορικών δεδομένων και της διαδικασίας κατασκευής τους διευκολύνει την κατανόηση των κινδύνων που ενδέχεται να προκύψουν. Επιπλέον, η διαχείριση κινδύνων είναι ένας τομέας που περιλαμβάνει διάφορες καινοτόμες τακτικές, ορισμένες εκ των οποίων αξιοποιούνται στην παρούσα εργασία. Επίσης, παρατίθενται όλες οι κλίμακες που χρησιμοποιούνται στην ανάλυση των κινδύνων, με βασική κατηγοριοποίηση σε τρεις κατηγορίες κινδύνου: χαμηλής, μεσαίας και υψηλής διακινδύνευσης. Με τον τρόπο αυτό, ο αναγνώστης αποκτά πλήρη και πολυδιάστατη εικόνα του αντικειμένου και της μεθοδολογίας που ακολουθείται στην ανάλυση των κινδύνων κατά την κατασκευή ενός φωτοβολταϊκού πάρκου.

Ένα βασικό βήμα της εργασίας είναι η αναγνώριση όλων των πιθανών κινδύνων που ενδέχεται να επηρεάσουν το χρονοδιάγραμμα της κατασκευής. Κατά το βήμα αυτό, παρουσιάζονται όλοι οι επιλήψιμοι κίνδυνοι που αναγνωρίστηκαν και ομαδοποιούνται βάσει της φύσης τους. Πολλοί από αυτούς τους κινδύνους έχουν διαφορετικό αντίκτυπο ανάλογα με την περιοχή, το μέγεθος ή ακόμα και την χρονική επιλογή μιας εταιρείας για την κατασκευή ενός φωτοβολταϊκού πάρκου. Για το λόγο αυτό, κρίθηκε σκόπιμο να χρησιμοποιηθεί ως παράδειγμα ένα συγκεκριμένο φωτοβολταϊκό πάρκο και να αξιολογηθούν οι διάφοροι κίνδυνοι με βάση αυτό.

Στην εργασία, παρουσιάζεται ένα συγκεκριμένο φωτοβολταϊκό πάρκο ισχύος 1 MW στην περιοχή του Προχώματος Θεσσαλονίκης, για το οποίο θα αξιολογηθούν οι εντοπισμένοι κίνδυνοι. Ένα βασικό εργαλείο που χρησιμοποιείται για τη διαχείριση αυτών των κινδύνων είναι τα φύλλα ανάλυσης κινδύνων (risk sheets) και οι πίνακες κινδύνων (risk tables), τα οποία προσφέρουν μια συστηματική μεθοδολογία για την καταγραφή, αξιολόγηση και

αντιμετώπιση των κινδύνων. Τα φύλλα ανάλυσης κινδύνων περιλαμβάνουν λεπτομερή περιγραφή κάθε κινδύνου, την πιθανότητα εμφάνισής του, τον αντίκτυπό του στο έργο και τις στρατηγικές μετριασμού του. Επίσης, προσδιορίζεται ο εργαζόμενος που θα είναι υπεύθυνος σε περίπτωση εμφάνισης του κινδύνου.

Ιδιαίτερη μνεία γίνεται στα risk sheets ως προς τις στρατηγικές μετριασμού των διάφορων κινδύνων. Πέρα από τον αναλυτικό στρατηγικό σχεδιασμό που λαμβάνεται για κάθε κίνδυνο, αναφέρεται και ο αντίκτυπος που αναμένεται από τις συγκεκριμένες στρατηγικές στη πιθανότητα εμφάνισης ή στον αντίκτυπο του κινδύνου. Κατά την εφαρμογή αυτών των στρατηγικών, παράγεται ένα νέο risk score, το οποίο αντιστοιχεί στη νέα κατηγορία διακινδύνευσης. Με αυτόν τον τρόπο, είναι δυνατή η κατηγοριοποίηση των κινδύνων βάσει του βαθμού επικινδυνότητάς τους, είτε πριν είτε μετά την εφαρμογή των στρατηγικών αντιμετώπισής τους.

Για ορισμένους κινδύνους, ήταν εφικτό να αντληθούν ποσοτικά στοιχεία από κατασκευαστική εταιρεία φωτοβολταϊκών πάρκων. Τα στοιχεία αυτά βοήθησαν στην ακριβέστερη ανάλυση της πιθανότητας εμφάνισης και του αντίκτυπου των κινδύνων, τόσο πριν όσο και μετά την εφαρμογή στρατηγικών αντιμετώπισής τους. Έτσι, πέντε κίνδυνοι αναλύθηκαν εις βάθος και αποτέλεσαν τη βάση για την εφαρμογή της μεθόδου Monte Carlo. Με τη χρήση της, παράγονται συμπεράσματα σχετικά με την ακρίβεια της αρχικής ανάλυσης για τους συγκεκριμένους κινδύνους.

Μέσω της μεθόδου Monte Carlo, πραγματοποιείται ποσοτική αξιολόγηση των κινδύνων που σχετίζονται με τις πιθανές βλάβες του εξοπλισμού, τη μεταβλητότητα των τιμών των υλικών, τις ποιοτικές αστοχίες υλικών, τα ακραία καιρικά φαινόμενα και τα προβλήματα που σχετίζονται με τη σταθερότητα του εδάφους. Η προσομοίωση χιλιάδων σεναρίων επιτρέπει τη στατιστική αποτίμηση των επιπτώσεων κάθε κινδύνου, παρέχοντας μια σαφή εικόνα της κατανομής των πιθανών εκβάσεων.

Για την εφαρμογή της μεθόδου, χρησιμοποιήθηκε το πρόγραμμα Crystal Ball της Oracle. Στο πρόγραμμα εισάχθηκαν οι τιμές που αρχικά ορίστηκαν στα risk sheets των κινδύνων για την πιθανότητα εμφάνισης και τον αντίκτυπό τους. Επιλέχθηκε η τριγωνική κατανομή για τις δύο αυτές παραμέτρους και τα αποτελέσματα επιβεβαίωσαν γενικά τις αρχικές εκτιμήσεις μας. Ιδιαίτερο ενδιαφέρον παρουσίασαν τα αποτελέσματα του κινδύνου της μεταβλητότητας των τιμών των υλικών, καθώς τα αποτελέσματα του risk score διαμοιράστηκαν κυρίως σε δύο κατηγορίες διακινδύνευσης.

Συμπερασματικά, παρατηρούμε ότι υπάρχουν αρκετοί κίνδυνοι κατά την κατασκευή ενός φωτοβολταϊκού πάρκου. Πολλοί από αυτούς εκτιμώνται ως χαμηλής διακινδύνευσης και δεν αποτελούν σημαντική ανησυχία για τις κατασκευαστικές εταιρείες. Άλλοι, ωστόσο, θεωρούνται ότι μπορούν να οριοθετηθούν και να μειωθούν με απλές μεθόδους, μειώνοντας την πιθανότητα εμφάνισης ή τον αντίκτυπό τους. Παρά ταύτα, υπάρχουν και κίνδυνοι που ενδέχεται να καθυστερήσουν το χρονοδιάγραμμα ενός έργου, ακόμα και με τα μέτρα αντιμετώπισης που λαμβάνονται. Για κάποιους από αυτούς, η επικινδυνότητά τους παραμένει σε υψηλά επίπεδα, ακόμη και μετά την εφαρμογή στρατηγικών αντιμετώπισης. Συνεπώς, διαμορφώνεται ένα σύμπλεγμα κινδύνων που πρέπει να ληφθεί υπόψη πριν την ανάληψη τέτοιων έργων.

Η μέθοδος Monte Carlo συνέβαλε στην εις βάθος ανάλυση των κινδύνων, για τους οποίους ήταν εφικτό να ληφθούν περισσότερα ποσοτικά δεδομένα. Μέσω αυτής, κατανοείται το εύρος των τιμών που μπορεί να λάβει το risk score κάθε κινδύνου με μια μικρή διακύμανση στις παραμέτρους που το καθορίζουν. Τα αποτελέσματα, τα οποία προήλθαν από 20.000 δοκιμές, παρουσίασαν σταθερότητα και επιβεβαίωσαν την αξιοπιστία της μεθόδου.

Ιδιαίτερη έμφαση δίνεται στην αξιοποίηση της μεθόδου Monte Carlo ως εργαλείου λήψης αποφάσεων, το οποίο επιτρέπει την ανάλυση των κινδύνων βάσει μοντέλων που παρέχουν περαιτέρω στοιχεία για τη σοβαρότητα κάθε κινδύνου. Τα αποτελέσματα της έρευνας καταδεικνύουν ότι η εφαρμογή τέτοιων μεθόδων μπορεί να ενισχύσει την πληροφόρηση έναντι των κινδύνων και να προσφέρει πολύτιμα δεδομένα για τους επενδυτές, τους μηχανικούς έργων και τους φορείς στον τομέα των ανανεώσιμων πηγών ενέργειας. Συνδυάζοντας τη θεωρητική ανάλυση κινδύνων με πρακτικές εφαρμογές, η εργασία αυτή προσφέρει νέα γνώση στη διαχείριση κινδύνων και προτείνει μεθόδους για τη βελτιστοποίηση της απόδοσης και της βιωσιμότητας έργων ανανεώσιμων πηγών ενέργειας.

Στοιχεία, όπως αυτά που αντλούνται από την παρούσα εργασία, είναι ιδιαίτερα σημαντικά για τις κατασκευαστικές εταιρείες που ειδικεύονται στον τομέα των ανανεώσιμων πηγών ενέργειας, αλλά και για τους φορείς που καταστρώνουν πολιτικές στον συγκεκριμένο κλάδο. Ο κάθε επενδυτής μπορεί να αντλήσει κρίσιμα δεδομένα για τους τομείς στους οποίους πρέπει να ληφθούν άμεσα μέτρα, ώστε να είναι προετοιμασμένος για τις βασικές δυσκολίες που πιθανόν να αντιμετωπίσει κατά την υλοποίηση ενός τέτοιου εγχειρήματος. Με την κατανόηση και την πρόληψη κινδύνων, όπως αυτοί που αναλύονται στην παρούσα εργασία, επιτυγχάνεται η ασφαλέστερη δυνατή συνθήκη για την κατασκευή ενός φωτοβολταϊκού έργου.

Λέξεις Κλειδιά: Ανάλυση Κινδύνων, Διαχείριση Κινδύνων, Φωτοβολταϊκό πάρκο, Στρατηγικές αντιμετώπισης Κινδύνων, Risk Score

Abbreviations

AC: Alternating Current
AI: Artificial Intelligence
AHP: Analytic Hierarchy Process
BIPV: Building-Integrated photovoltaics
CdS: Cadmium Sulfide
CIGS: Copper indium gallium selenide
COVID-19: Coronavirus disease
DC: Direct Current
EBITDA: Earnings Before Interest, Tax, Depreciation, and Amortization
ERM: Enterprise Risk Management
ESG: Environmental, Social, and Governance
IRR: Internal Rate of Return
kW: Kilovolt
kW: Kilowatt
kWh: Kilowatt hours
LTV: Loan-to-Value
Max: Maximum
MCDM: Multi-criteria decision-making
MCS: Monte Carlo Simulation
Min: Minimum
ML: Machine learning
mm: Millimeter
MW: Megawatt
NREL: National Renewable Energy Laboratory
OPEX: Operational Expenditures
OPV: Organic Photovoltaics
PID: Potential Induced Degradation
PPA: Power Purchase Agreement
PV: Photovoltaic
RBS: Risk Breakdown Structure
Risk ID: Risk Identification Number
UHVC: Ultra High Voltage Center
USD: United States Dollar
WBS: Work Breakdown Structure
μ: Mean value
σ: Standard deviation

1. Chapter 1 - Introduction

1.1 Thesis Framework

There are a number of dangers and uncertainties associated with the quick growth of photovoltaic (PV) parks as a renewable energy source, which could have a big influence on their long-term sustainability, operational effectiveness, and financial feasibility. The stability of PV investments and the mitigation of these issues depend on effective risk management. The implementation of the Monte Carlo method as a probabilistic risk analysis tool to evaluate PV park uncertainties is the main emphasis of this thesis. This study intends to offer a quantitative evaluation of numerous risk factors that impact the lifecycle of PV projects, from development to operation, by utilizing stochastic modeling methodologies.

Given the inherent variability in solar energy generation, which is impacted by technical performance, economic variables, and meteorological circumstances, risk assessment is essential in PV parks. Project uncertainties are also influenced by outside variables including shifting regulations, shifting market conditions, and altered policies. A popular simulation technique that can be used to represent complicated systems when deterministic approaches might not be enough is the Monte Carlo method. This approach improves decision-making for investors, engineers, and politicians in the renewable energy sector by making it easier to estimate risk probability distributions by iterative random sampling.

This thesis' main goal is to use the Monte Carlo approach to create a thorough risk assessment framework for PV parks. Project management, technical, environmental, financial, regulatory, operational, social, and cybersecurity risks will all be methodically categorized in this study. This study advances the subject of risk management in renewable energy projects by measuring uncertainty and evaluating their effects on PV park performance.

1.2 Scope

The application of risk assessment techniques specific to solar parks is the main focus of this thesis. The study includes probabilistic simulation methods, risk management concepts, and a theoretical analysis of PV park development. A systematic approach to risk mitigation is made possible by the application of the Monte Carlo method to the analysis of uncertainty in different risk categories.

An analysis of the construction of a 1 MW photovoltaic park in Prochoma, Thessaloniki, Greece, is done. A quantitative assessment of the hazards related to the building and operation of PV parks is made possible by this case study, which acts as a real-world implementation of the Monte Carlo method. Aspects including environmental circumstances, financial volatility, equipment reliability, and regulatory compliance are all covered in the study. Risk factors are carefully documented and analyzed using risk sheets, risk tables, and risk breakdown structures (RBS).

This research attempts to close the gap between risk analysis methodology and practical implementations in renewable energy projects by combining theoretical and computational approaches. For those involved in the development of PV parks, including investors, project managers, legislators, and energy planners, the results will offer insightful information.

1.3 Delimitation of Thesis

Although this thesis offers a thorough framework for risk analysis, some limitations must be noted. First off, other renewable energy sources like wind and hydroelectric power are not included in the analysis; they are solely focused on solar parks. Certain risk parameters that might not be directly relevant to other energy infrastructure projects are introduced by the peculiarity of PV projects.

Second, the study's scope is restricted to a single case study in Greece, which would restrict how broadly the results can be applied to other regions. Different markets may be affected by regional characteristics, such as economic stability, regulatory frameworks, and climate conditions, in different ways.
Furthermore, even though the Monte Carlo approach is dependable for probabilistic modeling, it is inevitably reliant on the caliber and precision of the input data. The accuracy of risk assessments may be impacted by uncertainties in data collection, model assumptions, and computing limitations. However, this study aims to reduce potential biases and improve the reliability of the findings by applying an organized method to risk categorization and sensitivity analysis.

In conclusion, this thesis uses the Monte Carlo approach to improve decision-making by offering a thorough examination of risk factors influencing PV parks. Notwithstanding its limitations, the study adds to the current discussion on risk management for renewable energy and provides a methodological framework that can be used for future projects of a similar nature.

2. Chapter 2 – Theoretical Insights into Photovoltaic Parks, Risk Management and Monte Carlo Simulation

2.1 Historic Development of photovoltaic parks

Since its discovery in the 19th century, photovoltaic technology has undergone multiple stages of theoretical investigation, material development, and extensive commercialization, all of which have contributed to its ongoing innovation. photovoltaics' evolution from a theoretical idea to a useful and essential part of modern energy systems demonstrates the significant advancements in solar technology over the past two hundred years.

The essential processes guiding the conversion of light into electricity were discovered during the foundational period of photovoltaic development, which lasted from 1839 to 1899. The first major discovery was made in 1839 when French physicist Alexandre Edmond Becquerel discovered the photovoltaic phenomenon, which showed that electrical conductivity in a system with metal electrodes and electrolytes increased under illumination. His research laid the groundwork for further investigations into solar energy conversion. Willoughby Smith discovered that selenium has photovoltaic qualities in 1873. Shortly after, Richard Evans Day and William Grylls Adams noticed that light striking a platinum and selenium connection could cause an electrical current to flow. The first selenium solar cell was built in 1877 as a result of these observations, and in 1883 Charles Fritts gave a thorough explanation of how it worked. Heinrich Hertz's 1887 discovery that ultraviolet light could alter the voltage needed to generate electrical sparks between metal electrodes—a phenomenon that would later be central to the quantum theory of light—further improved scientific understanding of the photovoltaic effect (Butti, Ken and John Perlin, 1980).

The creation of the first usable solar cells and the theoretical justification of the photovoltaic effect defined the years 1900–1949. Albert Einstein won the Nobel Prize in Physics in 1921 for his groundbreaking work in 1905, which offered a quantum mechanical explanation of the effect. In 1916, Robert Millikan confirmed the quantum nature of light absorption in photovoltaic materials by experimentally validating his theoretical predictions. Simultaneously, developments in material science made it possible to create monocrystalline silicon, which was first identified by Polish scientist Jan Czochralski in 1918 and later proved crucial to produce solar cells. The viability of photovoltaic applications was further advanced by the successful construction of the first silicon sun cell in 1941. During this time, cadmium selenide—a material still essential to the manufacturing of thin-film solar cells today—was discovered to have a photovoltaic effect in 1932 (Butti, Ken and John Perlin, 1980).

In the 1950s and 1960s, photovoltaic technology advanced significantly, primarily because of the demands of the fledgling space industry. Dan Trivich of Wayne State University made theoretical calculations on solar cell performance across various materials and spectrum wavelengths in 1953 after the first germanium-based solar cells were manufactured in 1951.

The photovoltaic effect in cadmium sulfide (CdS), which would subsequently be employed in thin-film solar cells, was discovered by RCA Laboratories around the same time. The most notable achievement of this era was Bell Laboratories' 1954 creation of the first practical silicon solar cell, which had an initial efficiency of 4.5% before being increased to 6%. Hoffman Electronics produced radiation-resistant silicon solar cells for space technology by 1958, which contributed to the launch of the Vanguard I satellite, the first solar-powered spacecraft. With solar cells reaching 10% efficiency by 1959 and 14% by 1960, photovoltaic efficiency continued to increase throughout the 1960s. In 1963, Sharp Corporation produced the first silicon photovoltaic module for commercial use. Photovoltaic systems were also integrated into important space missions like OVI-13 and Nimbus (Butti, Ken and John Perlin, 1980).

Growing energy demand and geopolitical concerns about reliance on fossil fuels propelled the commercialization of photovoltaic technology in the 1970s. Large-scale industrial production of solar cells began at this time with the founding of significant photovoltaic firms, such as Solar Power Corporation in 1972 and Solarex Corporation in 1973. This decade saw the emergence of hybrid photovoltaic-thermal systems, such as Delaware University's Solar One project, which combined solar energy with residential heating applications. Government-led research initiatives, like Japan's Sunshine Project, which began in 1974, helped fast-track photovoltaic advancements. NASA, the U.S. space agency, was also instrumental in the development of the first amorphous silicon solar cell in 1976 and the installation of terrestrial photovoltaic systems. By 1977, global photovoltaic module output exceeded 500 kW, and the foundation of the Solar Energy Research Institute (SERI) in Colorado denoted rising institutional support for solar technology research (Butti, Ken and John Perlin, 1980).

The first large-scale solar power facilities were installed in the 1980s. In 1980, ARCO Solar became the first company to achieve annual production of photovoltaic modules exceeding 1 MW, a milestone in industrial-scale solar manufacturing. The decade saw the development of historic projects, such as the 105.6 kW system in Utah, which remains functioning today, and the advent of photovoltaic applications for vaccine refrigeration in distant places. The Solar Challenger, the first solar-powered aircraft, made its debut in 1981, demonstrating the potential of photovoltaics in aviation By 1982, global photovoltaic module output exceeded 9.3 MW, while research efforts led to the introduction of amorphous silicon solar modules by ARCO Solar in 1984 and high-efficiency silicon solar cells topping 20% efficiency by 1985. The growing economic feasibility of solar power was demonstrated by large-scale photovoltaic power plants, such as BP's installations in Sydney and Madrid and a 1 MW facility in Sacramento, California (Janzing, Bernward, 2011).

The photovoltaic sector grew dramatically in the 1990s, and large corporations became the industry leaders in the manufacturing of solar cells. Growing corporate interest in photovoltaics was indicated by the establishment of United Solar Systems Corporation in 1990 and Siemens' 1991 acquisition of ARCO Solar. The Solar Energy Research Institute was rebranded as the National Renewable Energy Laboratory (NREL) in 1991, reflecting its broader mandate to advance renewable energy technologies. International collaborations, including World Bank-sponsored solar projects in India, facilitated the adoption of photovoltaics in developing regions. The introduction of solar-powered aircraft like Icar in Germany and the commercialization of copper indium selenide (CIS) solar cells by BP Solar were two examples of commercial developments that further highlighted the technological advancements of this era (Janzing, Bernward, 2011).

Multi-megawatt photovoltaic power plants began to appear in the early 2000s, especially in Germany, where extensive solar deployment was fueled by laws like the Renewable Energy Sources Act. To keep up with the growing demand for solar energy in Europe, companies like Sanyo, Kyocera, and Sharp increased their production. The HELIOS solar-powered aircraft from NASA and AeroVironment Inc., which broke altitude records in 2001, is an example of how technological developments have permeated aerospace applications. With a peak power of 4 MW in 2003, the Solar Park Hemau in Bavaria, Germany, was the biggest photovoltaic plant in the world (Janzing, Bernward, 2011).

Beginning in the 19th century and becoming widely used in the 21st, photovoltaic technology has developed into an essential part of the world's energy landscape. Together with manufacturing advancements and widespread deployment, the ongoing improvement in solar cell efficiency highlights the growing significance of photovoltaics in the shift to sustainable energy sources.

High-efficiency solar cells have become a major topic in photovoltaic (PV) research due to their potential to boost energy conversion rates and lower costs. Perovskite solar cells, which have become a competitive alternative to conventional silicon-based cells, are among the most promising developments. The light-harvesting active layer of these cells is a perovskite-structured substance, usually a material based on tin halide or a hybrid organic-inorganic lead. According to recent research, efficiencies have surpassed 25%, outperforming silicon cells that are sold commercially (Nature Communications, 2023). They have been the focus of much research due to their tunable material properties and simplicity of fabrication, which could lower the cost of producing solar energy.

Another notable innovation in PV technology is the development of bifacial solar panels, which capture sunlight from both the front and rear surfaces of the module. By utilizing reflected light from surrounding surfaces, these panels can increase energy yields by up to 30%, depending on factors such as albedo, tilt angle, and module height (Robin Sun, 2023). Since maximizing energy output is crucial for economic viability in large-scale PV parks, their increased efficiency has led to their widespread adoption.

Multi-junction solar cells, often known as tandem cells, represent another advance in high-efficiency PV technology. To capture more energy, these cells combine several layers of materials, each of which is made to absorb distinct parts of the sun's spectrum. Recent advancements in materials science and device engineering have enabled efficiency near 50%

under concentrated sunlight, making them an attractive option for high-performance applications despite their higher cost (IEA, 2022).

Modern solar technologies have also helped PV systems become more versatile and efficient. By transforming the direct current (DC) produced by solar panels into alternating current (AC) for grid integration, smart inverters are essential components of contemporary PV installations. These inverters enhance energy efficiency and guarantee grid stability by enabling real-time monitoring and control (IEEE Xplore, 2022). The dependability of solar electricity has been significantly increased with the use of energy storage technologies, especially lithium-ion and flow batteries. For instance, the Tesla Powerwall can store up to 13.5 kWh of energy, which may be used to improve energy management for both commercial and residential systems and provide backup power during outages (Tesla, 2023). Battery storage offers vital grid functions like frequency management and voltage support, as well as mitigating variations in solar energy generation in large-scale PV parks.

The capacity of solar tracking systems to enhance energy capture by modifying panel orientation during the day has also contributed to their rise in popularity. These systems, which are divided into single-axis and dual-axis trackers, are a desirable option for large-scale installations since they can increase energy production by up to 25% when compared to fixed-tilt systems (Science Direct, 2023).

Building-Integrated photovoltaics (BIPV), which integrates photovoltaics into constructed surroundings, is another crucial area of research. These systems combine energy-generating and architectural features by integrating solar cells into building elements including windows, roofs, and facades. For example, transparent solar cells make it possible to generate power without sacrificing aesthetic appeal or natural light, opening the door to more environmentally friendly urban energy options (Solar Energy Materials & Solar Cells, 2023).

The application of flexible and transparent solar panels is another development in PV technology. Advances in materials research have enabled the production of ultra-thin, flexible solar cells that may be installed on curved surfaces, like those used in automobiles and portable devices. Technologies such as amorphous silicon, copper indium gallium selenide (CIGS), and organic photovoltaics (OPV) have enabled these flexible solar panels, which can also be integrated into transparent structures like windows and greenhouses (Renewable Energy Journal, 2023).

Cost reductions have been a distinguishing trend in the solar energy industry during the last 10 years. Since 2010, the cost of solar panels has dropped by over 80% due to advancements in technology, economies of scale, and better production techniques. As solar energy becomes more cost-effective than fossil fuels, its use has expanded globally, contributing to the transition to sustainable energy (World Economic Forum, 2022).

Another crucial challenge in PV production and disposal is sustainability. Researchers are continually looking into new materials and production methods that reduce the environmental impact of producing solar panels. Initiatives to develop effective recycling strategies for used solar panels are also advancing a circular economy in the solar sector (PV Tech, 2023).

Future developments in PV technology are anticipated to be influenced by ongoing improvements in sustainability, cost effectiveness, and efficiency. Researchers are working to increase multi-junction solar cells' efficiency above 50%, while energy management systems are incorporating AI and machine learning to maximize PV parks' performance. Furthermore, the smooth integration of solar energy into electrical grids is being made possible by developments in energy storage and smart grid technology, guaranteeing a more reliable and effective power supply (IEA, 2022).

Photovoltaics are positioned to be a key component of the global switch to renewable energy as these advances develop further. PV technology will improve energy efficiency and help create a more sustainable and fair energy future with continued research and development.

2.2 The five phases of developing a solar park

Finding an appropriate site with ideal solar irradiation and closeness to the electrical grid is the first step in creating a solar park. A number of considerations, including flood danger, sunlight exposure, and land topography, must be carefully considered during the site selection process. For optimal energy yield, the selected ground should ideally be level, free of obstacles, and flood resistant. Due to their constant sunshine, arid places frequently offer higher solar yields; nevertheless, issues with infrastructure and grid connectivity need to be resolved (Smith et al., 2021).

The solar park's (Figure 1 and 2) anticipated capacity determines the necessary land area. About one hundred square feet of space are needed for every kilowatt (kW) of installed capacity, or about 2.5 acres for every megawatt (MW). A total of 5 to 10 acres of land are required per MW, which includes additional room for equipment, access roads, and infrastructure (Johnson & Lee, 2020). Because it directly affects the cost and viability of transmitting the generated electricity, site proximity to the electrical grid is crucial. Utility-scale solar parks typically connect to substations that regulate power to the required voltage levels or to transmission lines with voltages of 69 kV or higher. In contrast, three-phase distribution lines with voltages lower than 69 kV are usually connected to community solar parks (Anderson, 2019). When the interconnection point is within a mile of the park, transmission losses and infrastructure expenses are reduced, increasing the solar project's financial feasibility.

Figure 1: Example of 1MW PV Park

In addition to technical factors, local zoning laws must be followed when choosing a location, and the high initial expenditure should be countered by minimizing land purchase expenses. In certain cases, local governments might provide land or offer it at preferential lease rates to promote the development of renewable energy (Miller & Rodriguez, 2022). Before moving on to later stages of the project, a suitable location must be secured.

Following the selection of a suitable site, technical design and permitting are the next steps. Solar panels, inverters, racking systems, and storage units, if any, are the four main parts of a solar system. For the system to operate as efficiently and effectively as possible, its design must consider the amount of land that is accessible. Installation quality, energy yield optimization, and component warranties—most manufacturers provide performance guarantees ranging from 20 to 30 years—are crucial considerations throughout the design phase (Chen et al., 2021). Selecting the right equipment is essential. Reputable manufacturers like Canadian Solar, Jinko, Phono, and Trina offer affordable options, while QCells, LG, SunPower, and Megasol offer more expensive options (Harris, 2020).

After choosing the equipment, thorough technical planning and regulatory authority permission are needed. Depending on site-specific conditions and legal requirements, the permitting process may take one to five years. To determine how the project may affect nearby ecosystems and species, an environmental impact assessment (EIA) may be required. Obtaining construction approval requires proving to the authorities that the project is feasible and sustainable (Davies & Kumar, 2018).

Negotiating a Power Purchase Agreement (PPA), which lays out the contractual arrangements between the solar electricity generator and the electricity distribution business or other large-scale energy consumers, is an essential part of project development. The PPA outlines the energy purchase period, which is normally 18 to 25 years following the solar park's commissioning. Depending on geography and market conditions, the negotiated price per kWh varies between USD 3.5 and 7.0 cents (Garcia, 2021). By lowering market exposure and offering financial security, the PPA lessens the risk of unsold electricity. Securing advantageous financing terms and guaranteeing long-term contractual compliance depend heavily on the power buyer's creditworthiness (Nguyen & Patel, 2020). Project feasibility is increased by a well-negotiated PPA, which is frequently a requirement for securing funding.

The next important step is obtaining funding, which usually happens once permission and PPA discussions are over. The two main types of funding for solar parks are loan and equity financing. Project promoters and early-stage investors contribute funds for equity financing, taking on construction risk in the hope of earning returns later. Once the solar park is up and running, these investors frequently leave the project and transfer their shares to institutional investors looking for steady, long-term earnings. One important indicator for assessing the viability of investments is the Levered Internal Rate of Return (IRR); the term "levered" describes the use of debt financing to increase returns by lowering reliance on equity capital (Williams, 2021). Prior to investing their money, equity investors usually need concurrent loan financing arrangements.

Large-scale solar farms require a significant amount of capital, which makes debt financing necessary. Since interest payments are less than the anticipated returns on equity investments, debt financing is more economical than equity financing. The quality of cash flow predictions and collateral assets (such land, solar panels, and inverters) are used by lenders to evaluate project risks. Lender evaluations heavily rely on standard financial statistics, such as the Loan-to-Value (LTV) ratio, Debt to EBITDA ratio, Debt to Equity ratio, Debt Service Coverage Ratio, and Interest Coverage Ratio (Brown & Thomas, 2019). Securing funding requires a solid financial strategy that shows the project's capacity to fulfill debt commitments and uphold covenant compliance.

Figure 2: Example of 1MW PV Park

The construction phase starts after funding is obtained and the required approvals are obtained. The procurement of equipment is started, and supply chain logistics, customs processes, and documentation need all effect delivery schedules. Usually, lasting several months to several years, the construction period varies according to the project's size, infrastructure preparedness, and regulatory issues. Phased development of large-scale solar parks enables gradual capacity augmentation (Peters et al., 2021).

Commissioning, the project's last phase, comprises testing and verifying power generation in relation to predetermined performance standards. Getting official approval from the electricity buyer, who incorporates solar energy into the larger grid network, is part of this phase. To ensure that the solar park is prepared for full-scale operation, commissioning entails a number of technical assessments to verify system functionality and adherence to regulatory criteria (Martinez, 2020).

2.3 Risk Management

In the quickly changing business environment of today, risk management has become an essential discipline that companies need to adopt to successfully navigate uncertainty. An initiative-taking and all-encompassing strategy to risk management is required due to the complexity of contemporary hazards, which are fueled by environmental issues, geopolitical changes, and technological breakthroughs. It is impossible to overestimate the significance of putting in place strong risk management frameworks given the variety of dangers that firms face, from cyber attacks to problems with regulatory compliance.

The idea of enterprise risk management (ERM), which stresses a thorough approach to detecting and managing risks across all levels of a business, is one important trend in modern risk management. The realization that risks are interrelated and can have significant effects on an organization's success is reflected in this shift in fundamental beliefs. Seventy percent of risk managers are increasingly concentrating on strategic risk responses, per a recent FERMA study, suggesting a rising understanding of the necessity of coordinating risk management procedures with business strategy (FERMA, 2024). Through this integration, businesses may take advantage of possibilities that come from successfully managing risks in addition to protecting against any threats.

The contemporary landscape of risk management is shaped by a number of megatrends that have emerged because of the growing complexity of threats. These include the need for operational resilience, the increase in cybersecurity threats, and the focus on Environmental, Social, and Governance (ESG) considerations (IERP, 2024). To evaluate risks more precisely and effectively, organizations must now implement data-driven risk management methods that make use of artificial intelligence and advanced analytics. Businesses can find patterns in data that guide their decision-making procedures and improve their capacity to proactively reduce risks by employing machine learning and predictive analytics (IERP, 2024).

Organizations must also modify their risk management plans as they go through digital transformation to manage new vulnerabilities brought on by developing technologies. In addition to increasing productivity, integrating digital technologies into company operations raises new dangers including data privacy and technological disruptions (IERP, 2024). To keep companies robust in the face of disruptions, good risk management must take these changing trends into account.

The technique of risk analysis is fundamental to efficient risk management. Organizations can systematically discover, assess, and rank risks with the help of risk analysis, a fundamental technique. This procedure entails evaluating the impact and likelihood of hazards that have been discovered, enabling decision-makers to deploy resources efficiently and put suitable mitigation plans into place (Logic Manager, 2024). Organizations can learn a lot about their risk profiles by using formal approaches like probability-impact matrices or qualitative evaluations.

Moreover, by offering a thorough grasp of potential hazards, risk analysis helps make well-informed decisions. It gives businesses the ability to balance the advantages and disadvantages of different strategies while taking the risks into account (MetricStream, 2023). As stakeholders become more conscious of their responsibilities in risk management, this analytical approach not only improves operational efficiency but also cultivates an accountability culture inside businesses.

In conclusion, effective risk management has become essential as firms traverse a risk landscape that is becoming more complex due to rapid technological breakthroughs and changing regulatory frameworks. This framework's incorporation of risk analysis as a key tool enables firms to proactively identify certain hazards and create customized mitigation plans. Organizations can strengthen their ability to withstand unforeseen events and set themselves up for long-term success in a constantly shifting environment by giving risk analysis top priority within their overall risk management procedures.

The discovery, evaluation, and mitigation of risks are all part of the risk analysis process, which is essential to successful project management and organizational success. A Risk Breakdown

Structure (RBS), risk sheets, and risk tables are frequently used in a thorough approach to risk analysis. This systematic framework not only helps to comprehend the different risks that engage in a project, but it also makes it easier to create methods to properly manage these risks.

By starting with broad categories and gradually dividing them into more focused subcategories, the RBS functions as a hierarchical tool that divides risks into discrete levels. Project managers and stakeholders can more easily see the terrain of risks using this methodical approach. Technical, operational, external, and organizational risks are among the main types (ProjectManager.com, 2022). Sub-risks within the technical category, for example, could include problems with software development, hardware malfunctions, or integration difficulties. Teams can make sure that all pertinent factors are considered during the risk identification phase by structuring risks in this way.

An essential initial step in the risk management process is risk identification. To identify hazards, a number of methods can be used, such as workshops, stakeholder interviews, brainstorming sessions, and historical data analysis (Wikipedia, 2024). Teams can also find the project's possibilities, threats, vulnerabilities, and strengths by using methods like SWOT analysis. Because risk identification is iterative, it should be reviewed frequently over the project lifetime to consider new information or modifications to the project's scope.

Risks are recorded in risk sheets when they have been recognized and grouped according to the RBS framework. These documents function as thorough logs for every risk that has been identified and usually contain details like the risk description, effects on project goals, probability of occurrence, controls or mitigations already in place, and designated roles for risk monitoring. Maintaining team clarity and making sure that everyone is aware of the dangers the project faces depend on this documentation.

Qualitative measures are used to evaluate each identified risk's impact and likelihood. Impact evaluates the possible outcomes if a risk materializes, whereas likelihood refers to the likelihood that a risk will occur. According to Mehdizadeh (2024), both criteria are typically ranked on a scale of 1 to 5 or divided into levels like low, medium, and high. Teams can rank hazards according to their seriousness and probability of happening with this rating method. High-scoring risks need to be addressed right away and require stronger mitigation techniques.

Risk tables are made to systematically illustrate these scores after the initial assessment phase, which is conducted using the RBS and risk sheets. Usually, these tables use a matrix style that compares impact levels to likelihood. Project managers may swiftly determine which hazards need immediate attention and which can be tracked over time with the help of such visual representations. To manage significant threats, resources can be allocated efficiently by classifying risks into low, medium, high, or extremely high levels.

Mitigation techniques are implemented to lessen the impact or likelihood of hazards that have been identified in the next stage. Creating backup plans for high-risk situations or improving current procedures to reduce vulnerabilities are two examples of mitigation techniques. Through post-mitigation assessments, which recalculate likelihood and impact scores based on implemented interventions, the efficacy of these techniques is assessed.

While continuously enhancing their overall risk management procedures, this method guarantees that firms maintain their flexibility in responding to new threats.

In conclusion, using an RBS in conjunction with comprehensive risk sheets and organized risk tables offers a strong foundation for conducting in-depth risk analysis. In addition to making, it easier to identify risks, this method gives businesses useful information for efficient mitigation plans. Organizations can increase their resilience to uncertainties and optimize resource allocation toward efficiently managing essential risks by methodically evaluating risks both before and after putting control mechanisms in place.

2.3.1 Risk Breakdown Structure (RBS)

An organized method of risk identification, analysis, and management is made possible by a Risk Breakdown Structure (RBS), a hierarchical framework that methodically classifies potential risks related to a project. RBS breaks down risks to increasingly precise levels, improving the clarity and thoroughness of risk assessment. This is like how a Work Breakdown Structure (WBS) breaks down project deliverables into manageable components (Hillson, 2002).

Usually, the RBS is divided into several tiers, each of which denotes a distinct degree of risk classification. Broad risk categories, including technical, managerial, commercial, and external threats, are included in the highest level. Within these categories, more detailed risk factors are covered in later times. For example, technical risks can include hazards associated with performance, software, or hardware, whereas external risks could include environmental concerns, market fluctuations, or changes in regulations (PMI, 2002).

When it comes to project risk management, this hierarchical decomposition has various benefits. First, it reduces the possibility of missing important risk factors by methodically investigating every conceivable source, guaranteeing a thorough identification of potential hazards. Second, it facilitates a better knowledge of how risks are distributed and relate to one another across the project, which allows for more efficient resource allocation and prioritization for risk mitigation techniques (PMI, 2002). Furthermore, the RBS facilitates cooperative risk management initiatives by providing a common framework for stakeholder communication and encouraging a common understanding of risk exposures (Hillson, 2002).

The use of an RBS might be very advantageous in photovoltaic (PV) parks. A comprehensive risk assessment is required due to the intricate nature of PV projects, which include technical elements, regulatory compliance, environmental considerations, and financial investments. The efficacy of the risk management procedure can be increased by using an RBS designed specifically for PV parks to systematically classify risks unique to this area, such as equipment failure, weather variability, regulatory changes, and changes in market demand.

The RBS's usefulness is further increased by combining it with quantitative analytic methods like the Monte Carlo approach. A more thorough and reliable risk assessment is made possible by the Monte Carlo approach, which enables probabilistic analysis of risk implications in contrast to the RBS's structured qualitative assessment. By facilitating well-informed decision-making, this combined approach enables project managers to create robust plans that improve PV park projects' sustainability and success.

2.3.2 Risk Sheets and Risk Tables

Risk sheets and risk tables are essential tools for project risk management because they facilitate the systematic discovery, evaluation, and mitigation of hazards. This helps stakeholders communicate clearly and makes decisions more efficient (Hillson, 2017). To guarantee that risks are managed proactively and that projects stay on schedule, these technologies offer methodical frameworks for recording and evaluating hazards.

A risk sheet is a thorough document created to record precise information about a risk, serving as a central repository for information essential to that risk's management and monitoring. Several essential elements make up a risk sheet's conventional structure. The first step in risk identification is to write down the risk's name, unique identification, and a brief description. Since it guarantees that each risk can be readily distinguished and cited without ambiguity, clear identification is essential (Schwalbe, 2015). Likelihood and Impact are two essential components of the following section, Risk Assessment. To standardize assessments across various risks, the likelihood is an estimate of the probability that a risk event will occur. This estimate is usually quantified using a specified scale, such as low, medium, or high. Impact, on the other hand, evaluates the possible outcomes if the risk materializes; it is frequently scored on a defined scale and assessed in terms of cost, time, scope, or quality (PMI, 2017). These two elements worked together to create a Risk Rating; a metric that helps prioritize risks. It is created from likelihood and impact assessments and is frequently represented by a risk score (e.g., low, moderate, or high).

Creating mitigation strategies and contingency plans is part of the risk sheet's Risk Response Planning component. Proactive measures to lessen a risk's impact or likelihood to prevent or lessen its repercussions are known as mitigation methods. Conversely, contingency plans are predetermined actions to be taken if the risk materializes, with the aim of preventing and controlling negative consequences (Hillson, 2017). To ensure accountability and timely action, when necessary, the risk sheet also allocates Risk Ownership, designating a person or group in charge of keeping an eye on the risk and putting the appropriate reaction plans into place. Finally, Review and Monitoring plans frequent evaluations of the risk situation and the efficiency of the reaction tactics, preserving a flexible risk management procedure that adjusts to changing conditions (Schwalbe, 2015).

A visual tool that makes it easier to compare and rank various hazards within a project is a risk table, also known as a risk assessment matrix. An easily readable summary of the risks is provided by this tabular layout, facilitating rapid reference and analysis. A standard risk table has multiple columns: The following factors are rated on a numerical or categorical scale: Impact, which indicates the seriousness of the risk's consequences; Likelihood, which is the assessed probability of the risk occurring; Risk ID, which acts as a unique identifier for convenient reference; and Risk Description, which gives a concise synopsis of the risk event or condition. The likelihood and impact evaluations are combined to create the Risk Score, which helps rate the risks according to importance (PMI, 2017). The Risk Response, which summarizes the intended steps to minimize or address the risk, including both mitigation and contingency solutions, is also included in the risk table. While the Status column shows the risk's current condition (e.g., active, resolved, monitoring), the Risk Owner column identifies the person or group in charge of risk management and offers information on how well risk management initiatives are going.

By comparing their scores, risk tables help project teams prioritize risks and determine which ones need immediate attention and resource allocation, making them essential tools in the risk assessment process (Hillson, 2017). To guarantee that the most important risks are dealt with first, this comparative analysis also helps in the creation of suitable Response Strategies. Furthermore, ongoing risk status monitoring is made possible by routinely updating the risk table, which enables teams to assess the efficacy of response plans and make required modifications (Schwalbe, 2015).

The application of risk tables and risk sheets is particularly beneficial in the context of photovoltaic (PV) parks. PV projects are distinguished by intricate technical, financial, and environmental factors, each of which poses distinct risks that call for careful planning, analysis, and documentation. Project managers can improve project resilience and raise the possibility of successful project outcomes by systematically identifying, evaluating, and managing these risks using structured risk management tools like risk sheets and risk tables (PMI, 2017).

2.3.3 Risk score values and thresholds

2.3.3.1 Risk Score Scale

The table below outlines how the risk score is calculated and interpreted based on the impact and likelihood scales. Each risk is evaluated on a scale from 0.05 to 0.8 for impact and from 0.1 to 0.9 for likelihood (Kirytopoulos 2006, based on / PMI 2013). The risk score is the product of these two values, which helps determine the priority and necessary response actions.

Table 1: Risk Score Scale

Likelihood \ Impact	**0,05 (Low Impact)**	**0,1 (Minor Impact)**	**0,2 (Moderate Impact)**	**0,4 (Major Impact)**	**0,8 (Catastrophic Impact)**
0,1 (Rare)	0,01	0,01	0,02	0,04	0,08
0,3 (Unlikely)	0,02	0,03	0,06	0,12	0,24
0,5 (Possible)	0,03	0,05	0,1	0,2	0,4
0,7 (Likely)	0,04	0,07	0,14	0,28	0,56
0,9 (Almost Certain)	0,05	0,09	0,18	0,36	0,72

(Kirytopoulos 2006, based on / PMI 2013)

2.3.3.2 Risk Score Chart

The chart below shows graphically the above risk score values. The x-axis has the impact values, while the y-axis has the likelihood values. Each pair of values produces a risk score which is represented graphically. Each point has the corresponding color of the risk category it represents. Thus, in green there are the low risk values, in orange there are the medium risk values and in red there are the high risk values. Finally, two curves have been drawn which define the limits of each risk category. These curves were created by joining several points corresponding to pairs of impact and likelihood values which result in an intermediate risk score between the two risk categories. Between the low and medium risk category this value is 0.045 and between the medium and high risk category this value is 0.145.

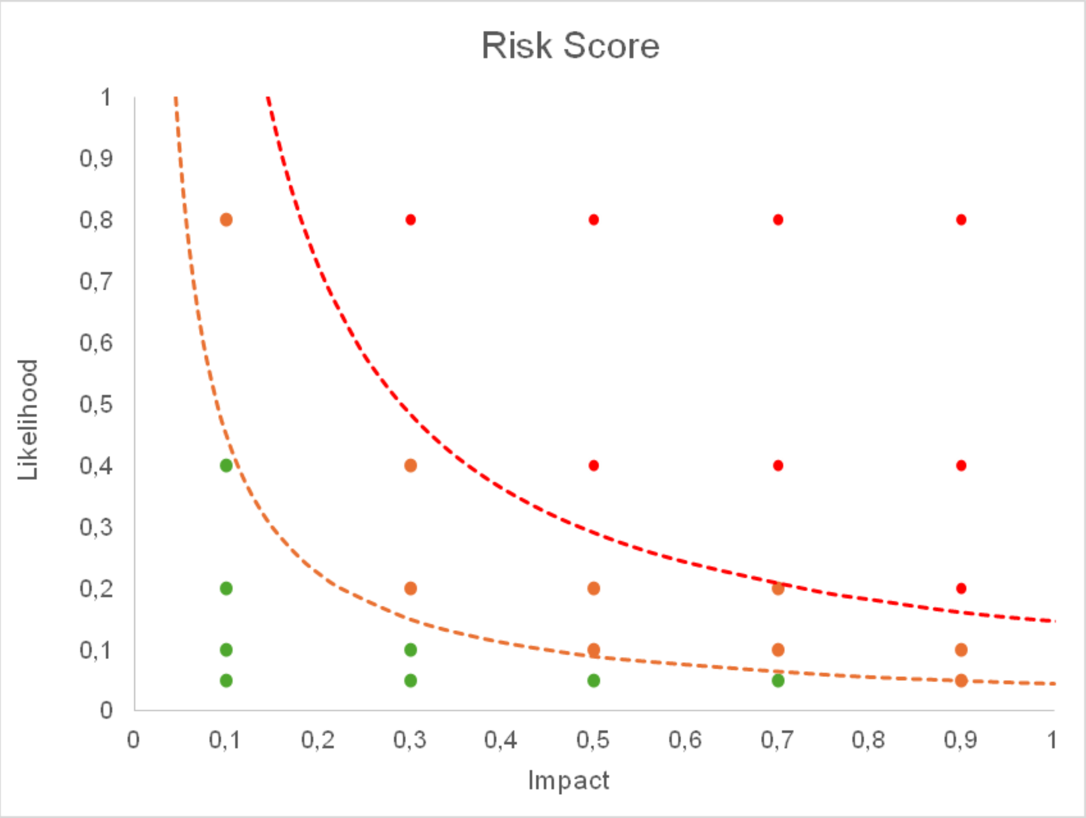


Figure 3: Risk Score Chart

2.3.3.3 *Interpretation of Risk Scores*

Risk assessment is a critical component of decision-making in various fields, including finance, engineering, and environmental management. It allows organizations to evaluate potential hazards and implement appropriate mitigation strategies. The table below categorizes risk scores into three levels—low, medium, and high—based on numerical thresholds. Each category is associated with a specific response action to ensure that risks are managed effectively.

Table 2: Interpretation of Risk Scores

Risk Score	Interpretation	Response Action
0,01 - 0,04	Low Risk	Monitor and maintain current controls
0,05 - 0,14	Medium Risk	Implement additional controls
0,15 -0,72	High Risk	Develop and implement risk response plans

(Kirytopoulos 2006, based on / PMI 2013)

2.3.3.4 Likelihood Scale

The likelihood of an event occurring is a fundamental factor in risk assessment, influencing decision-making processes across various disciplines, including finance, engineering, and project management. Likelihood is typically expressed as a probability percentage, providing a quantitative basis for evaluating potential risks. The table below categorizes likelihood into five levels, ranging from "Very Low" to "Very High," with an additional category for near-certain events that are no longer considered risks but certainties.

Table 3: Likelihood Scale

Likelihood	Interpretation
Up to 10%	Very low
10-30%	Low
30-50%	Medium
50-70%	High
70-90%	Very high
>90%	it is a certainty and not a risk

(Kirytopoulos 2006, based on / PMI 2013)

2.3.3.5 Impact Scale

Impact assessment is a crucial element in risk management, as it evaluates the potential consequences of identified risks on a project's key performance criteria. The severity of an impact is typically categorized into different levels, ranging from "Very Low" to "Very High," based on quantifiable thresholds. The following table presents an impact classification system, incorporating multiple dimensions such as cost, time, scope, and quality/performance, to provide a comprehensive framework for assessing risk consequences.

Table 4: Impact Scale

Impact	Very low 0,05	Low 0,1	Medium 0,2	High 0,4	Very high 0,8
Cost (Increase project costs)	Insignificant	<5% increase	5-10% increase	10-20% increase	> 20% increase

Impact	**Very low** **0,05**	**Low** **0,1**	**Medium** **0,2**	**High** **0,4**	**Very high** **0,8**
Time (Increase project duration)	Insignificant	<5% increase	5-10% increase	10-20% increase	> 20% increase
Scope	Almost no identifiable change	Small part of the of the total range affected	Significant part of the total of the total range affected	The range affected in to the point of no acceptable	The range affected to degree of cancellation of the project
Quality / Performance	Almost no identifiable change	Demanding only applications affected	Point to needed approval of customer	Point of no accepted	Point leading to cancellation of the project

(Kirytopoulos 2006, based on / PMI 2013)

It is emphasized that the risk matrix and the associated scales may vary from project to project or from project to project, for example depending on the risk appetite of the organization (risk appetite for risk. However, it is certain that the scales should not change during a project but should be decided in the planning process and adhered to throughout the project.

2.4 Monte Carlo Method for Risk Analysis

A reliable statistical method used for quantitative risk analysis in a variety of fields, including project management, engineering, and finance, is the Monte Carlo method. By simulating multiple possibilities, this approach is crucial for modeling uncertainty and variability in complex systems. Named after the Monte Carlo Casino in Monaco to emphasize the unpredictability in its simulations, the method was initially created in the 1940s by mathematicians Stanislaw Ulam and John von Neumann in response to difficulties in nuclear physics (Ulam & von Neumann, 1940s). By creating random samples from predetermined probability distributions, the Monte Carlo method has its roots in probability and statistics—allows researchers to assess the likelihood of different events (Metropolis & Ulam, 1949).

Random sampling, probability distributions, and repetitive simulation are the cornerstones of the Monte Carlo method. By creating values for ambiguous parameters, random sampling enables the investigation of a wide variety of potential outcomes. Probability distributions, such as normal, uniform, or triangular distributions, which specify the likelihood of different values happening, are used to characterize the simulation's input variables. Many iterations—

often hundreds of millions—are conducted in the iterative simulation process to generate a range of outcomes. These can subsequently be examined to extract information regarding risk and uncertainty (Hammersley & Handscomb, 1964).

Implementing a Monte Carlo simulation for risk analysis is a methodical and structured procedure that consists of multiple steps. Clearly defining the issue and goals, identifying the major factors affecting the result, and identifying the risks that need to be evaluated are the initial steps. It is therefore necessary to identify the uncertain input variables—like costs, durations, or demand rates—and give each one a suitable probability distribution. The triangular distribution, which is appropriate for situations with limited data and is characterized by a minimum, maximum, and most likely value, the uniform distribution, which is appropriate for circumstances where all outcomes within a specified range are equally likely, and the normal distribution, which is appropriate for variables that are symmetrically distributed around a mean value, are examples of frequently used distributions (Smith, 2003).

A mathematical model that depicts the connections between the input variables and the intended result is created following the identification and characterization of the variables. This model provides the basis for simulation and enables the computation of outcomes using input values that are produced at random. The simulation is then run using specialized software that generates random values for the input variables based on their prescribed distributions. Because of the inherent diversity in the input parameters, the simulation yields a different result with each iteration (Rockwell & Ames, 2012).

A probability distribution of events is produced by combining the results of a sufficient number of simulations. This distribution, which includes metrics like the mean, median, standard deviation, and percentiles, offers important insights into the range of outcomes. The most expected outcomes, the dangers of extreme occurrences like cost overruns or schedule delays, and the effects of changing input factors are among the important insights that are uncovered by analyzing the combined data. To support well-informed decision-making and resource allocation based on the identified risks and uncertainties, the last stage is to interpret the results considering the initial issue and make sure that the findings are properly conveyed to stakeholders (Pires & de Oliveira, 2006).

Numerous fields use the Monte Carlo approach extensively for risk assessments. By simulating returns and losses under various market situations, it is used in finance to evaluate the risks associated with investment portfolios and provide investors with an idea of the probability of reaching financial objectives or suffering substantial losses (Smith, 2003). Monte Carlo simulations are used in project management to assign probability distributions to task durations and expenditures to assess the uncertainty and unpredictability of project schedules and budgets. This method enables project managers to produce a variety of budget and completion date scenarios, offering insightful information for spotting cost overruns and schedule delays and supporting initiative-taking risk management.

Monte Carlo simulations are used in supply chain management to model demand variations, transit durations, and manufacturing rates to improve operations. Decision-makers can determine bottlenecks, evaluate the effects of uncertainty, and create plans to reduce expenses and boost productivity by modeling various supply chain topologies (Pires & de Oliveira, 2006). The technique is used in reliability engineering to evaluate the performance and dependability of complex systems by considering variables including environmental unpredictability, operational conditions, and material attributes. This helps to optimize maintenance methods by offering insights into life cycle costs and failure probabilities (Hammersley & Handscomb, 1964).

To sum up, the Monte Carlo approach is a vital instrument for risk analysis that provides important insights into the unpredictability and uncertainty inherent in complex systems. In the face of uncertainty, analysts can make well-informed decisions by simulating a variety of situations using random sampling and probability distributions. Its use in a wide range of industries, such as engineering, finance, project management, and supply chain management, highlights how important it is as a method for contemporary risk analysis. The Monte Carlo approach will remain essential for comprehending and successfully managing risks as businesses embrace data-driven decision-making procedures (Metropolis & Ulam, 1949; Rockwell & Ames, 2012).

2.4.1 Advantages of utilizing Monte Carlo simulation in Risk Analysis

A sophisticated statistical method that is frequently used in risk analysis to model uncertainty and assess outcomes in complicated systems is the Monte Carlo simulation (MCS). MCS is a potent instrument for thorough risk assessment, decision support, and stakeholder communication since it generates a large number of random samples based on predetermined probability distributions, offering crucial insights into the possibility of various events (Metropolis & Ulam, 1949). Monte Carlo simulation's capacity to enable a comprehensive assessment of risks by considering a large number of input variables and their interactions is one of its main benefits. MCS creates a probability of distribution of outcomes as opposed to deterministic models, which, given set inputs, yield a single conclusion. Decision-makers can comprehend the entire range of risks and their ramifications thanks to this thorough approach, which successfully represents the inherent complexity and unpredictability of real-world events. Organizations are therefore better able to foresee and prepare for a variety of situations, which results in more effective risk management plans (Hammersley & Handscomb, 1964).

The ability of MCS to measure uncertainty is another important advantage. MCS provides a more sophisticated view of risk by estimating the likelihood of various outcomes by modeling input factors as probability distributions. By helping businesses determine the likelihood of occurrences, such cost overruns or project delays, this quantification promotes better decision-making. Project managers, for example, can determine the probability of finishing a project on time or within budget, enabling better planning for any obstacles that may arise. In complicated projects where several risks need to be addressed at once, this capacity to measure uncertainty is especially helpful (Smith, 2003).

By offering a strong basis for making decisions in the face of uncertainty, Monte Carlo simulation also improves decision support. Decision-makers can assess the possible effects of alternative tactics by modeling different scenarios and examining the distributions that follow. In project management, where stakeholders can evaluate the trade-offs between several options, this expertise is extremely beneficial. Project managers can evaluate risks, distribute resources effectively, and create backup plans based on facts rather than gut feeling thanks to MCS. The likelihood of project success is increased and decision-making quality is improved overall using this data-driven approach (Rockwell & Ames, 2012).

MCS helps with sensitivity analysis, which is essential for determining which input variables have the most effects on results, in addition to its function in risk assessment and decision assistance. Analysts can identify the elements that most influence a project's success or failure by methodically changing inputs and tracking changes in outcomes. This knowledge enhances the effectiveness of resource allocation and mitigation tactics by enabling firms to concentrate their risk management efforts on the most crucial factors. So, sensitivity analysis can make risk management strategies more focused and efficient (Pires & de Oliveira, 2006).

Monte Carlo simulation's usefulness as a risk analysis tool is further increased by its adaptability and versatility. Because MCS is flexible in simulating a wide range of variables, including market swings, resource availability, and technology advancements, it can be used in a variety of domains, including finance, engineering, project management, and environmental science. Because of its adaptability, MCS is a useful tool for a variety of industries, enabling firms to customize the simulation to their unique requirements and circumstances (Smith, 2003). Furthermore, it is possible to efficiently show the large amount of data produced by MCS to improve comprehension and communication. Monte Carlo simulation results can be displayed in a number of ways, such as tornado diagrams, cumulative distribution functions, and histograms. By helping stakeholders understand the range of outcomes and the corresponding probability, these visualizations promote more transparent communication about risks and uncertainties. Because it allows all stakeholders to have a common knowledge of the risks involved, this transparency is essential for stakeholder participation and well-informed decision-making (Hammersley & Handscomb, 1964).

Another significant benefit of Monte Carlo simulation is enhanced stakeholder communication. MCS helps clients, investors, and project teams develop trust by offering transparent, data-driven insights into risks and their effects. Discussions become more cooperative and knowledgeable when stakeholders have a greater understanding of the reasoning behind choices and the possible effects of risks. Achieving consensus and guaranteeing that all parties involved have the same understanding and expectations depend on this enhanced communication (Metropolis & Ulam, 1949). Monte Carlo simulation also facilitates ongoing enhancements to risk management procedures. Organizations can improve the quality of their simulations and more accurately predict future hazards by routinely revising the input distributions considering fresh information or insights. By encouraging a culture of learning and adaptation, this iterative strategy helps businesses adjust to changing conditions more skillfully. Consequently, MCS helps to strengthen risk management techniques over the long term in addition to helping to control present hazards (Rockwell & Ames, 2012).

To sum up, the Monte Carlo simulation has many benefits for risk analysis, such as thorough risk assessment, uncertainty quantification, better decision support, sensitivity analysis, and greater stakeholder communication. It is an essential tool for firms trying to manage the complexity of risk because of its adaptability and cross-field applicability. Organizations can enhance their risk management tactics, make better decisions, and accomplish more effective projects and initiative results by utilizing the insights obtained from Monte Carlo simulations (Pires & de Oliveira, 2006).

3. Chapter 3 – Computational Risk Assessment for Photovoltaic Parks

3.1 About the Risk Analysis

The development of a 1-megawatt (MW) photovoltaic park (Figures 1 and 2) in the Prochoma neighborhood of Thessaloniki, Greece, is the focus of this risk analysis. Prochoma, a region in northern Greece, is well known for having year-round sunshine and ideal weather for solar energy generation. It’s ideal levels of solar irradiance and the availability of adequate land, which are essential for optimizing the efficiency and production of solar energy installations, support the strategic selection of this region for renewable energy projects.

By connecting a transformer to a company owned Ultra High Voltage Center, the photovoltaic park will be incorporated into the grid, guaranteeing effective transmission and distribution of the electricity produced. The stability and dependability of the local power system depend on this integration, especially as the area becomes more dependent on renewable energy sources. This project is a component of the company's larger plan, which includes building over 232 solar parks throughout the surrounding area. At the UHVC in Prochoma, all these parks will be connected. To lessen Greece's reliance on fossil fuels and support international efforts to tackle climate change, this ambitious project intends to increase the region's potential for renewable energy and strengthen Greece's commitment to sustainable energy sources.

Figure 4: UHVC in Prochoma (12/2025)

Because of the concentration of construction enterprises in the area, Prochoma's strategic location close to Thessaloniki is favorable. Large-scale projects can be conducted because of the easy access to a sizeable workforce made possible by the area's proximity to Thessaloniki. Thessaloniki's competent labor pool guarantees that large-scale projects can be effectively planned and carried out in this area.

The company has carefully placed its solar parks in a number of areas, including Kilkis and Prochoma. The comparatively level ground in these areas makes them ideal for solar panel installation. Because of the flat terrain, less substantial site preparation is required, and photovoltaic panels can be positioned to best catch solar energy.

The viability of large-scale solar projects is also greatly influenced by the affordable land that is available in these locations. The financial feasibility of large-scale photovoltaic park developments is supported by the affordability of land purchase in Prochoma and the neighboring areas. Prochoma and the surrounding territories are perfect for the company's renewable energy activities because of this economic advantage, as well as its strategic position and large workforce.

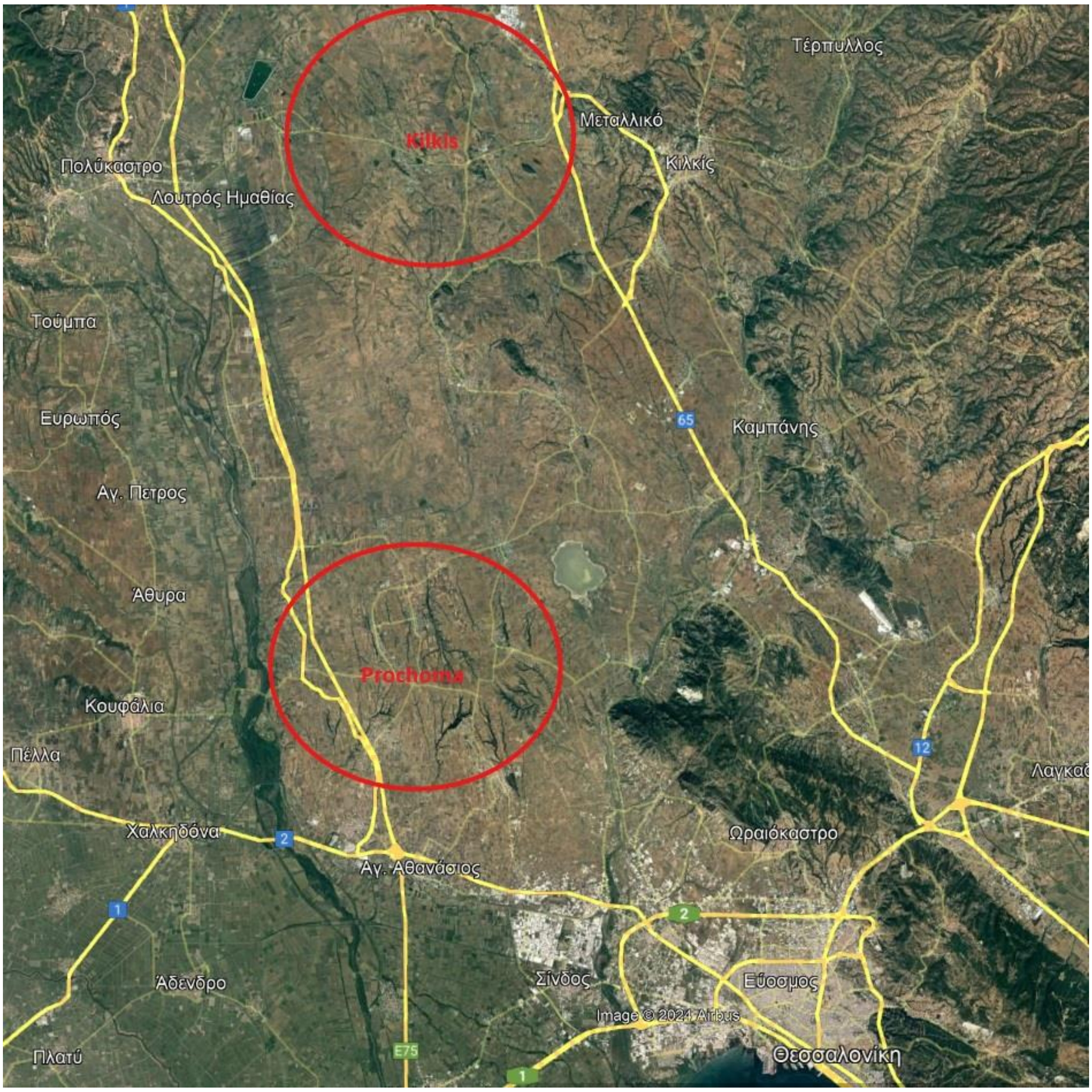


Figure 5: The location of 232 PV Parks

Site selection, design, building, commissioning, and operational management are the several stages involved in any photovoltaic park, including the 1 MW installation under discussion. The success of the project depends on the careful identification and management of the unique risks that each phase brings. Potential land use disputes and the requirement for environmental impact evaluations to make sure the installation will not negatively influence nearby ecosystems are hazards during the site selection stage. To maximize energy capture, solar panel placement and orientation must be carefully considered throughout the design phase. The installation's structural integrity and longevity under varied weather conditions must also be taken into consideration. Risks associated with construction include delays brought on by severe weather, interruptions in the supply chain, and shortages of experienced workers. Making sure all systems are fully functional and adhere to legal requirements is known as commissioning. Continuous maintenance, performance tracking, and resolving any emerging technical difficulties are all part of operational management.

The Prochoma region offers plenty of room for solar panel installation without significantly altering the current land use due to its combination of semi-arid and agricultural settings. A major benefit of this land availability is that it permits the extensive installation of solar panels, which are essential for producing a sizable amount of energy. Access to transportation networks, skilled labor, and necessary services are among the logistical benefits of being close to Thessaloniki, a significant urban center. To address issues with land use, community involvement, and ecological preservation, a comprehensive risk assessment is necessary due to the region's distinct natural and social dynamics. To allay any worries local communities may have about the project and guarantee that the advantages of developing renewable energy are widely distributed, it is imperative that local communities be involved.

This risk analysis aims to provide a thorough understanding of the potential difficulties and uncertainties related to the construction and operation of the 1 MW photovoltaic park by focusing on the unique circumstances of Prochoma and the overall goals of the company's renewable energy initiative. The success and sustainability of the project will be improved by using the knowledge gathered from this analysis to guide the creation of efficient risk mitigation plans. Strong plans for engaging stakeholders, thorough environmental impact analyses, and the use of innovative monitoring and maintenance technologies to guarantee peak performance and little downtime are a few examples of such tactics.

In conclusion, the development of a 1 MW photovoltaic park in Prochoma, Thessaloniki, is a crucial step toward the advancement of Greece's infrastructure for renewable energy. The initiative seeks to overcome the numerous obstacles presented by technical, social, environmental, and regulatory variables through careful risk management and analysis. In addition to increasing the area's capacity for renewable energy, the project's successful completion will set the standard for future renewable energy initiatives in Greece and elsewhere. This project supports Greece's transition to sustainable energy sources and strengthens its position in international efforts to create a low-carbon future by helping to meet regional and national goals for the spread of renewable energy.

3.2 Risk Breakdown Structure for the Construction of a Photovoltaic Park

A methodical framework for classifying project hazards, a risk breakdown structure (RBS) makes it easier to identify, evaluate, and manage these risks. Photovoltaic (PV) park development and operation entail a number of risk factors that might impact project viability, financial performance, and operational efficiency. Project management, technical, environmental, financial, regulatory, operational, social, and cybersecurity hazards are some broad categories into which these risks might be divided.

Risks associated with project management are mostly caused by scheduling and planning issues, such as ineffective resource allocation and delays in regulatory approval. Obtaining permits from many government agencies can lengthen project schedules, raise expenses, and impact the viability of the project. Furthermore, poor resource management could result in less-than-ideal labor and material distribution, which would hinder advancement. Since bad information management or miscommunication can result in misunderstandings, data loss, and poor decision-making, stakeholder communication is also essential to project execution.

Because of the dependence on recent technologies and the possibility of equipment malfunctions, technical hazards present serious difficulties. System reliability may be unclear because of advanced solar panel designs and energy storage systems that do not always work as planned. Additionally, operational disruptions may result from equipment problems including inverter failures or module degradation. Uncertainties are further increased by performance hazards, such as energy yield variability and potential-induced degradation (PID), since poor design, shading, and ambient conditions can affect energy output and long-term efficiency.

The unpredictability of weather patterns and site-specific factors make environmental concerns a critical concern. Hurricanes and hailstorms are examples of extreme weather events that can harm infrastructure and solar panels, requiring expensive repairs and causing extended outages. Furthermore, unanticipated ecological issues can require design changes, and unstable soil conditions might jeopardize structural integrity, making project planning even more difficult.

Market volatility, cost overruns, funding and investment concerns are all considered financial risks. Project construction may be halted by a lack of funding, and costs may exceed initial projections due to shifting interest rates and material price volatility. Accurate cost planning and sufficient financial support are crucial since understated operating expenditure (OPEX) can put a strain on financial sustainability.

Permitting issues, legislative modifications, and compliance with environmental standards are all sources of regulatory and compliance concerns. Project approvals may be delayed by complicated regulatory frameworks, and compliance requirements may change in the middle of a project due to unforeseen legal changes. Environmental standards violations can lead to fines or closures, and local populations' legal challenges based on ecological or land use issues can further affect project budgets and schedules.

Operational hazards include workforce-related problems, supply chain interruptions, and maintenance difficulties. Long-term efficiency requires the establishment of efficient maintenance procedures, whereas operational inefficiencies and safety risks can result from insufficient training. Disruptions to the supply chain, like delayed component deliveries and inadequate quality control, can also affect system dependability and building timelines.

Because labor relations and public opposition can impact project execution, social and community risks are key factors to consider. Protests or legal issues may result from community opposition brought on by perceived land use implications or aesthetic concerns. Furthermore, ethical land-use practices and thorough engagement are necessary when it comes to indigenous rights problems. Project stakeholders may face additional difficulties because of labor disputes, strikes, and workplace safety accidents that can further delay construction and raise expenses.

Lastly, as PV parks incorporate innovative operational technology, cyber security threats have grown in importance in the digital age. While breaches involving sensitive project information can damage stakeholder confidence and have an impact on investor relations, cyber-attacks that target control systems have the potential to interrupt operations and jeopardize data security.

To address these risks, stakeholders can quantify uncertainty and create mitigation plans by using systematic analysis techniques like the Monte Carlo method. Decision-makers can evaluate the impact of risk, improve project planning, and strengthen PV parks' resistance to unforeseen difficulties by utilizing probabilistic models. In a changing economic and environmental context, the long-term viability and sustainability of photovoltaic energy projects depend on the incorporation of strong risk management procedures.

There are numerous risks associated with building a solar park that need to be methodically recognized and controlled over the course of the project. A thorough Risk Breakdown Structure, as described above, can help stakeholders better comprehend potential problems and put mitigation plans into action. The successful implementation and long-term viability of photovoltaic installations will be aided by this proactive approach.

3.3 Risk Analysis Sheets

3.3.1 Project Management Risks

3.3.1.1 *Regulatory Approval Delays and Resource Misallocation*

Table 5: Risk Identification of R1 and R2

Risk ID	Risk Description	Category	Source of Risk
R1	Regulatory Approval Delays	Planning and Scheduling Risks	Government/Regulatory Bodies
R2	Resource Misallocation	Planning and Scheduling Risks	Internal Project Management

Table 6: Risk Assessment of R1 and R2

Risk ID	Impact	Likelihood	Risk Score	Priority
R1	0,4	0,7	0,28	High
R2	0,4	0,7	0,28	High

Firstly, the initial risk assessment for regulatory approval delays and resource misallocation in constructing the 1 MW photovoltaic park in Prochoma, Thessaloniki, highlighted significant challenges. The complexity of obtaining necessary permits and potential bureaucratic hurdles (Table 5) led to high ratings for the impact and likelihood of delays (Table 6). Additionally, managing resources across multiple projects in the region presented substantial potential issues, with high impact and likelihood scores due to the risk of cost overruns and delays.

Table 7: Risk Response Plan of R1 and R2

Risk ID	**Mitigation Strategies**	**Responsible Person**
R1	Early engagement with regulators	Regulatory Affairs Manager
	Hire a regulatory consultant	
	Regular follow-ups with approval authorities	
R2	Detailed project planning and resource allocation	Project Manager
	Regular project review meetings to track resource usage	
	Implement project management software for monitoring	

Table 8: Recalculated Risk Assessment after every Mitigation of R1 and R2

Risk ID	**Impact**	**Likelihood**	**Risk Score**	**Priority**
R1	0,4	0,5	0,2	High
	0,2	0,3	0,06	Medium
	0,2	0,1	0,02	Low
R2	0,4	0,5	0,2	High
	0,4	0,3	0,12	Medium
	0,4	0,1	0,04	Low

Mitigation strategies for regulatory approval delays (Table 7) included proactive engagement with regulatory authorities, thorough documentation preparation, and hiring experienced consultants. A resolute team was also established to monitor and promptly address permit application issues, significantly reducing the likelihood of delays and slightly mitigating their impact. To address the risk of resource misallocation, a detailed resource management plan was developed (Table 7), project management software was used to track resources, and regular reviews and adjustments of resource allocation were conducted (Raz & Michael, 2001). Additionally, training sessions for project managers were held to enhance their resource management skills. These strategies significantly reduced the likelihood of misallocation and its potential impact on the project (Table 8).

3.3.1.2 Miscommunication Among Stakeholders and Information Management Failures

Table 9: Risk Identification of R3 and R4

Risk ID	Risk Description	Category	Source of Risk
R3	Miscommunication Among Stakeholders	Stakeholder Communication Risks	Internal and External Stakeholders
R4	Information Management Failures	Stakeholder Communication Risks	IT Systems/Data Management

Table 10: Risk Assessment of R3 and R4

Risk ID	Impact	Likelihood	Risk Score	Priority
R3	0,2	0,5	0,1	Medium
R4	0,2	0,5	0,1	Medium

The primal risk assessments for miscommunication among stakeholders and information management failures (Table 9) in constructing the photovoltaic park in Prochoma, identified mediocre potential issues. The moderate impact and medium likelihood scores for miscommunication (Table 10) were due to the complexity of coordinating multiple parties, including regulatory bodies, contractors, local authorities, and community groups. Similarly, the scores for information management failures (Table 10) were attributed to the challenges of handling vast amounts of project data, coordinating between multiple systems, and ensuring data accuracy and accessibility.

Table 11: Risk Response Plan of R3 and R4

Risk ID	Mitigation Strategies	Responsible Person
R3	Implement regular communication channels (meetings, updates)	Communications Director
	Use collaboration tools (e.g., Slack, Microsoft Teams)	
	Clearly define roles and responsibilities	
R4	Implement robust information management systems	IT Manager
	Regularly back up data and test data recovery plans	
	Conduct training in information management best practices	

Table 12: Recalculated Risk Assessment after every Mitigation of R3 and R4

Risk ID	Impact	Likelihood	Risk Score	Priority
R3	0,2	0,3	0,06	Medium
	0,2	0,1	0,02	Low
	0,2	0,1	0,02	Low
R4	0,2	0,3	0,06	Medium
	0,2	0,1	0,02	Low
	0,2	0,1	0,02	Low

To mitigate the risks of miscommunication among stakeholders and information management failures, multiple strategies were implemented (Table 11). A robust communication plan, centralized project management and communication tools, and regular stakeholder meetings ensured alignment and promptly addressed concerns. A dedicated communications manager oversaw stakeholder interactions for clear and consistent messaging (Lee, et al., 2012). For information management, a robust system was deployed with data integration across platforms, regular audits and backups, and training sessions for all team members. Additionally, a resolute IT manager ensured data integrity and system performance. These measures significantly reduced the likelihood and impact of both miscommunication and information management failures on the project (Table 11).

3.3.2 Technical Risks

3.3.2.1 Dependence on Emerging Technologies and Equipment Failure Risks

Table 13: Risk Identification of R5 and R6

Risk ID	Risk Description	Category	Source of Risk
R5	Dependence on Emerging Technologies	Technology Reliability Risks	Rapid Technological Changes
R6	Equipment Failure Risks	Technology Reliability Risks	Equipment/Hardware

Table 14: Risk Assessment of R5 and R6

Risk ID	Impact	Likelihood	Risk Score	Priority
R5	0,2	0,5	0,1	Medium
R6	0,4	0,7	0,28	High

The initial risk evaluations for reliance on emerging technologies and equipment failure (Table 13) in the construction of the photovoltaic park that we discuss identified some potential challenges. The moderate impact and likelihood ratings for emerging technologies (Table 14) were due to the dependence on new, untested technologies, which could lead to performance issues, increased costs, and added complexity. On the other hand, the risk of equipment failure, with a high impact and likelihood (Table 14), was attributed to the potential for operational disruptions, costly repairs, and project delays due to equipment defects or malfunctions.

Table 15: Risk Response Plan of R5 and R6

Risk ID	Mitigation Strategies	Responsible Person
R5	Conduct thorough vetting of emerging technologies	Technical Director
	Establish partnerships with technology providers	
	Allocate budget for technology updates and training	
R6	Regular maintenance and inspection of equipment	

Risk ID	Mitigation Strategies	Responsible Person
	Establish contingency plans for equipment failure	Maintenance Manager
	Train staff on equipment managing and emergency procedures	

Table 16: Recalculated Risk Assessment after every Mitigation of R5 and R6

Risk ID	Impact	Likelihood	Risk Score	Priority
R5	0,2	0,3	0,06	Medium
	0,2	0,1	0,02	Low
	0,1	0,1	0,01	Low
R6	0,4	0,5	0,2	High
	0,2	0,5	0,1	Medium
	0,1	0,3	0,03	Low

To minimize the risks of reliance on emerging technologies and equipment failure, various strategies were implemented (Table 15). For emerging technologies, this included rigorous vetting and testing prior to deployment, maintaining a balance of proven and innovative technologies, and building strong relationships with technology providers for better support. Contingency plans were created for potential failures, and staff received ongoing training on the latest advancements. For equipment failure, strategies included careful selection and testing of equipment, a comprehensive maintenance schedule, and ensuring availability of essential spare parts (Tang et al., 2020). On-site personnel received enhanced training for proper handling and early detection, while a resolute maintenance team conducted regular inspections and preventive maintenance (Table 16).

Failures in construction equipment are common and can significantly impact project timelines. These failures can be attributed to several factors, including the hardness of the soil, improper handling, and the age or wear of the machinery. The hardness of the soil can place excessive stress on equipment, leading to mechanical breakdowns. Incorrect handling or the operation of machinery by personnel can also result in damage or malfunction. Additionally, as machinery ages, the likelihood of component failure increases due to wear and tear.

The delays caused by such equipment failures can vary widely in duration, ranging from a few hours to several weeks, depending on the nature and severity of the issue. Minor mechanical issues might be resolved quickly with basic repairs or part replacements, resulting in only brief interruptions to construction activities. However, more severe failures, such as major mechanical breakdowns or the need for specialized parts that are not readily available, can lead to prolonged delays. In such cases, the repair process may involve extensive diagnostics, ordering and shipping of parts, and potentially significant repair work, all of which contribute to extended project timelines. Consequently, the impact of equipment failures on construction projects underscores the importance of regular maintenance, proper training for equipment operators, and contingency planning to mitigate potential delays.

3.3.2.2 Energy Yield Variability and Potential Induced Degradation (PID)

Table 17: Risk Identification of R7 and R8

Risk ID	Risk Description	Category	Source of Risk
R7	Energy Yield Variability	Performance Risks	Weather Conditions/Climate Change
R8	Potential Induced Degradation (PID)	Performance Risks	PV Modules/Material Quality

Table 18: Risk Assessment of R7 and R8

Risk ID	Impact	Likelihood	Risk Score	Priority
R7	0,4	0,5	0,2	High
R8	0,4	0,3	0,12	Medium

In this case, the initial risk assessments for energy yield variability and induced degradation (PID) (Table 17) identified significant potential challenges. Energy yield variability, with high impact and likelihood ratings (Table 18), stemmed from the unpredictability of solar energy production, potentially affecting the project's financial performance and stability. Similarly, induced degradation (PID) posed some issues, as it could significantly reduce the efficiency and lifespan of solar panels, leading to decreased energy output and increased maintenance costs. The impact of PID was rated high, with a medium likelihood (Table 18) due to potential environmental and operational factors.

Table 19: Risk Response Plan of R7 and R8

Risk ID	Mitigation Strategies	Responsible Person
R7	Use advanced weather forecasting tools to predict energy yield	Performance Analyst
	Implement energy storage systems to balance yield variability	
	Diversify geographic location of PV installations	
R8	Use PID-resistant materials in PV modules	Quality Assurance Manager
	Regular testing for PID in PV modules	
	Implementing preventive maintenance to reduce PID	

Table 20: Recalculated Risk Assessment after every Mitigation of R7 and R8

Risk ID	Impact	Likelihood	Risk Score	Priority
R7	0,4	0,3	0,12	Medium
	0,2	0,3	0,06	Medium
	0,2	0,1	0,02	Low
R8	0,4	0,1	0,04	Low
	0,4	0,1	0,04	Low
	0,2	0,1	0,02	Low

To reduce the risks of energy yield variability and induced degradation (PID), several strategies were implemented (Table 19). For energy yield variability, detailed site analysis and selection were used to optimize solar exposure, advanced forecasting tools were employed for accurate energy yield predictions, and energy storage systems were installed to balance fluctuations. Regular performance monitoring and adjustment protocols were also established to ensure consistent energy production. For PID, mitigation strategies included selecting PID-resistant solar panels, implementing proper grounding and insulation techniques, and using advanced monitoring systems to detect early signs of degradation. Additionally, regular maintenance and inspection schedules were set up to promptly address PID issues, ensuring the solar park's long-term performance and reliability (Table 20).

3.3.3 Environmental Risks

3.3.3.1 *Severe Weather Events and Unpredictable Climate Patterns*

Table 21: Risk Identification of R9 and R10

Risk ID	Risk Description	Category	Source of Risk
R9	Severe Weather Events	Weather-Related Risks	Natural Disasters/Extreme Weather
R10	Unpredictable Climate Patterns	Weather-Related Risks	Long-term Climate Change

Table 22: Risk Assessment of R9 and R10

Risk ID	Impact	Likelihood	Risk Score	Priority
R9	0,8	0,5	0,4	High
R10	0,4	0,5	0,2	High

The preliminary risk evaluations for severe weather events and unpredictable climate patterns (Table 21) in the construction identified substantial challenges. Severe weather, such as storms, heavy rainfall, and high winds, can cause considerable damage to solar infrastructure, leading to costly repairs, downtime, and safety hazards, resulting in high impact and medium likelihood ratings (Table 22) due to regional climate patterns. Similarly, unpredictable climate changes, such as unexpected temperature fluctuations and irregular precipitation, can affect the efficiency and reliability of solar energy production, with high impact and medium likelihood ratings (Table 22) due to increasing global climate volatility.

Table 23: Risk Response Plan of R9 and R10

Risk ID	Mitigation Strategies	Responsible Person
R9	Design infrastructure to withstand severe weather conditions	Environmental Manager
	Develop emergency response plans and protocols	
	Regular maintenance and inspections	
R10	Implement flexible and adaptive energy management systems	

Risk ID	Mitigation Strategies	Responsible Person
	Use climate-resilient materials and technologies	Environmental Analyst
	Conduct regular climate risk assessments and update strategies	

Table 24: Recalculated Risk Assessment after every Mitigation of R9 and R10

Risk ID	Impact	Likelihood	Risk Score	Priority
R9	0,4	0,5	0,2	High
	0,2	0,5	0,1	Medium
	0,1	0,5	0,05	Medium
R10	0,2	0,5	0,1	Medium
	0,1	0,5	0,05	Medium
	0,05	0,5	0,03	Low

To lessen the risks of severe weather events and unpredictable climate patterns, some strategies were implemented (Table 23). For severe weather, robust infrastructure design, advanced weather monitoring systems for early warnings, and comprehensive emergency response plans were developed, along with regular maintenance and inspections to ensure resilience. To address unpredictable climate patterns, flexible and adaptive design elements were incorporated into the solar park, high-efficiency and climate-resilient solar panels were used, and sophisticated climate modeling tools were employed. Ongoing climate monitoring and adaptive management practices were also established to ensure the solar park's operational stability and efficiency (Table 24).

Prochoma, situated in the Thessaloniki region of Greece, is characterized by a Mediterranean climate, marked by warm, dry summers and cool, wet winters. The average annual precipitation in Prochoma is approximately 458.4 mm, with rainfall distributed unevenly across the months. January experiences 36.9 mm of rainfall over 11 days, while February receives 40.3 mm over 8 days. March follows with 45.7 mm over 9 days, and April sees 36.1 mm over 9 days. May experiences 44 mm of rainfall over 10 days, and June receives 31.6 mm over 7 days. The summer months are drier, with July recording 25.6 mm of rain over 4 days, and August receiving only 20.8 mm over 3 days. Rainfall increases again in the autumn months, with September recording 26.2 mm over 5 days, October 40.6 mm over 8 days, November 57.7 mm over 11 days, and December 52.9 mm over 11 days. On average, Prochoma experiences about 96 rainy days per year.

In contrast, the area enjoys a substantial amount of sunshine throughout the year, with the percentage of sunny daylight hours varying by month. January has approximately 40% of daylight hours sunny, while February sees a slight increase to 46%. The percentage of sunshine continues to rise through the spring, with March at 47%, April at 56%, and May at 63%. The summer months, particularly July and August, are the sunniest, with about 81% and 82% of daylight hours sunny, respectively. September remains sunny, with 67% of daylight hours clear, while October experiences 54% sunshine. In the winter months, the percentage of sunshine decreases again, with November and December both having around 39% of daylight hours sunny. On average, July is the sunniest month, with approximately 11.3 hours of sunlight per day (HNMS, 2024).

3.3.3.2 Ecological Concerns and Soil Stability Issues

Table 25: Risk Identification of R11 and R12

Risk ID	Risk Description	Category	Source of Risk
R11	Ecological Concerns	Site Conditions Risks	Impact on local flora and fauna
R12	Soil Stability Issues	Site Conditions Risks	Soil erosion and land subsidence

Table 26: Risk Assessment of R11 and R12

Risk ID	Impact	Likelihood	Risk Score	Priority
R11	0,2	0,5	0,1	Medium
R12	0,8	0,5	0,4	High

Additionally, the initial risk evaluations for ecological concerns and soil stability issues (Table 25) in the construction revealed significant challenges. Ecological concerns, with moderate impact and likelihood scores (Table 26), stemmed from the potential disruption of local ecosystems, wildlife habitats, and biodiversity due to construction activities and solar infrastructure presence. On the other hand, soil stability issues, with very high impact and medium likelihood ratings (Table 26), were attributed to potential structural problems, increased maintenance costs, and safety hazards due to variable soil conditions in the region.

Table 27: Risk Response Plan of R11 and R12

Risk ID	Mitigation Strategies	Responsible Person
R11	Conduct environmental impact assessments	Environmental Specialist
	Develop and implement conservation plans	

Risk ID	**Mitigation Strategies**	**Responsible Person**
	Monitor and manage ecological impacts regularly	
R12	Conduct geotechnical surveys before construction	Geotechnical Engineer
	Implement soil stabilization techniques	
	Regular monitoring of soil stability and erosion control measures	

Table 28: Recalculated Risk Assessment after every Mitigation of R11 and R12

Risk ID	**Impact**	**Likelihood**	**Risk Score**	**Priority**
R11	0,1	0,5	0,05	Medium
	0,1	0,3	0,03	Low
	0,05	0,1	0,01	Low
R12	0,8	0,3	0,24	High
	0,4	0,3	0,12	Medium
	0,4	0,1	0,04	Low

To mitigate the risks of ecological concerns and soil stability issues, many strategies were implemented (Table 27). For ecological concerns, thorough environmental impact assessments were conducted, the project was designed to minimize habitat disruption, and biodiversity preservation measures were incorporated (Hernandez et al., 2014). Ongoing environmental monitoring was also established to track impacts and adjust practices as needed. For soil stability issues, comprehensive geotechnical surveys were conducted, soil stabilization techniques were employed during construction, and robust foundations were designed to withstand potential soil movement. Regular soil monitoring and maintenance practices were also established to ensure ongoing soil stability and structural integrity (Table 28).

During the construction of 232 photovoltaic parks in the Prochoma area, soil stability issues necessitated the use of concrete for pile stabilization in fifteen instances. The requirement for concrete significantly extended the construction timeline for these parks. Specifically, the embedding of piles for a 1 MW park typically ranges from one to two days. However, when concrete stabilization is required, this duration extends to six to eight days. This variation depends on the efficiency of local concrete suppliers in delivering the required quantities to the site and the prevailing weather conditions during the concrete placement period (Internal Source).

3.3.4 Financial Risks

3.3.4.1 Inadequate Funding and Interest Rate Fluctuations

Table 29: Risk Identification of R13 and R14

Risk ID	Risk Description	Category	Source of Risk
R13	Inadequate Funding	Funding and Investment Risks	Insufficient financial resources
R14	Interest Rate Fluctuations	Funding and Investment Risks	Changes in market interest rates

Table 30: Risk Assessment of R13 and R14

Risk ID	Impact	Likelihood	Risk Score	Priority
R13	0,8	0,5	0,4	High
R14	0,4	0,5	0,2	High

In the case that we are discussing, the initial risk assessments for inadequate funding and interest rate fluctuations (Table 29) in the construction highlighted significant challenges. Inadequate funding could lead to delays, compromised quality, or even project cancellation, with a high impact and medium likelihood (Table 30) due to the difficulties of securing sufficient and timely funding. Similarly, interest rate fluctuations posed considerable concerns, as they could significantly increase financing costs and cause financial instability, with high impact and medium likelihood (Table 30) due to global financial market volatility.

Table 31: Risk Response Plan of R13 and R14

Risk ID	Mitigation Strategies	Responsible Person
R13	Secure multiple sources of funding (e.g., grants, loans, investors)	Finance Manager
	Develop a detailed financial plan and budget	
	Establish a contingency fund	

Risk ID	Mitigation Strategies	Responsible Person
R14	Lock in fixed interest rates where possible	Financial Analyst
	Hedge against interest rate fluctuations using financial instruments	
	Regularly review and adjust financial strategies based on market trends	

Table 32: Recalculated Risk Assessment after every Mitigation of R13 and R14

Risk ID	Impact	Likelihood	Risk Score	Priority
R13	0,8	0,3	0,24	High
	0,8	0,1	0,08	Medium
	0,4	0,1	0,04	Low
R14	0,4	0,3	0,12	Medium
	0,2	0,3	0,06	Medium
	0,2	0,1	0,02	Low

To reduce the risks of inadequate funding and interest rate fluctuations (Table 31), multiple strategies were implemented. For inadequate funding, multiple funding sources were secured to diversify financial support, a detailed financial plan with contingencies was established, and strong relationships with investors and financial institutions were maintained. Regular financial monitoring and reporting were also set up for transparency and early identification of issues. For interest rate fluctuations, fixed interest rates were locked where possible, financial hedging instruments were used to manage rate volatility, and a robust financial model was developed to account for potential rate changes (Kunreuther, 1996). Additionally, maintaining close relationships with financial advisors and institutions was crucial for staying informed about market trends and adapting strategies accordingly (Table 32).

3.3.4.2 *Material Price Volatility and Underestimated Operational Expenditures (OPEX)*

Table 33: Risk Identification of R15 and R16

Risk ID	Risk Description	Category	Source of Risk
R15	Material Price Volatility	Cost Overrun Risks	Fluctuations in market prices for materials
R16	Underestimated Operational Expenditures (OPEX)	Cost Overrun Risks	Inaccurate forecasting of operational costs

Table 34: Risk Assessment of R15 and R16

Risk ID	Impact	Likelihood	Risk Score	Priority
R15	0,4	0,5	0,2	High
R16	0,4	0,5	0,2	High

The initial risk assessments for material price volatility and underestimated operational expenditures (OPEX) (Table 33) in the construction of the 1 MW photovoltaic park in Thessaloniki, identified significant potential challenges. Material price volatility, due to fluctuations in the prices of essential materials like solar panels and metals, could lead to increased project costs and budget overruns, with a high impact and medium likelihood (Table 34) due to the unpredictable nature of global supply chains. Similarly, underestimated OPEX could cause financial strain, reduced profitability, and operational inefficiencies, with a high impact and medium likelihood (Table 34) due to the difficulty of accurately forecasting all operational expenses in advance.

Table 35: Risk Response Plan of R15 and R16

Risk ID	Mitigation Strategies	Responsible Person
R15	Enter long-term contracts with suppliers	Procurement Manager
	Diversify material sources	
	Use financial hedging strategies	
R16	Conduct thorough market and operational research	Operations Manager
	Include a contingency budget for OPEX	

Risk ID	Mitigation Strategies	Responsible Person
	Regularly review and adjust OPEX estimates	

Table 36: Recalculated Risk Assessment after every Mitigation of R15 and R16

Risk ID	Impact	Likelihood	Risk Score	Priority
R15	0,2	0,3	0,06	Medium
	0,2	0,1	0,02	Low
	0,1	0,1	0,01	Low
R16	0,4	0,3	0,12	Medium
	0,2	0,3	0,06	Medium
	0,2	0,1	0,02	Low

To lessen the risks associated with material price volatility and underestimated OPEX, some strategies were implemented (Table 35). For material price volatility, strategies included securing long-term contracts with suppliers to lock in prices, diversifying material sources, and incorporating price contingencies into the budget. Close monitoring of market trends and maintaining strong supplier relationships were also essential. To address underestimated OPEX, thorough and realistic cost assessments were conducted during planning, a margin for unexpected expenses was included, and robust financial monitoring systems were implemented. Additionally, periodic budget reviews and adjustments ensured operational expenditure remained aligned with financial projections (Table 36).

The volatility in the prices of essential equipment for photovoltaic parks significantly impacts the overall construction costs. Factors such as pandemics, wars, and other events contribute to this volatility. A recent and notable example is the COVID-19 pandemic, which caused substantial disruptions in global markets. For instance, the prices of overhead DC cables necessary for completing a photovoltaic park experienced considerable fluctuations. At the beginning of 2020, the purchase price for these cables was approximately €0.35 per meter. By the following year, this price had increased to €0.50 per meter, representing a 43% rise in just one year. In 2022 and 2023, the price stabilized at €0.49 per meter, with a further decrease to €0.46 per meter in 2024. Comparable price fluctuations were observed for most critical components of a photovoltaic park, with such variability posing significant risks to project costs (Internal Source).

3.3.5 Regulatory and Compliance Risks

3.3.5.1 Regulatory Hurdles and Impact of Regulatory Changes

Table 37: Risk Identification of R17 and R18

Risk ID	Risk Description	Category	Source of Risk
R17	Regulatory Hurdles	Permitting and Approval Delays	Complex and time-consuming approval processes
R18	Impact of Regulatory Changes	Permitting and Approval Delays	Changes in laws and regulations affecting project viability

Table 38: Risk Assessment of R17 and R18

Risk ID	Impact	Likelihood	Risk Score	Priority
R17	0,4	0,7	0,28	High
R18	0,4	0,5	0,2	High

The preliminary risk assessment for regulatory hurdles (Table 37) in the construction of the photovoltaic park in the region we discuss highlighted significant challenges. Navigating complex regulatory frameworks and obtaining necessary permits can lead to delays and increased costs, while sudden regulatory changes may impact project viability, financial projections, and operational strategies. The impact of these risks was rated as high and the likelihood as high and medium (Table 38), respectively, reflecting the intricate and unpredictable nature of regulatory approval processes and the dynamic environment of policy shifts.

Table 39: Risk Response Plan of R17 and R18

Risk ID	Mitigation Strategies	Responsible Person
R17	Engage with regulatory authorities early in the project	Regulatory Affairs Manager
	Hire consultants with expertise in regulatory processes	
	Maintain thorough documentation and compliance records	
R18	Monitor legislative changes and adapt strategies accordingly	

Risk ID	Mitigation Strategies	Responsible Person
	Develop flexible project plans to accommodate regulatory updates	Regulatory Affairs Manager
	Engage in industry advocacy to influence favorable regulatory outcomes	

Table 40: Recalculated Risk Assessment after every Mitigation of R17 and R18

Risk ID	Impact	Likelihood	Risk Score	Priority
R17	0,4	0,5	0,2	High
	0,2	0,3	0,06	Medium
	0,2	0,1	0,02	Low
R18	0,4	0,3	0,12	Medium
	0,4	0,3	0,06	Medium
	0,2	0,1	0,02	Low

To mitigate the risks associated with regulatory hurdles and changes, several strategies were implemented (Table 39). These included early engagement with regulatory bodies during project planning, hiring experienced legal and compliance experts, and maintaining open communication with relevant authorities. Additionally, comprehensive documentation and adherence to regulatory requirements were prioritized to streamline approval processes. To address potential regulatory updates, the team stayed informed, maintained flexibility in project planning, engaged in active dialogue with policymakers and industry groups, and incorporated scenarios of regulatory changes into risk management plans to prepare for unforeseen adjustments (Table 40).

3.3.5.2 Regulatory Hurdles and Impact of Regulatory Changes

Table 41: Risk Identification of R19 and R20

Risk ID	Risk Description	Category	Source of Risk
R19	Environmental Regulation Non-compliance	Compliance Issues	Failure to adhere to environmental regulations

Risk ID	Risk Description	Category	Source of Risk
R20	Legal Challenges from Communities	Compliance Issues	Opposition from local communities and ensuing legal battles

Table 42: Risk Assessment of R19 and R20

Risk ID	Impact	Likelihood	Risk Score	Priority
R19	0,8	0,5	0,4	High
R20	0,8	0,3	0,24	High

The preliminary risk assessment for the construction of the 1 MW photovoltaic park identified significant challenges related to both environmental regulation and non-compliance and legal issues from local communities (Table 41). Non-compliance with environmental regulations could lead to substantial penalties, project delays, and reputational damage, with a very high impact and medium likelihood (Table 42) due to the complex nature of these laws (Kolk & Pinkse, 2005). Similarly, potential community opposition and legal actions pose risks of project delays, increased costs, and strained local relationships, also rated as catastrophic impact and medium likelihood (Table 42), reflecting the possibility of resistance and legal conflicts.

Table 43: Risk Response Plan of R19 and R20

Risk ID	Mitigation Strategies	Responsible Person
R19	Conduct comprehensive environmental assessments	Environmental Manager
	Implement and monitor adherence to all relevant regulations	
	Train staff on compliance requirements	
R20	Engage with community leaders and stakeholders early in the project	Legal Counsel
	Develop a communication plan to address community concerns	
	Prepare a legal defense fund	

Risk ID	Mitigation Strategies	Responsible Person
	Offer benefits to the local community (e.g., jobs, infrastructure)	

Table 44: Recalculated Risk Assessment after every Mitigation of R19 and R20

Risk ID	Impact	Likelihood	Risk Score	Priority
R19	0,4	0,3	0,12	Medium
	0,4	0,1	0,04	Low
	0,2	0,1	0,02	Low
R20	0,8	0,1	0,08	Medium
	0,8	0,1	0,08	Medium
	0,4	0,1	0,04	Low
	0,4	0,1	0,04	Low

To ease the risks associated with environmental regulation non-compliance and legal challenges from local communities, several proactive strategies were implemented (Table 43). These included conducting comprehensive environmental impact assessments, adhering strictly to environmental guidelines, and hiring experienced consultants for ongoing compliance monitoring. Simultaneously, the project team engaged with the community to address concerns, maintained transparent communication about project benefits, and collaborated with local leaders. Additionally, a legal team was prepared to manage disputes and negotiations, ensuring efficient resolutions to any issues that arose (Table 44).

3.3.6 Operational Risks

3.3.6.1 *Regulatory Hurdles and Impact of Regulatory Changes*

Table 45: Risk Identification of R21 and R22

Risk ID	Risk Description	Category	Source of Risk
R21	Establishment of Maintenance Protocols	Maintenance Challenges	Lack of standardized maintenance procedures

Risk ID	Risk Description	Category	Source of Risk
R22	Training Deficiencies	Maintenance Challenges	Inadequate training programs for staff

Table 46: Risk Assessment of R21 and R22

Risk ID	Impact	Likelihood	Risk Score	Priority
R21	0,2	0,5	0,1	Medium
R22	0,4	0,7	0,28	High

The preliminary risk evaluation for the 1 MW photovoltaic park in Prochoma, Thessaloniki, identified some challenges related to non-compliance with maintenance protocols and training deficiencies (Table 45). Failure to adhere to maintenance protocols can lead to equipment malfunctions, reduced efficiency, and increased operational costs, with a moderate impact and medium likelihood (Table 46) due to the essential nature of consistent maintenance for solar installations. On the other hand, insufficient training can result in operational errors, safety incidents, and decrease overall efficiency, also rated as high impact and high likelihood (Table 46), highlighting the critical importance of well-trained staff for the successful operation of the park.

Table 47: Risk Response Plan of R21 and R22

Risk ID	Mitigation Strategies	Responsible Person
R21	Develop comprehensive maintenance protocols	Maintenance Manager
	Regularly review and update maintenance procedures	
	Implement a tracking system for maintenance activities	
R22	Design and implement a robust training program	Training Coordinator
	Conduct regular training sessions and refreshers	
	Monitor and evaluate the effectiveness of training programs	

Table 48: Recalculated Risk Assessment after every Mitigation of R21 and R22

Risk ID	Impact	Likelihood	Risk Score	Priority
R21	0,2	0,3	0,06	Medium
	0,2	0,1	0,02	Low
	0,1	0,1	0,01	Low
R22	0,4	0,5	0,2	High
	0,4	0,3	0,12	Medium
	0,2	0,1	0,02	Low

To reduce the risks associated with non-compliance with maintenance protocols and training deficiencies, some strategies were implemented (Table 47). These included developing clear maintenance schedules and comprehensive training programs for all staff, alongside thorough training for maintenance personnel. Strict oversight and auditing mechanisms were established, along with regular reviews and updates of maintenance protocols to align with industry standards. Additionally, regular training sessions and a robust certification process ensured that training materials remained current with the latest technological advancements and safety protocols, confirming that all personnel met the required competency standards (Table 48).

3.3.6.2 Regulatory Hurdles and Impact of Regulatory Changes

Table 49: Risk Identification of R23 and R24

Risk ID	Risk Description	Category	Source of Risk
R23	Component Delivery Delays	Supply Chain Disruptions	Delays in delivery of key components
R24	Quality Control Failures	Supply Chain Disruptions	Failure to meet quality standards in components

Table 50: Risk Assessment of R23 and R24

Risk ID	Impact	Likelihood	Risk Score	Priority
R23	0,4	0,7	0,28	High
R24	0,4	0,7	0,28	High

The preliminary risk assessment for the photovoltaic park in the area identified significant challenges related to component delivery delays and quality control failures (Table 49). Delays in delivering essential components can disrupt the construction schedule, increase costs, and extend the project timeline, with a high impact and likelihood (Table 50) due to the complexities of logistics and supply chain management. Similarly, quality control failures can result in substandard construction, increased maintenance costs, and diminished system performance, also rated as high impact and likelihood (Table 50), reflecting the stringent quality requirements for photovoltaic systems.

Table 51: Risk Response Plan of R23 and R24

Risk ID	Mitigation Strategies	Responsible Person
R23	Establish strong relationships with suppliers	Procurement Manager
	Implement a rigorous tracking and follow-up system for deliveries	
	Maintain buffer stock of critical components	
	Identify and qualify alternative suppliers	
R24	Develop and enforce strict quality control standards	Quality Assurance Manager
	Conduct regular inspections and audits of supplier processes	
	Train staff on quality assurance practices	
	Utilize third-party testing and certification for critical components	

Table 52: Recalculated Risk Assessment after every Mitigation of R23 and R24

Risk ID	Impact	Likelihood	Risk Score	Priority
R23	0,4	0,5	0,2	High
	0,4	0,3	0,12	Medium
	0,2	0,3	0,06	Medium
	0,1	0,3	0,03	Low
R24	0,4	0,5	0,2	High
	0,4	0,3	0,12	Medium
	0,4	0,1	0,04	Low
	0,2	0,1	0,02	Low

To mitigate the risks of component delivery delays and quality control failures in the construction of the 1 MW photovoltaic park in Prochoma, Thessaloniki, numerous strategies were implemented (Table 51). Reliable partnerships with multiple suppliers were established, along with buffer stock for critical components and a detailed logistics plan. Regular communication with suppliers and real-time tracking of shipments helped anticipate and address potential delays. For quality control, rigorous assurance processes were adopted, including regular inspections, personnel training in quality management practices, and the establishment of clear quality standards with thorough documentation to ensure compliance with required specifications (Table 52).

Inconsistencies in the quality of materials supplied by third-party vendors are an inevitable challenge in the supply chain management of any manufacturing company. This company, which typically processes approximately thirty-five orders from various suppliers in its warehouses daily, experiences quality issues in 1 to 4 of these orders. The problems encountered are minor, often involving slight deviations in the quality of specific materials within an order. These minor quality issues, while still requiring attention, usually result in manageable disruptions to the manufacturing process.

However, on rare occasions, the company faces more significant issues that affect the entire order. These comprehensive quality failures can have a substantial impact on production, leading to prolonged delays. Such instances may necessitate thorough inspections, extensive communication with the supplier, and potentially the return or replacement of the defective materials. This process can disrupt the manufacturing schedule and extend project timelines.

The presence of these material quality inconsistencies underscores the importance of robust quality control measures and effective supplier relationship management. Implementing rigorous inspection protocols upon receipt of materials, maintaining clear communication channels with suppliers, and establishing contingency plans for addressing substantial quality issues are crucial strategies for mitigating the adverse effects of these inconsistencies on the company's manufacturing operations (Internal Source).

3.3.7 Social and Community Risks

3.3.7.1 Community Resistance and Indigenous Rights Issues

Table 53: Risk Identification of R25 and R26

Risk ID	Risk Description	Category	Source of Risk
R25	Community Resistance	Public Opposition	Opposition from local communities
R26	Indigenous Rights Issues	Public Opposition	Potential infringement on Indigenous lands and rights

Table 54: Risk Assessment of R25 and R26

Risk ID	Impact	Likelihood	Risk Score	Priority
R25	0,4	0,3	0,12	Medium
R26	0,8	0,3	0,24	High

The initial risk assessment for the photovoltaic park in Prochoma, identified significant challenges related to community resistance and indigenous rights issues (Table 53). Opposition from local communities can cause delays, increased costs, and modifications to project plans, with a high impact and medium likelihood (Table 54) due to the necessity of community support for large-scale infrastructure projects. Similarly, failing to respect indigenous rights can lead to legal disputes, project delays, and reputational damage, rated as very high impact and medium likelihood (Table 54), highlighting the sensitivity and complexity of these issues in project development.

Table 55: Risk Response Plan of R25 and R26

Risk ID	Mitigation Strategies	Responsible Person
R25	Engage with local communities early in the project	

Risk ID	Mitigation Strategies	Responsible Person
	Hold public meetings to address concerns and gather input	Communications Director
	Develop community benefit programs (e.g., local jobs, infrastructure)	
	Provide transparent and continuous communication throughout the project	
R26	Conduct thorough consultations with Indigenous groups	Environmental Specialist
	Ensure compliance with all relevant laws and treaties regarding Indigenous rights	
	Negotiate agreements to ensure mutual benefits	
	Implement measures to protect Indigenous heritage sites and practices	

Table 56: Recalculated Risk Assessment after every Mitigation of R25 and R26

Risk ID	Impact	Likelihood	Risk Score	Priority
R25	0,4	0,1	0,04	Low
	0,4	0,1	0,04	Low
	0,4	0,1	0,04	Low
	0,2	0,1	0,02	Low
R26	0,8	0,3	0,24	High
	0,8	0,1	0,08	Medium
	0,4	0,1	0,04	Low
	0,2	0,1	0,02	Low

To lessen the risks of community resistance and indigenous rights issues for the 1 MW photovoltaic park, some strategies were implemented (Table 55). Engaging with community leaders early in the planning phase and conducting public consultations helped address concerns while providing transparent information about the project's benefits. Fostering community partnerships and offering local benefits-built support and reduced opposition (Jobert et al., 2007). Additionally, thorough assessments of indigenous rights were conducted, along with meaningful consultations with indigenous groups to ensure that project plans respected their land and rights. Developing agreements that included benefits for indigenous communities further mitigated potential conflicts and fostered positive relationships (Table 56).

3.3.7.2 Strikes and Labor Disputes and Safety Incidents on Site

Table 57: Risk Identification of R27 and R28

Risk ID	Risk Description	Category	Source of Risk
R27	Strikes and Labor Disputes	Labor Relations	Conflicts between labor and management
R28	Safety Incidents on Site	Labor Relations	Accidents and safety breaches during construction

Table 58: Risk Assessment of R27 and R28

Risk ID	Impact	Likelihood	Risk Score	Priority
R27	0,8	0,3	0,24	High
R28	0,8	0,5	0,4	High

The initial risk assessment for the photovoltaic park in Thessaloniki identified significant challenges related to strikes and labor disputes, as well as safety incidents on-site (Table 57). Labor unrest can disrupt project timelines and increase costs, with a catastrophic impact and medium likelihood (Table 58) due to potential disagreements in large construction projects. Similarly, safety incidents can lead to injuries, project delays, and increased costs from work stoppages and legal liabilities, also rated the same as strikes and labor disputes, given the inherent risks associated with construction activities.

Table 59: Risk Response Plan of R27 and R28

Risk ID	Mitigation Strategies	Responsible Person
R27	Foster open communication between labor and management	HR Manager
	Negotiate and review fair labor contracts	
	Implement conflict resolution mechanisms	

Risk ID	Mitigation Strategies	Responsible Person
	Monitor labor conditions and worker satisfaction	
R28	Develop and enforce comprehensive safety protocols	Safety Officer
	Conduct regular safety training and drills for all workers	
	Ensure proper use of personal protective equipment (PPE)	
	Regularly inspect and maintain equipment and site conditions	

Table 60: Recalculated Risk Assessment after every Mitigation of R27 and R28

Risk ID	Impact	Likelihood	Risk Score	Priority
R27	0,8	0,3	0,08	Medium
	0,8	0,1	0,08	Medium
	0,4	0,1	0,04	Low
	0,4	0,1	0,04	Low
R28	0,8	0,3	0,24	High
	0,8	0,3	0,24	High
	0,4	0,3	0,12	Medium
	0,4	0,1	0,04	Low

To mitigate the risks of strikes and labor disputes, numerous strategies were implemented, including fostering strong relationships with labor unions, ensuring fair wages and working conditions, and maintaining open communication with workers (Table 59). Establishing contingency plans for potential labor disruptions and negotiating agreements in advance further reduced the impact of disputes. To address safety risks on-site, rigorous safety protocols were implemented alongside regular training sessions to ensure all personnel had appropriate personal protective equipment (PPE). Additionally, a safety oversight team conducted frequent site inspections to promptly identify and rectify potential hazards (Table 60).

3.3.8 Cyber security Risks

3.3.8.1 *Cyber attacks on Operational Technology and Data Breaches Impacting Stakeholder Trust*

Table 61: Risk Identification of R29 and R30

Risk ID	Risk Description	Category	Source of Risk
R29	Cyberattacks on Operational Technology	Data Security Threats	Threats from malicious cyber actors targeting operational systems
R30	Data Breaches Impacting Stakeholder Trust	Data Security Threats	Unauthorized access to sensitive data affecting stakeholder confidence

Table 62: Risk Assessment of R29 and R30

Risk ID	Impact	Likelihood	Risk Score	Priority
R29	0,8	0,3	0,24	High
R30	0,4	0,3	0,12	Medium

Lastly, the preliminary risk evaluation identified significant challenges related to cyber attacks on operational technology and data breaches (Table 61). Cyberattacks can compromise critical systems, leading to operational disruptions, data loss, and increased security costs, with a very high impact and medium likelihood (Table 62) due to the growing sophistication of cyber threats. Similarly, data breaches can erode stakeholder confidence, damage the company's reputation, and result in legal and financial repercussions, also rated as high impact and medium likelihood (Table 62). These assessments underscore the critical importance of data security in maintaining stakeholder trust.

Table 63: Risk Response Plan of R29 and R30

Risk ID	Mitigation Strategies	Responsible Person
R29	Conduct regular security audits and penetration testing	IT Manager
	Train staff in cybersecurity best practices	

Risk ID	Mitigation Strategies	Responsible Person
	Unauthorized access to sensitive data affecting stakeholder confidence	
R30	Implement strict data access controls and encryption	Data Privacy Officer
	Regularly update and patch systems to fix vulnerabilities	
	Conduct regular data privacy training for employees	
	Establish a data breach response plan, including communication strategies	

Table 64: Recalculated Risk Assessment after every Mitigation of R29 and R30

Risk ID	Impact	Likelihood	Risk Score	Priority
R29	0,8	0,1	0,08	Medium
	0,4	0,1	0,04	Low
	0,4	0,1	0,04	Low
R30	0,4	0,1	0,04	Low
	0,2	0,1	0,02	Low
	0,2	0,1	0,02	Low
	0,1	0,1	0,01	Low

To address the risks associated with cyber attacks on operational technology and data breaches, multitudinous strategies were implemented (Table 63). These included deploying advanced cyber security measures, conducting regular security audits, and establishing robust access control protocols. Staff training on cyber security best practices and incident response plans ensured effective reactions to potential incidents. Additionally, stringent data protection policies were put in place, along with encryption for sensitive information and regular vulnerability assessments. Transparent communication with stakeholders regarding data protection measures further helped maintain trust and confidence (Table 64).

4. Chapter 4 - Monte Carlo Method

To gain a more precise understanding of the potential Risk Scores associated with five specific risks, the Monte Carlo method was employed prior to implementing any mitigation strategies. The selection of these five risks was based on the availability of additional supporting evidence, which allowed for a more robust assessment of our initial assumptions regarding their impact and likelihood.

The risks chosen for this detailed analysis are Equipment Failure Risks, Material Price Volatility, Quality Control Failures, Severe Weather Events and Soil Stability Issues. For each of these risks, the supporting evidence used to justify our initial assumptions is documented within their respective risk sheets. Additionally, further verification and data were provided by the company responsible for constructing the photovoltaic (PV) farms in our study area, serving as an internal source of information.

The Monte Carlo simulation utilized two primary input assumptions: the likelihood of occurrence and the potential impact of each risk. These inputs followed the expected trend identified during the initial risk assessment. To ensure a comprehensive forecast, the final risk score—calculated as the product of impact and likelihood—was explicitly tracked throughout the simulations.

A triangular distribution was chosen for the input assumptions, with defined minimum and maximum values to capture the realistic range of each parameter. This distribution was selected due to its effectiveness in modeling situations where precise data is limited but reasonable estimates can be made based on expert judgment and historical data.

To ensure the reliability and stability of the results, multiple test runs were conducted using a progressively increasing number of trials. The sequence of trials performed included 1,000, 2,000, 4,000, 7,000, 10,000, and 20,000 iterations. By analyzing the results across these different trial counts, it was determined that at 20,000 trials, the outcomes stabilized, demonstrating consistent values with minimal fluctuations. This stability indicated that further increases in the number of trials would not significantly alter the results, confirming the robustness of the Monte Carlo analysis.

This approach provided a more accurate and data-driven basis for evaluating the selected risks, allowing for a well-informed decision-making process regarding potential mitigation strategies.

4.1 Equipment Failure Risks

For the assessment of equipment failure risks, the Monte Carlo method was used to simulate potential risk scores. The impact parameter (Figure 6) was assigned an mean (μ) value of 0.4, with a deviation (σ) of ±0.1, resulting in a defined range between 0.3 (minimum) and 0.5 (maximum). Similarly, the likelihood parameter (Figure 7) was set with a mean (μ) value of 0.7, incorporating a variance (σ) of ±0.2, leading to a range between 0.5 (minimum) and 0.9 (maximum).

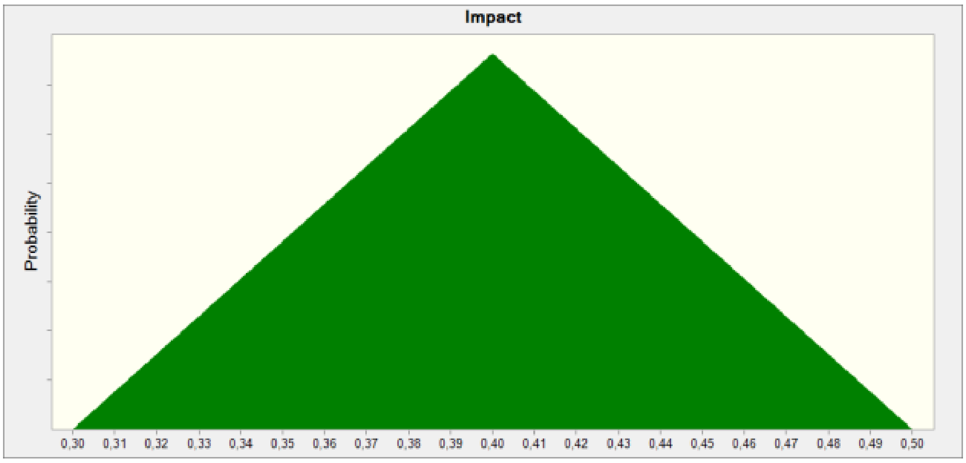


Figure 6: Input of Impact for Equipment Failure Risks

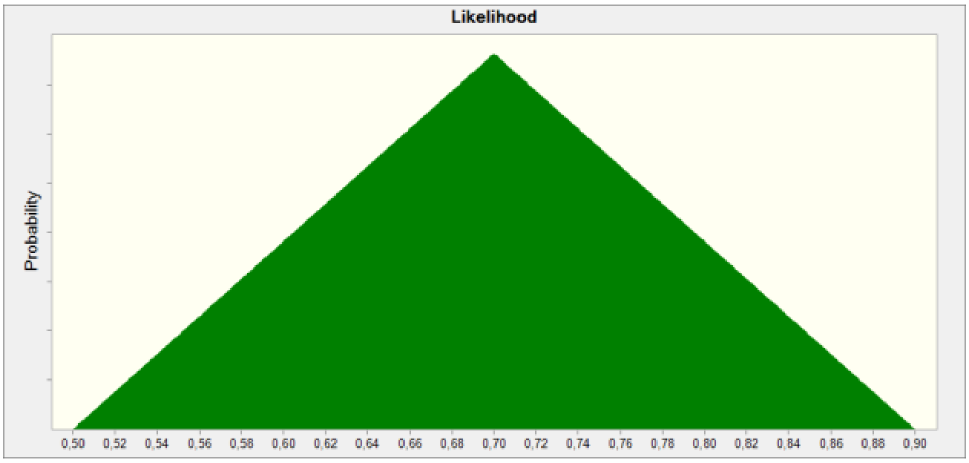
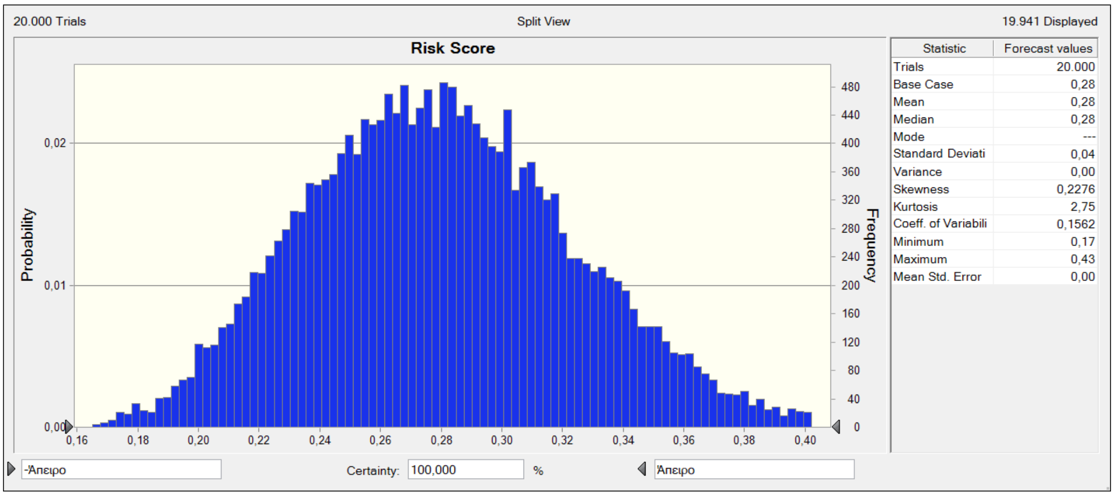


Figure 7: Input of Likelihood for Equipment Failure Risks

Following the completion of 20,000 simulation trials, the results for contingent risk scores were found to be conclusive. The generated risk score consistently fell within the high-risk range based on the predefined evaluation scale, demonstrating a 100% certainty of being classified as high risk. The statistical outcomes of the simulation showed a mean risk score of 0.28, with a minimum recorded value of 0.17 and a maximum of 0.43.



Statistic	Forecast values
Trials	20.000
Base Case	0,28
Mean	0,28
Median	0,28
Mode	---
Standard Deviati	0,04
Variance	0,00
Skewness	0,2276
Kurtosis	2,75
Coeff. of Variabili	0,1562
Minimum	0,17
Maximum	0,43
Mean Std. Error	0,00

-Άπειρο
Certainty: 100,000 %
Άπειρο

Figure 8: Risk Score Chart of Equipment Failure Risks

Examining the distribution curve of the generated risk scores (Figure 8), a significant concentration of values is observed near the mean (0.28). The distribution appears symmetrical, with an almost equal number of values above and below the mean. However, a slight asymmetry is present, as the frequency of values below 0.28 is lower compared to those above it. This suggests a slight right-skewed tendency, indicating that higher risk scores occur slightly more frequently than lower ones within the simulated range.

The histogram of the Monte Carlo simulation visually confirms these observations, reinforcing the reliability of the analysis in evaluating the risk associated with equipment failure.

4.2 Material Price Volatility

Potential risk scores were simulated using the Monte Carlo approach to evaluate the hazards associated with material price volatility. The impact parameter (Figure 9) was given a mean (μ) value of 0.4, with a minimum of 0.1 and a maximum of 0.6. With a variance (σ) of ±0.2 and a mean value of 0.5, the likelihood parameter (Figure 10), on the other hand, was chosen to range from 0.3 (minimum) to 0.7 (maximum).

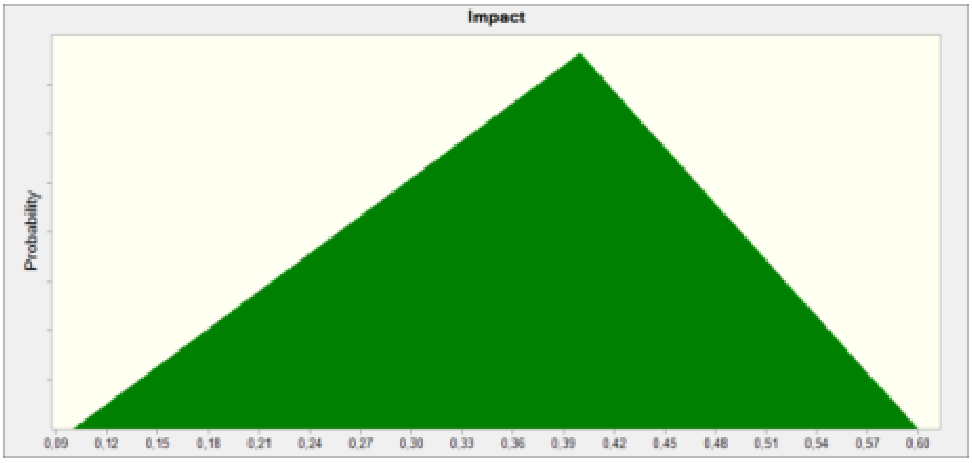


Figure 9: Input of Impact for Material Price Volatility Risks

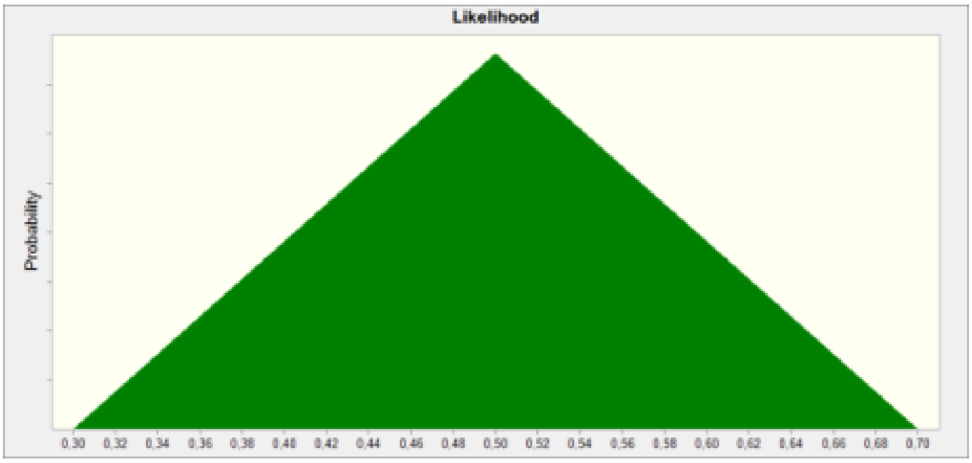
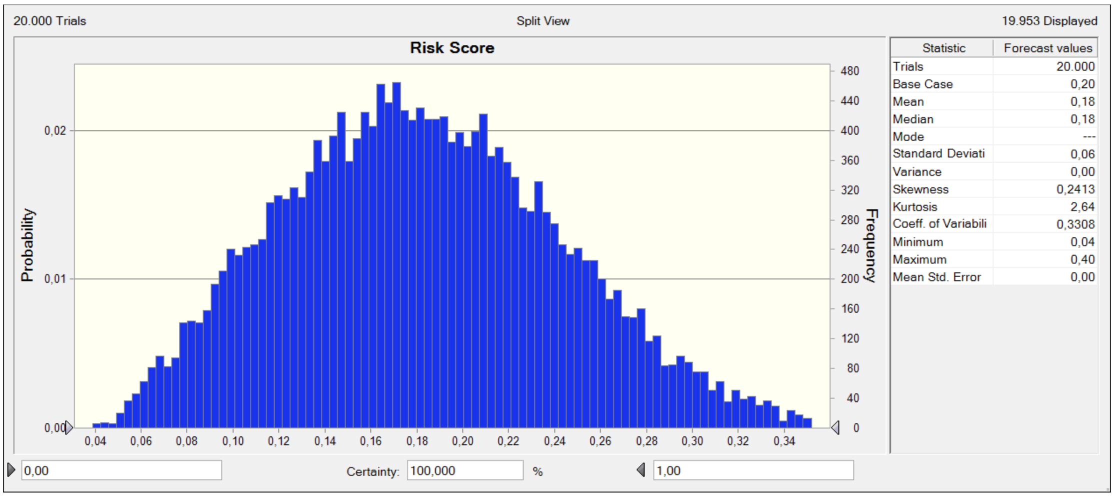


Figure 10: Input of Likelihood for Material Price Volatility Risks

In this case the generated risk scores gave results that belong to all risk categories (low, medium and high). The curves generated by the program (Figure 11) were examined in all cases of the different trials (1000, 2000, 4000, 7000, 10000, and 20000). Instability was observed in the percentage of probability for each risk category in the first three trials. From 7000 trials onwards the percentage of trials corresponding to each risk category seems to stabilize. To illustrate this, three diagrams were created (one for each risk category) with the number of trials listed on the x-axis and the percentage of trials belonging to each risk category (low, medium and high) on the y-axis.



Statistic	Forecast values
Trials	20.000
Base Case	0,20
Mean	0,18
Median	0,18
Mode	---
Standard Deviati	0,06
Variance	0,00
Skewness	0,2413
Kurtosis	2,64
Coeff. of Variabili	0,3308
Minimum	0,04
Maximum	0,40
Mean Std. Error	0,00

Figure 11: Risk Score Scale of Material Price Volatility Risks

In the case of low risk, the proportion of trials whose risk score results were in the low risk category was always very low (Figure 12). This seems normal as our original view of material price volatility risks gave a high risk score for material price volatility risks. Therefore, because the scores are at very low levels (from 0,05% to 0,14%) their normalization cannot be easily observed when the trials exceed the number of 7000. Also, such a low quota of low risk makes us consider it as negligible

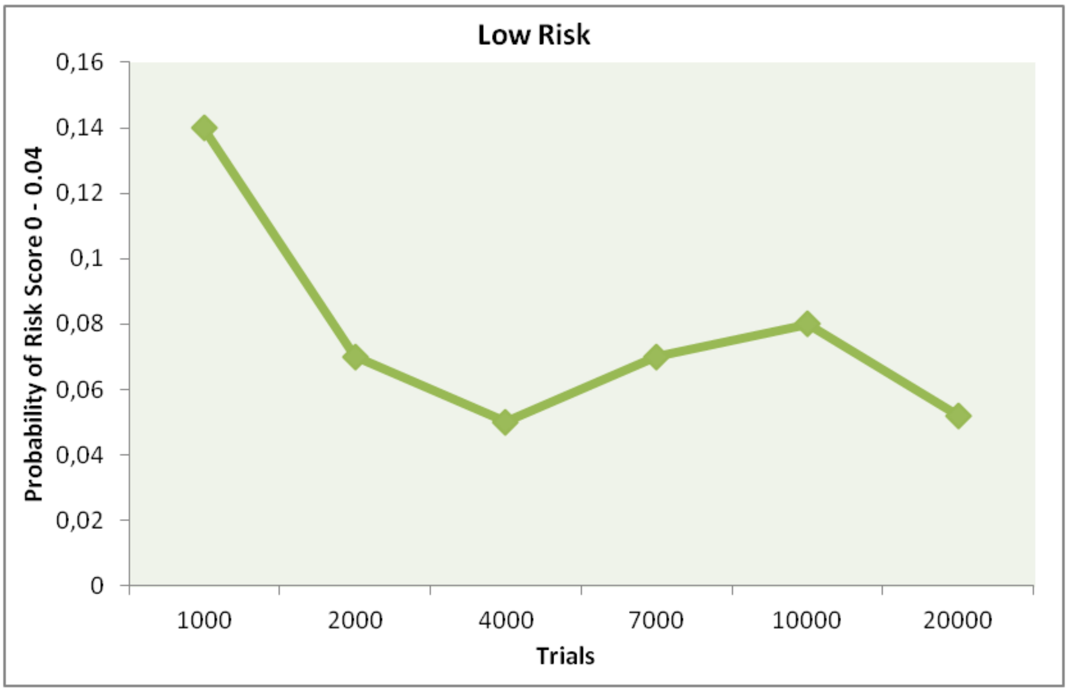


Figure 12: Low Risk Probability of Material Price Volatility Risks

In the case of medium risk (Figure 13), the percentage of trials whose risk score was in this category ranged from 28.54% to 30.24%. This seems normal as our original consideration of material price volatility risks gave a high risk score close to its low threshold (0.2). Their normalization when trials exceed the number of 7000 now is easily discernible with values stabilizing near 28.6%. This quota is considered significant and shows us that there is a possibility that this risk belongs to the medium category.

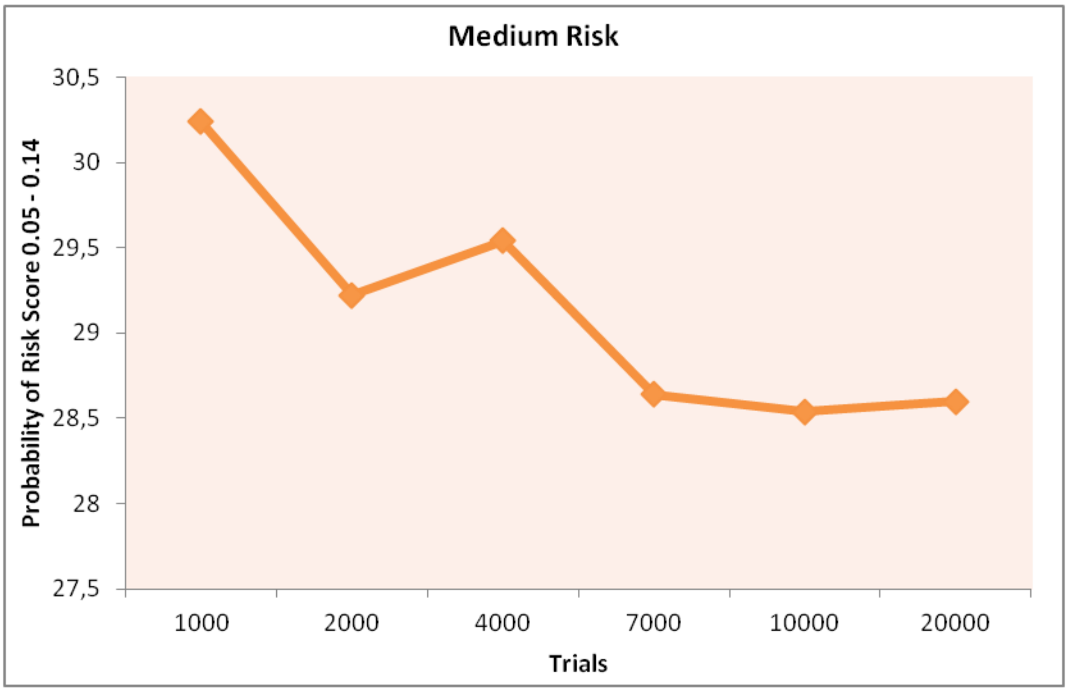


Figure 13: Medium Risk Probability of Material Price Volatility Risks

In the case of high risk (Figure 14), the percentage of trials whose risk score was in this category ranged from 69.61% to 71.38%. As mentioned above, this is normal as our original consideration of material price volatility risks gave a high risk score close to its low threshold (0.2). Their normalization when trials exceed the number of 7000 now is easily discernible with values stabilizing near 71.33%. This quota is considered significant and shows us that the scenario based on the inputs we defined is that the risk is considered high risk and a full mitigation strategy is needed to address it.

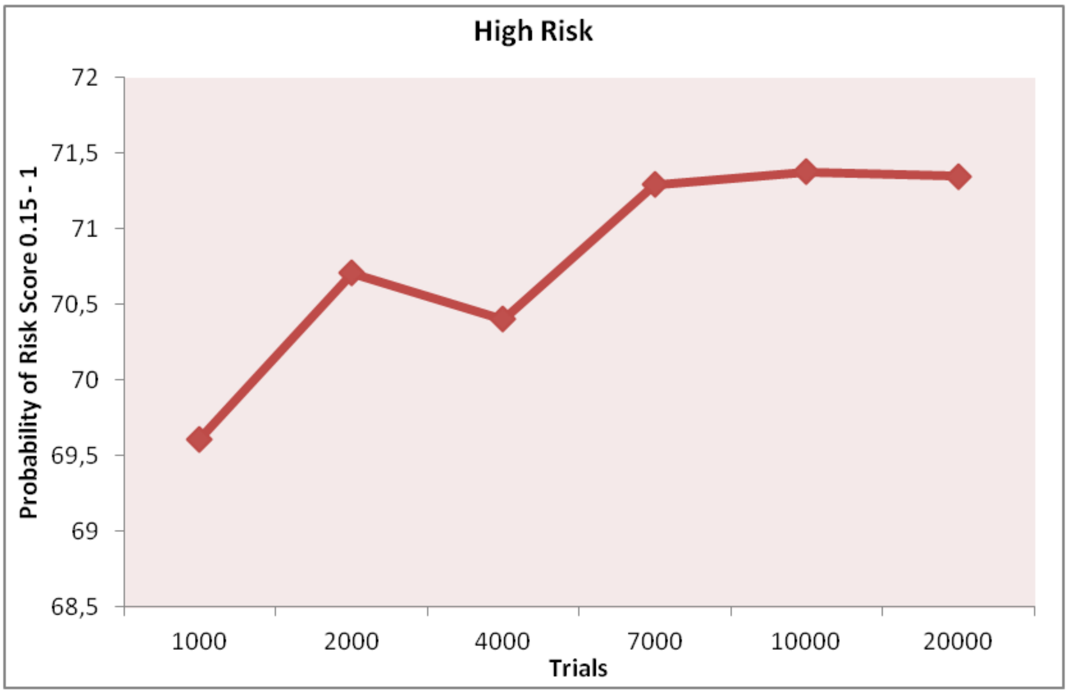


Figure 14: High Risk Probability of Material Price Volatility Risks

These findings are visually supported by the Monte Carlo simulation's histogram, which attests to the methodology's accuracy in predicting the risk of material price volatility.

4.3 Quality Control Failures

The Monte Carlo method was used to simulate potential risk scores to assess the risks related to quality control failures. With a minimum of 0.2 and a maximum of 0.5, the impact parameter (Figure 15) was assigned a mean value of 0.4. The likelihood parameter (Figure 16), on the other hand, was selected to range from 0.5 (minimum) to 0.8 (maximum), with variances (σ) of -0.2, +0.1, and a mean (μ) value of 0.7.

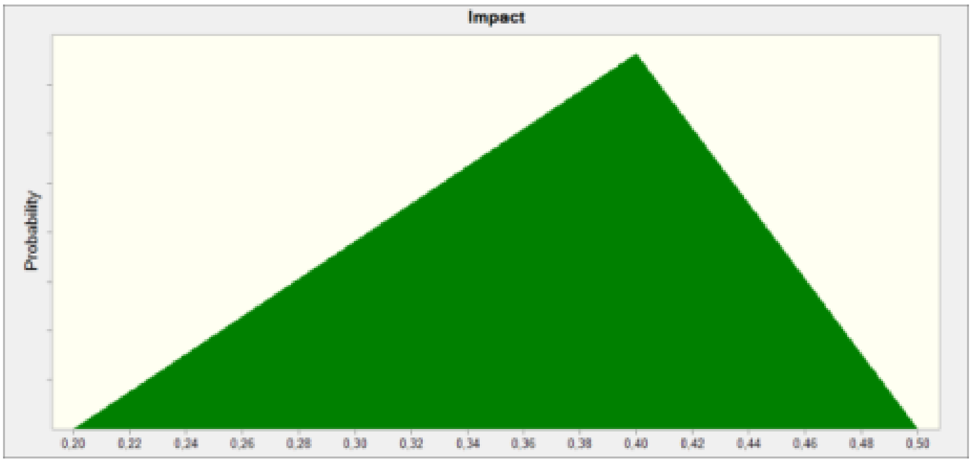


Figure 15: Input of Impact for Quality Control Failure Risks

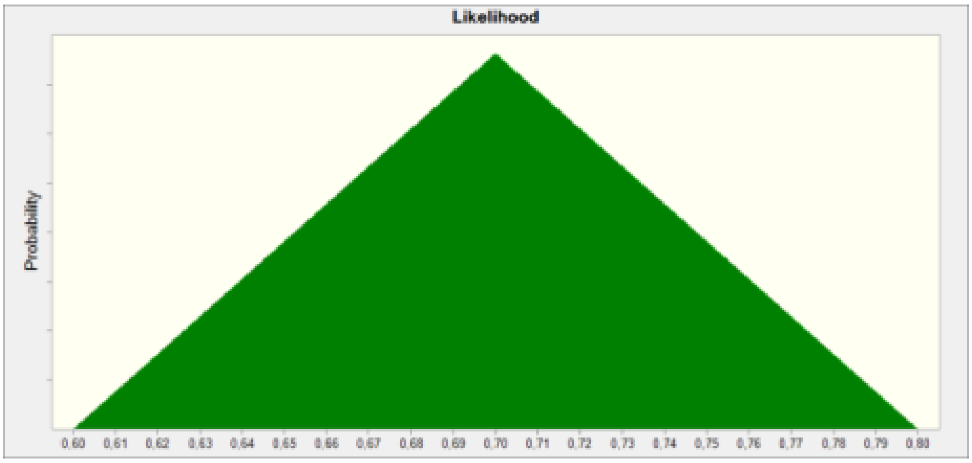
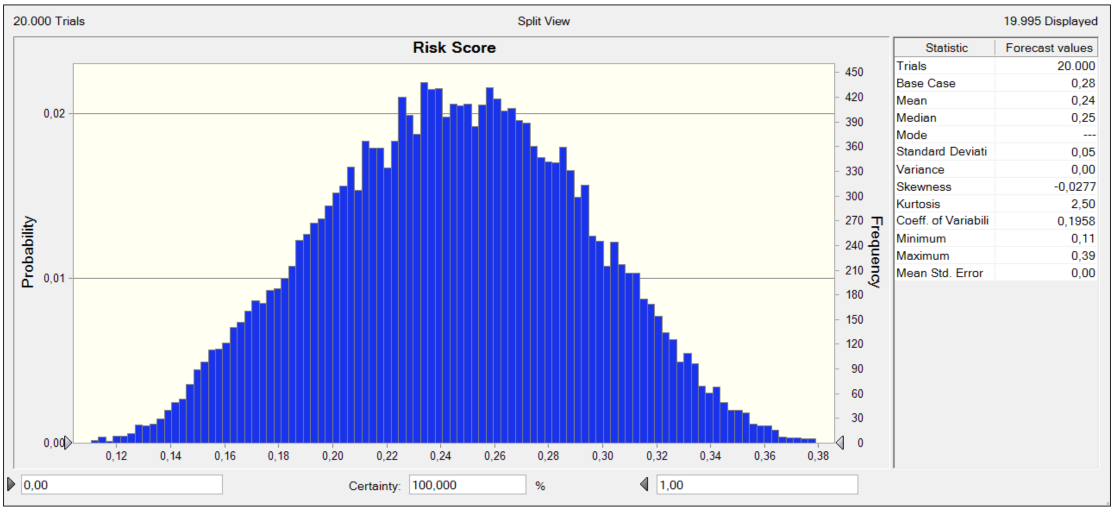


Figure 16: Input of Likelihood for Quality Control Failure Risks

The findings of the risk scores that were generated in this instance (Figure 17) fall within the medium and high risk categories. The program's curves were analyzed for each of the following trials: 1000, 2000, 4000, 7000, 10,000, and 20,000. During the first three trials, there was instability in the percentage of probability for each risk group. The proportion of trials that belong to each risk group appears to settle after 7000 trials. Two diagrams, one for each risk group, were made to show this. The x-axis showed the total number of trials, and the y-axis showed the proportion of trials that fell into the low, medium, and high risk categories.



Statistic	Forecast values
Trials	20.000
Base Case	0,28
Mean	0,24
Median	0,25
Mode	---
Standard Deviati	0,05
Variance	0,00
Skewness	-0,0277
Kurtosis	2,50
Coeff. of Variabili	0,1958
Minimum	0,11
Maximum	0,39
Mean Std. Error	0,00

Figure 17: Risk Score Scale of Quality Control Failure Risks

The proportion of trials with a risk score in the medium risk group varied between 1.11% and 1.46% (Figure 18). Given that our initial assessment of the hazards associated with material price fluctuation yielded a high risk score (0.28), this is typical. It is now easy to see how they normalize when the number of trials exceeds 7000, with values settling around 1.4%. The fact that this quota is not regarded as considerable indicates that the likelihood of this risk falling into the medium category is quite low.

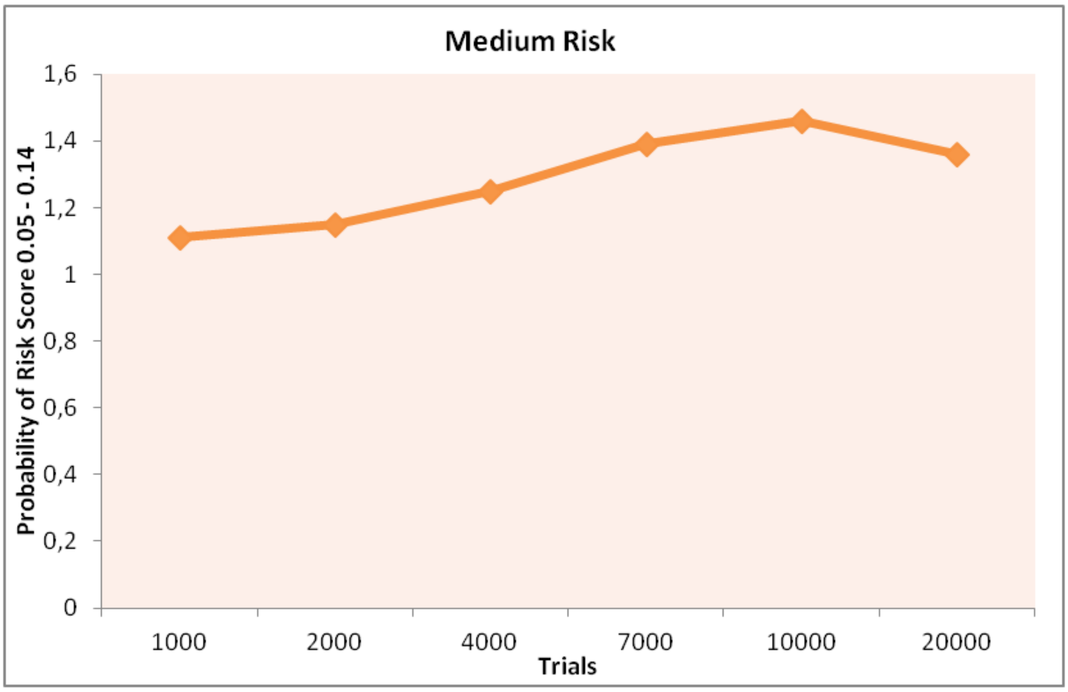


Figure 18: Medium Risk Probability of Quality Control Failure Risks

The proportion of trials that fell into the high risk group ranged from 98.54% to 98.89% within this heading (Figure 19). As previously stated, this is typical because our initial assessment of the risks associated with material price fluctuation yielded a high risk score that fell into the high group (0.28). It is now easy to see how they normalize when the number of trials exceeds 7000, with values settling around 98.6%. This quota is regarded as significant and indicates that, given the inputs we defined, the situation is that the risk is deemed high risk and that a comprehensive mitigation approach is required to address it.

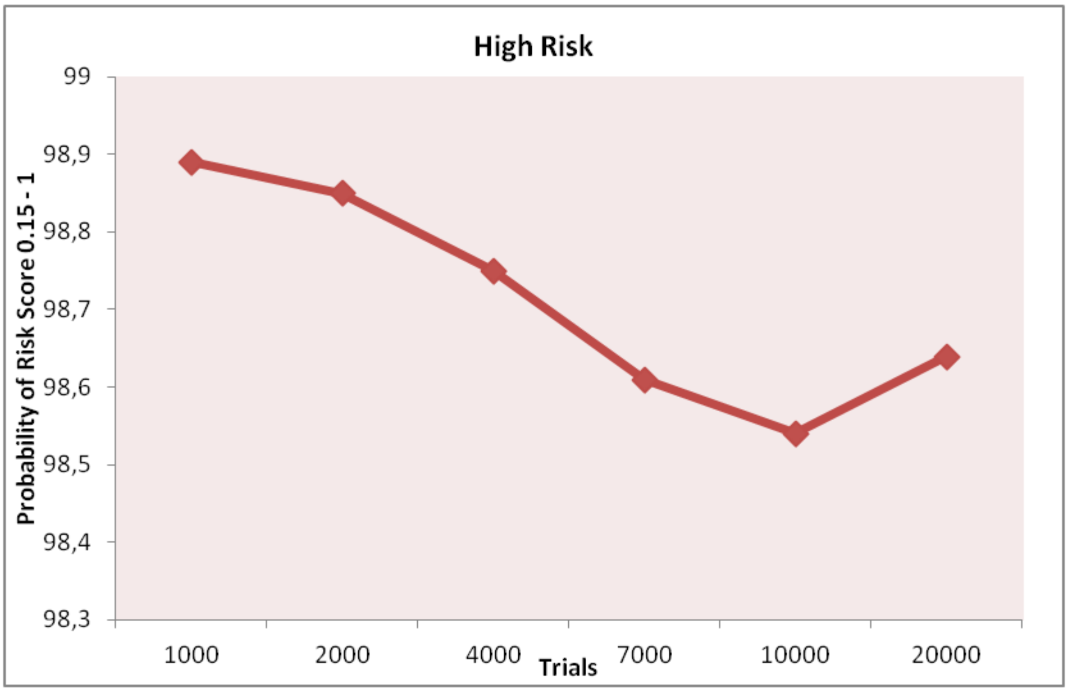


Figure 19: High Risk Probability of Quality Control Failure Risks

The histogram from the Monte Carlo simulation provides visual evidence for these conclusions, confirming the reliability of the methodology in estimating the risk of quality control failures.

4.4 Severe Weather Events

Potential risk scores were simulated using the Monte Carlo approach to evaluate the risks of equipment failure. With a variance (σ) of ±0.1 and a mean (μ) value of 0.4, the impact parameter (Figure 20) was given a defined range of 0.3 (minimum) to 0.5 (maximum). A range of 0.5 (minimum) to 0.9 (maximum) was also established for the likelihood parameter (Figure 21), which had a mean (μ) value of 0.7 and a variance (σ) of ±0.2.

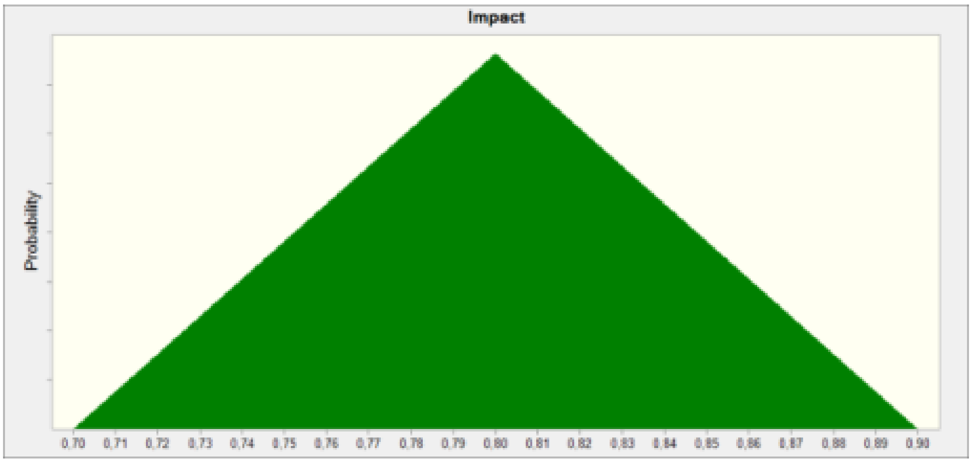


Figure 20: Input of Impact for Severe Weather Events Risks

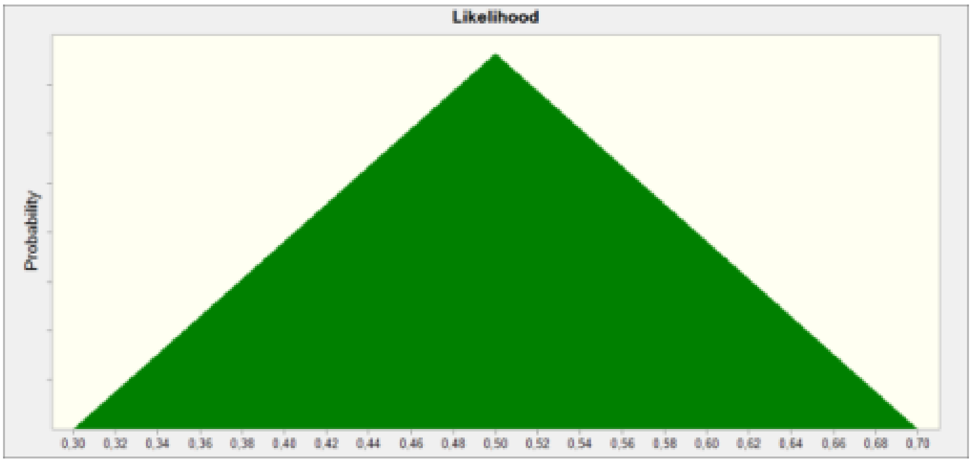
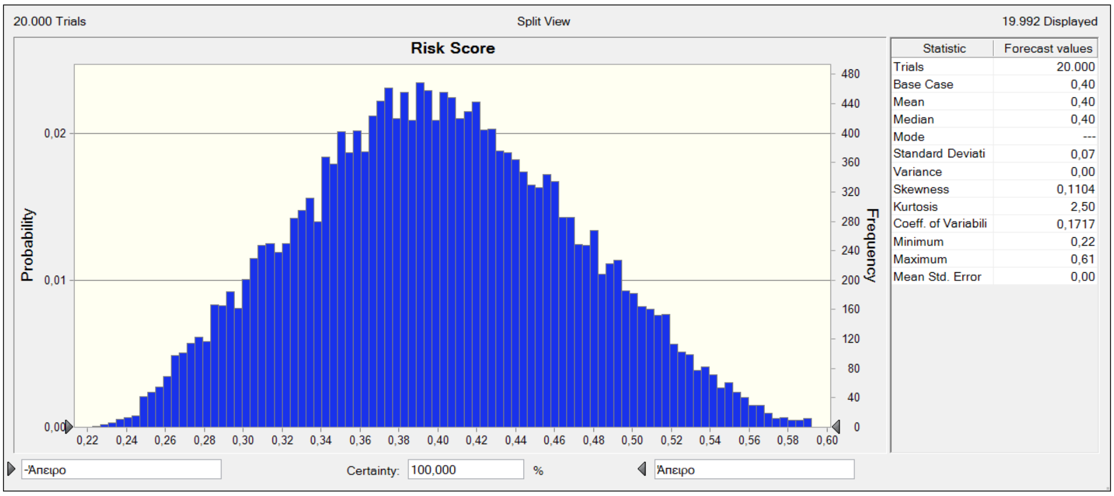


Figure 21: Input of Likelihood for Severe Weather Events Risks

The findings for the risk score forecast were determined to be definitive after 20,000 simulation trials. Based on the predetermined evaluation scale, the resulting risk score continuously fell into the high-risk region, indicating a 100% certainty of being categorized as high risk. According to the simulation's statistical results, the mean risk score was 0.4, with a minimum recorded value of 0.22 and a maximum of 0.61 (Figure 22).



Statistic	Forecast values
Trials	20.000
Base Case	0,40
Mean	0,40
Median	0,40
Mode	---
Standard Deviati	0,07
Variance	0,00
Skewness	0,1104
Kurtosis	2,50
Coeff. of Variabili	0,1717
Minimum	0,22
Maximum	0,61
Mean Std. Error	0,00

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Certainty: 100,000 %
Άπειρο

Figure 22: Risk Score Scale of Severe Weather Events Risks

A notable concentration of values is seen close to the mean (0.4) when looking at the distribution curve of the risk ratings that were created. There are about equal numbers of values above and below the mean, giving the distribution the appearance of being quite symmetrical. The frequency of values below 0.4 is lower than that of values above it, indicating a small asymmetry. Higher risk scores are more common than lower ones within the simulated range, suggesting a minor right-skewed tendency.

These findings are graphically supported by the Monte Carlo simulation's histogram, which further supports the analysis's dependability in assessing the danger of severe weather events.

4.5 Soil Stability Issues

The Monte Carlo method was used to simulate potential risk scores to assess the risk score of soil stability issues risks. The impact parameter (Figure 23) was assigned a predetermined range of 0.7 (lowest) to 0.9 (maximum), with a variance of ±0.1 and an average value of 0.8. The probability parameter (Figure 24), which had a mean (μ) value of 0.5 and a variance (σ) of ±0.1, was likewise set to range from 0.4 (minimum) to 0.6 (maximum).

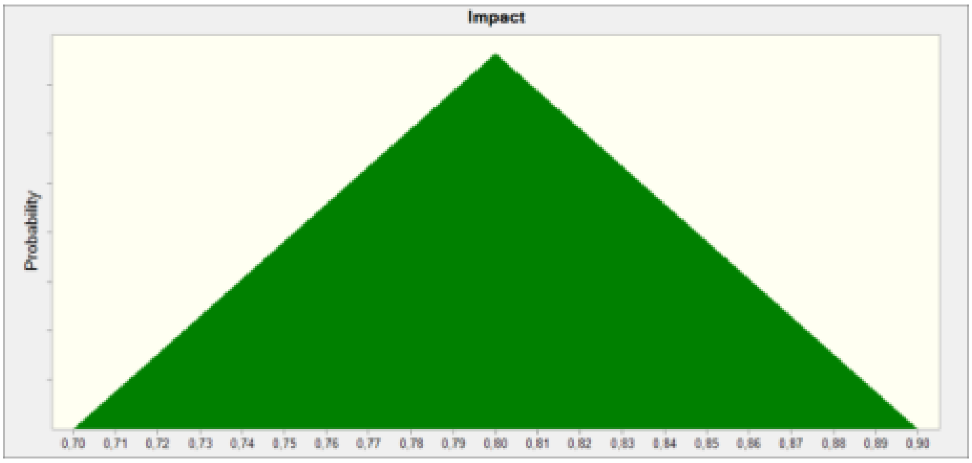


Figure 23: Input of Impact for Soil Stability Issues Risks

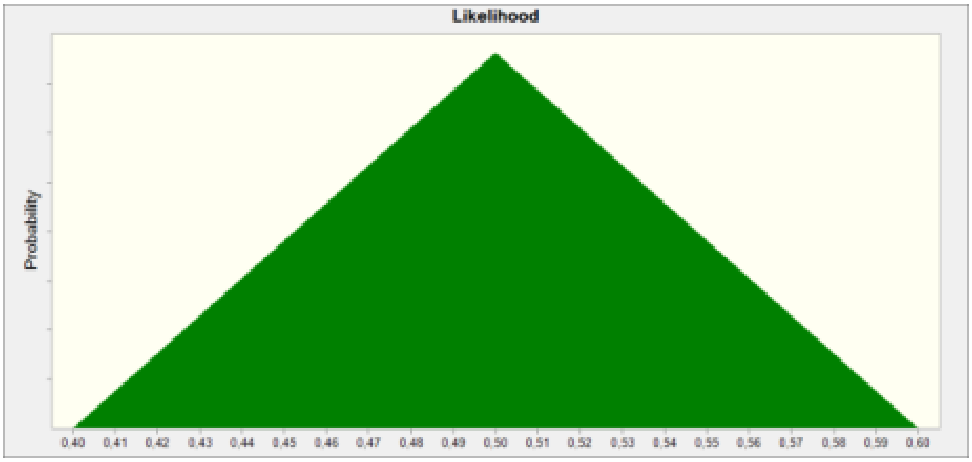
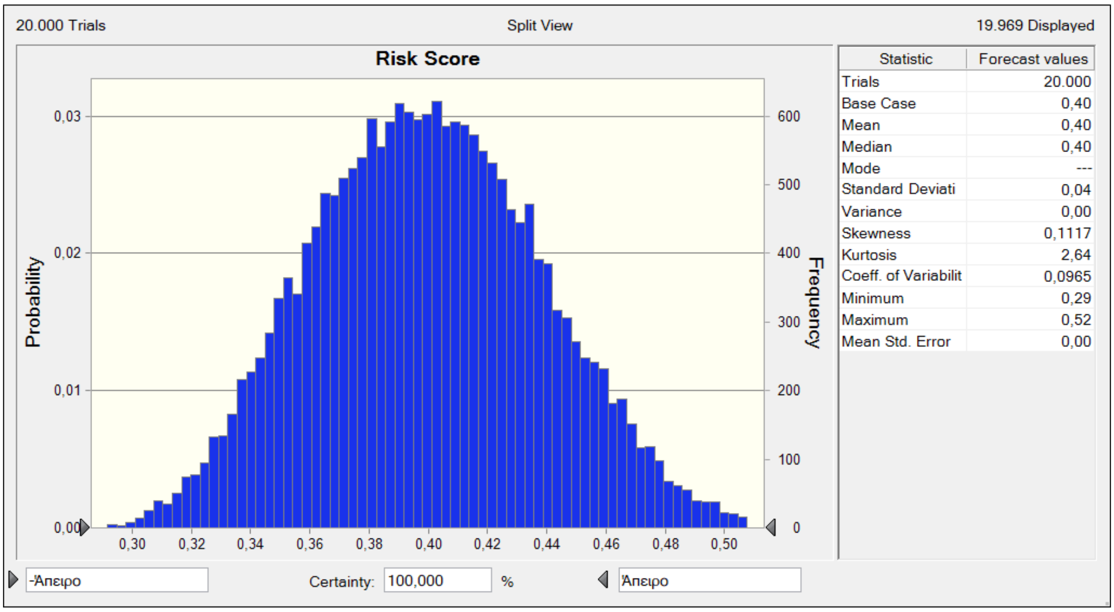


Figure 24: Input of Likelihood for Soil Stability Issues Risks

After 20,000 simulation sessions, the results for the risk score forecast were deemed conclusive. The resulting risk score consistently fell into the high-risk category according to the predefined evaluation scale, meaning that it was 100% certain to be classified as high risk.

Based on the statistical results of the simulation, the mean risk score was 0.4, with a maximum of 0.52 and a minimum of 0.29 (Figure 25).



Statistic	Forecast values
Trials	20.000
Base Case	0,40
Mean	0,40
Median	0,40
Mode	---
Standard Deviati	0,04
Variance	0,00
Skewness	0,1117
Kurtosis	2,64
Coeff. of Variabilit	0,0965
Minimum	0,29
Maximum	0,52
Mean Std. Error	0,00

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Certainty: 100,000 %
Άπειρο

Figure 25: Risk Score Scale of Soil Stability Issues Risks

The distribution curve of the developed risk ratings shows a significant concentration of values near the mean (0.4). The distribution is quite symmetrical because there are equal numbers of values above and below the mean. The risk score curve in this simulation deviates from the mean value the least. Around the mean value, the values have a smooth, linear form. This is because the variance used for the impact and likelihood parameters equals (0.1).

The Monte Carlo simulation's histogram graphically supports these conclusions, further proving the analysis's reliability in estimating the risk associated with soil stability issues.

5. Chapter 5 - Conclusions

5.1 Summary

This thesis concerns the analysis and management of risks during the construction of a photovoltaic park. To make the problem more specific, an indicative photovoltaic park of 1 mw power around Prochoma in Thessaloniki was used as a reference. The risks identified during the risk Breakdown Structure were evaluated based on the photovoltaic park mentioned; thus, risk sheets were created which included our initial assumptions regarding the impact and likelihood of each risk. In this way, a risk score was derived for each risk. A mitigation strategy was then presented which was in turn evaluated for its impact on each risk. Based on the above, each risk has a final risk score after the mitigation strategy.

For five of the risks mentioned in the risk breakdown structure, further data was found that helped in the in-depth analysis of their impact value and likelihood. For these five risks, therefore, the values were entered into Oracle's Crystall ball program to extract all possible risk scores for each risk. The results showed that three of the five risks (equipment failure, severe weather events and soil stability issues) would belong to the high risk category. On the other hand, one risk, quality control failures, has a low probability of belonging to the medium risk category and a strong probability of belonging to the high risk category. Finally, one risk, material price volatility, has a low probability of belonging to the low risk category, about 30 % of being in the medium risk category and most of being in the high risk category. All five risks when they were originally assessed in the risk sheets were calculated as high risk.

5.2 Conclusions

With emphasis on the example of a 1 MW PV park in Prochoma, Thessaloniki, this study investigated the use of the Monte Carlo method for risk analysis in PV parks. The study highlighted the need for risk management in renewable energy projects, as long-term sustainability and project viability can be impacted by uncertainties arising from technical, financial, environmental, and regulatory variables. This thesis used a probabilistic risk analysis methodology to show how the Monte Carlo method offers useful information about risks and their effects.

The results show how difficult it is to control risk in PV projects, because a number of interconnected elements affect the project's overall risk. The findings demonstrated that some hazards, like equipment failures, material price volatility and soil stability issues are highly likely to occur and have a significant effect on financial returns. A systematic classification and prioritizing of these risks were made possible using risk sheets and risk tables, which enabled an organized evaluation of these hazards. This method made it possible to identify high-priority hazards that call for initiative-taking mitigation techniques, such as better maintenance procedures, advanced forecasting software and a variety of investment plans.

This thesis makes a significant contribution by showing how Monte Carlo simulations can be included in the risk management procedure to produce numerical estimates of project outcomes. By producing probability distributions of different risk components, Monte Carlo simulations enable a more thorough examination of uncertainties than conventional deterministic risk assessment techniques. The use of this approach shows that although certain risks can be reduced by calculated actions, others are part of the nature of PV energy generation and necessitate ongoing observation and flexible management.

The Prochoma PV park also demonstrated the wider impact of risk management in major renewable energy initiatives. In addition to improving PV parks' long-term operational effectiveness and resilience to outside interruptions, effective risk reduction also increases their financial stability. According to the study's findings, incorporating probabilistic risk assessment techniques into PV project planning and execution can result in stronger frameworks for decision-making, which will increase project dependability and investor trust.

This thesis emphasizes the wider importance of risk analysis in the shift to renewable energy, going beyond the case study. Understanding and controlling the hazards associated with PV parks is essential for guaranteeing sustainable energy production as the world's energy sector shifts toward a greater reliance on solar power. The study's conclusions are applicable to related projects and provide insightful advice for investors and project developers looking to maximize risk management techniques in the renewable energy industry.

To sum up, this thesis has shown how the Monte Carlo method can improve risk analysis for PV parks by offering a methodical and data-driven approach to risk management. In order to further improve the risk assessment system, future studies could build on this work by adding more risk elements, such as geopolitical effects and developments in energy storage technology. Furthermore, using machine learning and artificial intelligence approaches may improve risk models' prediction power and provide even more accurate information about project vulnerabilities. The renewable energy sector may increase investment security, fortify its resilience, and quicken the shift to a more sustainable energy future by advancing and improving risk management techniques.

5.3 Suggestions for further research

The results of this diploma thesis demonstrate the importance of risk analysis in the Monte Carlo approach of developing photovoltaic (PV) parks. But as renewable energy develops, a number of areas need more study to strengthen risk management plans and raise the effectiveness, dependability, and financial viability of PV projects.

The incorporation of machine learning (ML) and artificial intelligence (AI) into risk assessment models is a crucial topic for further study. Although the Monte Carlo method offers a strong probabilistic foundation, real-time data from weather patterns, energy markets, and equipment performance might be included in AI-driven predictive analytics to improve the accuracy of risk projections. More dynamic risk mitigation techniques adapted to shifting circumstances may be provided via the creation of AI-enhanced Monte Carlo simulations.

Including hybrid energy storage options in risk analysis models is another crucial avenue. Although energy storage is essential for reducing the effects of solar radiation variability, little is known about the operational and financial hazards of the various storage technologies (such as lithium-ion batteries, flow batteries, and hydrogen storage). Future research could use sophisticated risk quantification techniques to evaluate the dependability and cost-benefit trade-offs of different storage solutions.

Additionally, the financial risks associated with regulatory changes and carbon pricing methods also require more research. The financial environment of PV parks is anticipated to shift as governments impose more stringent carbon emission regulations and provide incentives for the use of renewable energy. The possible effects of shifting tax laws, carbon credit markets, and subsidies on investment risk and return on capital for PV projects should be investigated.

Another new research topic is cyber security threats in PV parks. PV parks are more susceptible to cyber-attacks as they become more digitally integrated, incorporating smart inverters and Internet of Things-enabled monitoring systems. To protect PV infrastructure from potential assaults, further research might examine the efficacy of cyber security risk assessment frameworks and investigate block chain-based and encryption-based solutions.

Lastly, a more comprehensive approach to risk management might be offered by applying the Monte Carlo methodology to multi-criteria decision-making (MCDM) frameworks. Researchers could create more thorough frameworks for assessing investment choices in large-scale solar projects by combining Monte Carlo simulations with decision-support tools like fuzzy logic systems or the Analytic Hierarchy Process (AHP).

Ultimately, maximizing the resilience and financial sustainability of upcoming PV park improvements would require broadening the area of risk analysis through multidisciplinary research combining statistical modeling, artificial intelligence, financial risk management, and cyber security.

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Annex I

Risk Analysis Table

Table 65: Risk Analysis Table

Risk ID	Risk Description	Risk Score	Priority	Mitigation Strategies	Risk Score	Priority
R1	Regulatory Approval Delays	0,28	High	Early engagement with regulators	0,02	Low
				Hire a regulatory consultant		
				Regular follow-ups with approval authorities		
R2	Resource Misallocation	0,28	High	Detailed project planning and resource allocation	0,04	Low
				Regular project review meetings to track resource usage		
				Implement project management software for monitoring		
R3	Miscommunication Among Stakeholders	0,1	Medium	Implement regular communication channels	0,02	Low
				Use collaboration tools		
				Clearly define roles and responsibilities		
R4		0,1	Medium	Implement robust information management systems	0,02	Low
				Regularly back up data and test data recovery plans		

	Information Management Failures			Conduct training in information management best practices		
R5	Dependence on Emerging Technologies	0,1	Medium	Conduct thorough vetting of emerging technologies	0,01	Low
				Establish partnerships with technology providers		
				Allocate budget for technology updates and training		
R6	Equipment Failure Risks	0,28	High	Regular maintenance and inspection of equipment	0,03	Low
				Establish contingency plans for equipment failure		
				Train staff on equipment managing and emergency procedures		
R7	Energy Yield Variability	0,2	High	Use advanced weather forecasting tools to predict energy yield	0,02	Low
				Implement energy storage systems to balance yield variability		
				Diversify geographic location of PV installations		
R8	Potential Induced Degradation (PID)	0,12	Medium	Use PID-resistant materials in PV modules	0,02	Low
				Regular testing for PID in PV modules		
				Implementing preventive maintenance to reduce PID		
R9		0,4	High	Design infrastructure to withstand severe weather conditions	0,05	

	Severe Weather Events			Develop emergency response plans and protocols		Medium
				Regular maintenance and inspections		
R10	Unpredictable Climate Patterns	0,2	High	Implement flexible and adaptive energy management systems	0,03	Low
				Use climate-resilient materials and technologies		
				Conduct regular climate risk assessments and update strategies		
R11	Ecological Concerns	0,1	Medium	Conduct environmental impact assessments	0,01	Low
				Develop and implement conservation plans		
				Monitor and manage ecological impacts regularly		
R12	Soil Stability Issues	0,4	High	Conduct geotechnical surveys before construction	0,04	Low
				Implement soil stabilization techniques		
				Regular monitoring of soil stability and erosion control measures		
R13	Inadequate Funding	0,4	High	Secure multiple sources of funding	0,04	Low
				Develop a detailed financial plan and budget		
				Establish a contingency fund		
R14		0,2	High	Lock in fixed interest rates where possible	0,02	Low

	Interest Rate Fluctuations			Hedge against interest rate fluctuations using financial instruments		
				Regularly review and adjust financial strategies based on market trends		
R15	Material Price Volatility	0,2	High	Enter long-term contracts with suppliers	0,01	Low
				Diversify material sources		
				Use financial hedging strategies		
R16	Underestimated Operational Expenditures (OPEX)	0,2	High	Conduct thorough market and operational research	0,02	Low
				Include a contingency budget for OPEX		
				Regularly review and adjust OPEX estimates		
R17	Regulatory Hurdles	0,28	High	Engage with regulatory authorities early in the project	0,02	Low
				Hire consultants with expertise in regulatory processes		
				Maintain thorough documentation and compliance records		
R18	Impact of Regulatory Changes	0,2	High	Monitor legislative changes and adapt strategies accordingly	0,02	Low
				Develop flexible project plans to accommodate regulatory updates		
				Engage in industry advocacy to influence favorable regulatory outcomes		
R19		0,4	High	Conduct comprehensive environmental assessments	0,02	Low

	Environmental Regulation Non-compliance			Implement and monitor adherence to all relevant regulations		
				Train staff on compliance requirements		
R20	Legal Challenges from Communities	0,24	High	Engage with community leaders and stakeholders early in the project	0,04	Low
				Develop a communication plan to address community concerns		
				Prepare a legal defense fund		
				Offer benefits to the local community		
R21	Establishment of Maintenance Protocols	0,1	Medium	Develop comprehensive maintenance protocols	0,01	Low
				Regularly review and update maintenance procedures		
				Implement a tracking system for maintenance activities		
R22	Training Deficiencies	0,28	High	Design and implement a robust training program	0,02	Low
				Conduct regular training sessions and refreshers		
				Monitor and evaluate the effectiveness of training programs		
R23	Component Delivery Delays	0,28	High	Establish strong relationships with suppliers	0,03	Low
				Implement a rigorous tracking and follow-up system for deliveries		
				Maintain buffer stock of critical components		

				Identify and qualify alternative suppliers		
R24	Quality Control Failures	0,28	High	Develop and enforce strict quality control standards	0,02	Low
				Conduct regular inspections and audits of supplier processes		
				Train staff on quality assurance practices		
				Utilize third-party testing and certification for critical components		
R25	Community Resistance	0,12	Medium	Engage with local communities early in the project	0,02	Low
				Hold public meetings to address concerns and gather input		
				Develop community benefit programs		
				Provide transparent and continuous communication throughout the project		
R26	Indigenous Rights Issues	0,24	High	Conduct thorough consultations with Indigenous groups	0,02	Low
				Ensure compliance with all relevant laws and treaties regarding Indigenous rights		
				Negotiate agreements to ensure mutual benefits		
				Implement measures to protect Indigenous heritage sites and practices		
R27	Strikes and Labor Disputes	0,24	High	Foster open communication between labor and management	0,04	Low
				Negotiate and review fair labor contracts		

				Implement conflict resolution mechanisms		
				Monitor labor conditions and worker satisfaction		
R28	Safety Incidents on Site	0,4	High	Develop and enforce comprehensive safety protocols	0,04	Low
				Conduct regular safety training and drills for all workers		
				Conduct regular safety training and drills for all workers		
				Regularly inspect and maintain equipment and site conditions		
R29	Cyberattacks on Operational Technology	0,24	High	Conduct regular security audits and penetration testing	0,04	Low
				Train staff in cybersecurity best practices		
				Develop an incident response plan for cyberattacks		
R30	Data Breaches Impacting Stakeholder Trust	0,12	Medium	Implement strict data access controls and encryption	0,01	Low
				Regularly update and patch systems to fix vulnerabilities		
				Conduct regular data privacy training for employees		
				Establish a data breach response plan, including communication strategies		

Annex II

Table of results of the use of the Monte Carlo method

Table 66: Results of the use of the Monte Carlo method

Risk	Impact Parameter	Likelihood Parameter	Risk Score Outputs	Conclusion
Equipment Failure Risks	µ: 0.4 Min: 0.3 Max: 0.5	µ: 0.7 Min: 0.5 Max: 0.9	µ: 0.28 Min: 0.17 Max: 0.43	High risk, 100% certainty of high risk
Material Price Volatility	µ: 0.4 Min: 0.1 Max: 0.6	µ: 0.5 Min: 0.3 Max: 0.7	µ: 0.18 Min: 0.04 Max: 0.4	High risk, 71.33% certainty of high risk, 28.6% certainty of medium risk
Quality Control Failures	µ: 0.4 Min: 0.2 Max: 0.5	µ: 0.7 Min: 0.5 Max: 0.8	µ: 0.24 Min: 0.11 Max: 0.39	High risk, 98.6% certainty of high risk
Severe Weather Events	µ: 0.4 Min: 0.3 Max:0.5	µ: 0.7 Min: 0.5 Max:0.9	µ: 0.4, Min: 0.22, Max: 0.61	High risk, 100% certainty of high risk
Soil Stability Issues	µ: 0.8 Min: 0.7 Max: 0.9	µ: 0.5 Min: 0.4 Max: 0.6	µ: 0.4, Min: 0.29, Max: 0.52	High risk, 100% certainty of high risk

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