Solar PV Construction Project Delays and Mitigation Strategies to Enhance Projects Timeline Performance A case study from Dubai's Environment

أطروحة في مجال التأخيرات في بناء مشاريع الطاقة الشمسية الكهروضوئية
واستراتيجيات الحد من هذه التأخيرات لتعزيز أداء الجدول الزمني للمشاريع
دراسة حال من بيئة مدينة دبي

by

ABDULRAHMAN BASIL AL-KHALIDI

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ABSTRACT

Distributed renewable generation projects are currently taking the major focus worldwide since it acts as the key enabler to the advanced grid structures such as smart grids and Virtual Power Plants (VPPs). The solar PV project construction forms the main driver for the international ambition toward reliable and sustainable energy transition. The United Arab Emirates led the renewable energy deployment in the region since 2014 till 2022 with more than 2.5 GW of installed capacity. Dubai distributed energy sector took the lead with almost 300MW of installed solar PV capacity by the end of 2021 with the ambition to cover 75% of the emirate's energy mix by 2050. Such challenging targets will not be possible to materialize without optimizing project timeline management practices which will directly influence the deployment rates.

The fundamental project issue of having construction delays applies to the solar PV industry and impacts the deployment rates, this topic needs to be evaluated carefully to limit the sequential effect on the project's performance and the technology adaptability. This study looks to explore the actual delays in solar PV construction projects and consequently propose effective mitigation strategies to enhance the project's timeline performance. This case study targets Dubai's commercial solar PV industry using a quantitative data-collecting strategy and statistical analysis to draw the appropriate conclusion.

In conclusion, all analyzed case studies in Dubai's commercial scale solar PV construction projects were confirmed to be delayed by 43% on average. The detailed root cause analysis on the abovementioned delay contribution in Dubai's solar PV commercial scale projects resulted in four main delay categories starting with Site Condition Delays, Project Management Delays, Technical Design Delays and Logistical Delays. The study assessed the impact of each of these categories and proposed mitigation strategies to limit its occurrence in the future.

الملخص

تحظى مشاريع توليد الطاقة المتجددة الموزعة حاليًا باهتمام كبير في جميع أنحاء العالم لأنها تمثل عامل تمكين رئيسي لهياكل الشبكة المتقدمة مثل الشبكات الذكية ومحطات الطاقة الافتراضية (VPPs). يمثل بناء مشاريع الطاقة الشمسية الكهروضوئية المحرك رئيسي للطموح الدولي نحو انتقال موثوق ومستدام لمصادر الطاقة. قادت دولة الإمارات العربية المتحدة قطاع الطاقة المتجددة في المنطقة منذ عام 2014 وحتى عام 2022 بقدرة تركيب تزيد عن 2.5 جيجاوات. تولى قادة قطاع الطاقة في دبي زمام المبادرة بتركيب ما يقرب من 300 ميجاوات من التوليد الموزع بحلول نهاية عام 2021 مع الطموح لتغطية 75٪ من مزيج الطاقة الإنتاجي في الإمارة بحلول عام 2050 من الطاقة المتجددة والمستدامة. ولن يكون من الممكن تحقيق مثل هذه الأهداف الصعبة دون تحسين ممارسات إدارة الجداول الزمنية للمشاريع التي ستؤثر بشكل مباشر على معدلات الانتشار.

تنطبق قضية التأخير في مشاريع البناء على مشاريع الطاقة الشمسية الكهروضوئية أيضا وتؤثر على معدلات الانتشار التي يجب تقييمها بعناية للحد من التأثير المتسلسل على أدائها وقابليتها لإنعاش أسواق الطاقة المتجددة. تبحث هذه الاطروحة العلمية ماهية التأخيرات الفعلية في مشاريع بناء الطاقة الشمسية الكهروضوئية وتقييم تأثير كل من هذه التأخيرات ومن ثم طرح استراتيجيات للتخفيف منها او تجنبها لتعزيز أداء الجدول الزمني لكل مشروع. تستهدف دراسة الحال هذه قطاع الطاقة الشمسية الكهروضوئية التجارية في مدينة دبي باستخدام استراتيجية جمع البيانات الكمية والتحليل الإحصائي للوصول للنتائج المرجوة.

ختاما، تم تأكيد التأخيرات في جميع دراسات الحالة التي تم تحليلها في مشاريع بناء الطاقة الشمسية الكهروضوئية التجارية في دبي بنسبة 43٪ في المتوسط. أدى التحليل التفصيلي للأسباب الجذرية والتأخيرات المذكورة أعلاه في المشاريع إلى 4 فئات تأخير رئيسية تبدأ بتأخيرات بسبب حالة مواقع البناء، والتأخيرات بسبب طرق إدارة المشروع، وتأخيرات التصاميم الفنية والتقنية، واخيرا التأخيرات اللوجستية. قيمت الدراسة تأثير كل من هذه الفئات واقترحت استراتيجيات للحد من حدوثها في المستقبل.

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LIST OF ABBREVIATIONS

Acronym	**Definition**
AC	Alternating Current
APAB	As Planned vs. As Built
DC	Direct Current
DEWA	Dubai Water and Electricity Authority
DM	Dubai Municipality
EPC	Engineering, Procurement and Construction – Solar PV Contractor
FSR	Final Status Report
I	Current and measured in Amperes
kWh	Energy unit - Kilowatt Hours
kWp	Power unit - Kilowatt Peak
LOI	Letter of Intent
MESIA	Middle East Solar Industry Association
MMS	Module Mounting Structure
MNA	Middle East and North Africa
NOC	No Objection Certificate
PABD	Project As Built Duration
PABSD	Project As Built Starting Date
PAPD	Project As Planned Duration
PASPFD	Project As Planned Finishing Date
POD	Project Overall Delay
PV	Photovoltaics

QA	Quality assurance
TABFD	Task As Built Finishing Date
TABSD	Task As Built Starting Date
TABST	Task As Built Starting Time
TAPD	Task As Planned Duration
TAPFD	Task As Planned Finishing Date
TAPSD	Task As Planned Starting Date
TAPST	Task As Planned Starting Time
TASD	Task As Built Duration
TDC	Task Delay Contribution
TOD	Task Overall Delay
TWADC	Task Weighted Average Delay Contribution
UAE	United Arab Emirates
V	Voltage and measured in Volts

CHAPTER I

INTRODUCTION

1.1 Study Overview

Solar PV (Photovoltaics) economics have improved noticeably as the cost of solar panels and system auxiliaries have diminished sharply in the last decade, resulting in reduced need of grant's and allowing technology to race with other conventional energy (fossil fuels) generation technologies worldwide, which sooner or later will run, leading to the need for sustainable substitutes (Guerin, 2017).

The UAE, acting as the pioneering renewable hub in the MENA region, paved its way in meeting the climate changes by utilizing renewable energy strategies on federal, as well as emirates, levels. The UAE's 2050 Energy Strategy, in alignment with the United Nation's sustainable development goals (SDGs), aims to leverage 50% of its total energy mix to be attained from renewable sources resulting in forecasted savings of 700 million AED (u.ae, 2021). Nadimi & Atigheh Chian (2011), highlight the significant advantages that solar energy has, starting with the fact that solar irradiations will be available for the next upcoming millions of years hence why it is considered a sustainable source of energy. Additionally, solar energy is clean and abundant with zero pollution in the process of converting solar irradiation into usable electrical energy, which serves the international green energy transition. Finally, solar energy is considered as one of the safest sources compared to the conventional technologies.

Dubai took the leadership role in the renewable deployment among all other emirates, and consequently launched its clean energy strategy that aims to secure 7% of the emirate's peak load from renewables by 2020, which is planned to peak up to 75% by 2050 (u.ae, 2021). Dubai currently exceeded the 2020 target and had 9% of renewable coverage on the same year (Energy

& Utilities, 2020). Shams Dubai Solar PV program, which aims to inspire facility owners to install solar PV systems over the rooftops and help inject the surplus energy, when available, to DEWA's network under the Net Metering scheme, helped Dubai materialize such ambitious targets.

MESIA, (2021) reported that Dubai had more than 5,600 Solar PV rooftop projects with total capacity of 300+ MW by the end of 2021 under Shams Dubai Program. From initiation to completion, the bulk of rooftop solar PV projects in Dubai follows the same path; Starting from project development up until operations and maintenance. Each phase offers its own set of resources and tools to aid the successful implementation of the project (US EPA, 2018).

This study aims to explore the actual delays in solar PV construction projects, find the root causes of delays, and consequently propose effective mitigation strategies to enhance the project's timeline performance. This case study targets Dubai's commercial solar PV industry using quantitative data collection strategy and statistical analysis to draw appropriate conclusion.

1.1.1 Solar PV Projects Classifications

According to their installation capacity, solar PV projects can be Stratified primarily into three types: utility-scale projects, commercial projects, and residential projects. The size of these PV systems is essentially what makes a difference, with residential projects often being between 3 and 10 kWp, commercial projects typically being between 10 and 2 MWp, and utility-scale projects typically being over 2 MWp (Fu et al., 2016). Additionally, rooftop systems are the primary focus of residential solar PV projects, whereas rooftop systems and ballasted racking are included in commercial projects. Utility-scale projects include ground-mounted solar PV farms with fixed-tilt or single-axis tracking systems. The three primary circumstances in which the construction might be done are referenced in literature. These would consist of a sizable new utility or building, new residential areas, and the refurbishment of the building, which make up the final scenario. Building new and modern structures that would satisfy the organization's new requirements and sustainability objectives or remodeling an existing structure to modernize the facility and install solar PVs, are the two most common combinations in commercial PV construction. If the project is taken into account on the assumption that upgrades are made to the existing structure, then additional upgrades will need to be made, such as improving the current steel structure and various supports (Alghamdi, 2019). The main The main reason behind this issue is that the majority of the existing of the existing building structures did not take into account the extra weight distributed across numerous structural points during the solar PV installations and the additional loading that would be put over it.

1.1.2 Project Schedule Management in Construction Industry

The project's timeline performance over the course of the project management cycle includes the task's anticipated beginning and finishing dates. The project managers shall assess and analyze the projected schedule, percent completion, and overall work duration on a flexible time basis based on the project’s complexity and demands (Lawrence, 2015). Lekan and Dosunmu (2017) claim that poor planning, incorrect estimates, inadequate financing, changes in scope, and payment delays are the main causes of project timeline delays and budget overruns.

Additional consideration of the primary aspects that effect both time and cost performance has been proposed by Ismail, Aftab, Sasitharan, and Qadir (2012). They discovered that design changes had the most impact, followed by changes in how financial resources are managed as a result of the acquisition of resources, payment delays, and contractual difficulties. The Critical Chain Method, one of the techniques used to perform Network Schedule Analysis, evaluates the present project's stage based on the differences between the current time and projected completion time (PMI, 2008). The entire float variation must be taken into account in order to evaluate a project's effectiveness. Two well-liked project management systems, MS Project and I-task can be used to monitor planned and actual completion dates as well as foresee the effects of schedule adjustments.

According to Chin & Hamid (2015) and their 2018 article, "Cost and Time Risk Management in Construction Projects," time management is the practice of recording and controlling the amount of time that each employee spends on each task. A project is thought of as a collection of several tasks that entail planning, managing, and monitoring. Time and money are regarded as the success criteria in project consequently making time management skills an essential building block for projects.

1.1.3 Construction Project Delay Analysis Methodology

Construction delays are described as the act of going over the contractually agreed project completion date by more than anticipated. They can be related to a specific task that was supposed to be done within the given time limit but was not because of unanticipated events (Durdyev & Hosseini, 2020; Marzouk & El-Rasas, 2014). The majority of construction construction projects face the largest obstacle of delays, which frequently results in disputes or lawsuits. The delay analysis methodologies can be applied to estimate the effects of any delays that may occur. Numerous data analysis approaches have been created throughout the years. Analysis of delays is consistently thought to be difficult. The various analysis methods may be divided into prospective and retrospective methods, where the former examines the project's future while the latter focuses on the part of a completed events. The same objective of measuring project delays is pursued by both methods. The paragraphs that follow address these strategies, their potential, and their drawbacks.

1.2 Research Problem Statement

The solar PV projects in Dubai experienced an increased interest by public and private sectors since Shams Dubai program launching in 2014 to serve the national renewable targets which are tightly linked to critical timelines. The investigated literature review was focused on utility scale renewable projects with limited insight on solar PV cases. Additionally, the investigated cases didn't interact with similar environment to GCC (Gulf Cooperation Council) or UAE (United Arab Emirates including Dubai.

It is vital to raise awareness levels among the solar PV industry professionals about the delay causes and how to mitigate them as well as the amount to which it can impair the project's timelines (severity). Henceforth, while the past studies conducted in other geographical areas with different regulatory regimes and generic renewable scope rather than addressing Solar PV projects, a gap was identified on the delay causes in Dubai's Solar PV construction projects and how to mitigate such delays to enhance the project's timeline performance.

1.3 Research Aim and Objectives

1.3.1 Research Aim

Renewable projects in the developing economies usually experience cost overruns, time delays and at times project terminations which leads to profitability loss for the project developers and owners (NTWARI, 2019). However, delays are one of the most common hurdles in construction projects and have a significant impact on projects, stakeholders, and the industry as a whole. Therefore, the aim of this research is to have a clear understanding about solar PV construction project delays in Dubai environment to improve the project timeline performance.

1.3.2 Research Objective

The growing interest in photovoltaic systems and governmental backing regulations in Dubai encouraged facility owners to install solar PV systems to meet their energy needs and to protect firms from the potential tariff cost fluctuations in the future, given the energy price volatility worldwide. Hence, completing projects within the projected timelines will have a direct impact on the national renewable target plans as well as the investors energy cost saving due to solar contribution.

The objectives of this study are:

- Identify and evaluate the Solar PV construction project delays
- Identify and evaluate the root causes in each task of the selected case studies
- Propose delay mitigation strategies for the identified delay root causes to limit its occurrence in the future

1.4 Research Questions

This research answers the below research questions in the aim of achieving the project's objectives:

- What delay durations does Dubai solar PV projects experience during the execution stage?
- Which project task in Dubai's solar PV construction projects imposes the most significant delay impact?
- What are the key delay root causes in each of the selected projects?
- What are the strategies that could be adopted to overcome the identified delay causes?

1.5 Dissertation Organization

This dissertation report is organized into five main chapters in order to achieve the anticipated dissertation objectives. Below is the summary of the content of each chapter:

The first chapter gives a brief overview about the research prime idea related to the solar PV commercial scale construction projects and the key research guidelines that are adopted in the study.

The second chapter presents the key findings of the available literature to aid the comprehensive understanding of the research. The chapter starts with solar PV project categorization then differentiate between the construction industry projects, then tackles the delays management side and how mitigation strategies are formulated.

The third chapter presents the research methodology where the data inputs are explained in the form of real-life case studies, how the analysis will be conducted, and finally the anticipated outcomes.

The fourth chapter details the selected case studies and analyses each one separately in terms of project nature, schedule man agent, delays severity, and root cause analysis.

The fifth chapter summarizes the research's overall outcomes on how the delays impacted Dubai's commercial scale solar PV construction projects and gives the final research recommendations.

CHAPTER II

LITERATURE REVIEW

This chapter looks into the literature review of solar PV construction projects and the project management aspects to explore the previous work done to aid the study's objectives.

2.1 Categorization of Solar PV Projects

The solar PV Projects are energy generation projects and are classified mainly into three categories based on the installation capacity: residential projects, commercial projects, and Utility-scale projects. The difference is primarily linked to the size of these PV projects, starting with residential projects which ranges from 3-10 kWp while commercial projects range between 10 kWp to 2 MWp, and finally the utility scale project with over 2 MWp (Fu et al., 2016). In addition to this, the residential solar PV projects are primarily limited to rooftop systems, while commercial projects include rooftop systems and ballasted racking. The ground-mounted solar PV farms, either fixed-tilt or single-axis tracking systems are classified as utility-scale projects. The literature mentions three main scenarios under which the construction could be carried out. These would include a large new utility or building, new housing areas, and the last of the scenarios would consist of the renovation of the building. When it comes to commercial PV construction, the combination that is primarily seen is building new fresh structures that would meet the organization's new requirements and sustainability needs, or it could be renovating the building that would upgrade the facility to add the solar PVs. Suppose the project is considered under the scenario where upgrades are made to the existing structure, then other upgrades must be undertaken, including upgrading the current steel structure and different supports if these are present and an upgrade is required (Alghamdi, 2019). The main reason for this is that most of the existing building structures did not consider the additional loading that would be mounted over the it and the extra weight across multiple structural points during the solar PV installations.

The literature showed more focus on the commercial and utility scale projects compared to the residential ones due to its significance in terms sustainability targets and cost impacts, it is mentioned that PV projects undergoes almost similar phases till operations, which include (Gevorkian, 2011), (Mittal & Gorowara, 2020):

- Phase I: Project feasibility assessment (including site survey and preliminary analysis)
- Phase II: Project tendering process and contract awarding
- Phase III: Detailed design finalization
- Phase IV: Construction phase
- Phase V: Commissioning and testing (utility and project owner)
- Phase VI: System operation and maintenance

The first phase assesses the feasibility and possibility of the project to be executed. This includes the Environmental and Social Impact Assessment (ESIA) to see how the construction would impact the local environment. The preliminary assessment would provide an overview of what the project expects to achieve and establish the goals and objectives. This phase is critical as Solar PV projects do not work in every area, and there are specific guidelines to be met to ensure the project is viable from both technical as well as financial point of views (Akkas et al., 2017; Arán Carrión et al., 2008; Kereush & Perovych, 2017; Uyan, 2013). Some of the factors to be considered with the site survey include the solar energy yield potential, which measures the annual solar irradiation in the area or the site (Akkas et al., 2017). The second is the connection capacity of the feeder that has been allocated. Under the situation that it is not a green project but an upgrade, then area or building design, along with the slopes in the building and how the building is placed, and what obstacles are around the building all these factors are to be considered in the site survey. All the above factors have a significant impact on the efficiency and quality of the system. Thus, a project feasibility assessment is critical to the success of the project. Factors like solar irradiation at the project location, air temperature, and slope all have been identified to play a vital role in ensuring the system's efficiency. Figure 1 lists factors that are considered technically critical in the feasibility phase to ensure efficiency and dictates the construction requirement. (Al Garni & Awasthi, 2017).

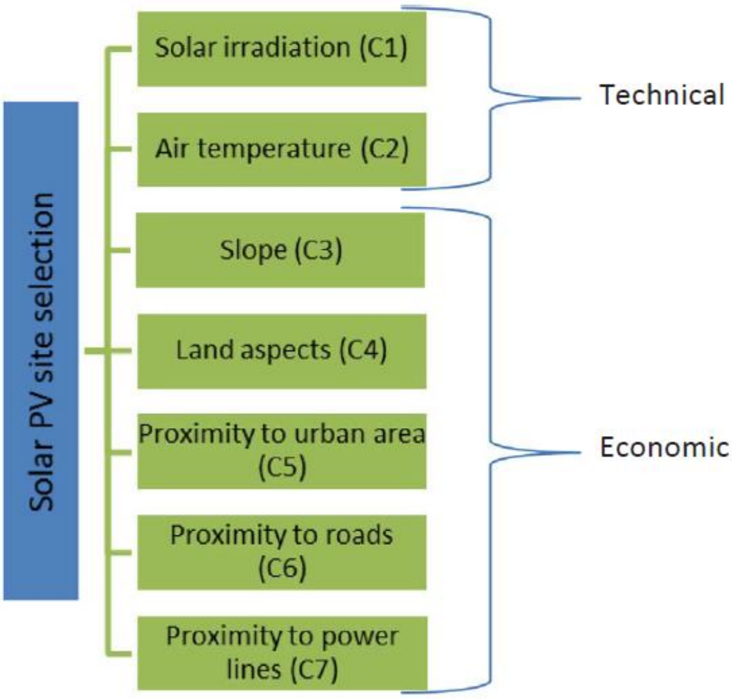


Figure 1: Solar Site Selection Criteria

(Al Garni & Awasthi, 2017)

The next step in the feasibility study includes calculating the required operating parameters of the new PV system. This is carried out with the help of consulting engineers (van Vuuren et al., 2019). The feasibility research would provide an in-depth report regarding the energy potential of the project. The architects also use this stage to design solutions and possibilities that could be used that would allow for the optimal design of the retrofitting or new building, which would be in tune with government regulations that have been established. For new installations, the feasibility studies would form the guidelines on which the building design would be built, which means the parameters identified in the feasibility study would influence the overall architecture of the building. One of the primary feasibility checks to be carried out in the solar PV commercial projects is analyzing its electrical network. Some of the factors that need to be considered under such technical evaluation would include (van Vuuren et al., 2021):

- Consumption Analysis: that includes technical analysis for the expected consumption compared to the solar generation to meet the regulatory requirements such as feed in tariff or net metering or self-consumption scheme.
- Grid infrastructure compatibility: checking the current electrical network status and if it needs to be renovated to meet the new system connection.
- Regulatory compatibility: checking the guidelines and regulations for the different project aspects such as the maximum capacity and connection scheme

In addition to the technical evaluation, other evaluations that check the economic, environmental, and organizational feasibility are undertaken. In addition to this, a risk assessment would need to be carried out though it would be done in the project's planning phase once a contract is signed. It has been seen that most of the risks that have been identified in the literature as expected risks have often been experienced in the field during the construction stage. Many risks range from the environment and community risks and regulatory risks that are to be considered for the project and the unexpected dangers during the construction of the projects (Guerin, 2017). As the tasks become more extensive, the complications are more, and the number of risks and unforeseen factors impacting them is also increasing.

The second phase is the tendering process, which calls for construction or development firms to provide their bids to undertake the project and complete it based on the guidelines and requirements (van Vuuren et al., 2019). It can be an open tender or selective invitation tender. Once the tender is invited, the client company would be able to choose based on the presentations made by the bidding company that could consider financial aspects and technical, aesthetical, and functional features of the proposed facility. The reliability of the company and its past projects could be viewed as measures to understand the capabilities and choose a company accordingly. Ensuring the performance of the solar PV system throughout the life cycle of the solar PV is critical, and the maintenance and quality guidelines are also to be established at this stage (Basson & Pretorius, 2016; Gevorkian, 2012).

The next step is where the contract is awarded to the preferred bidding Company. There are factors like costs, quality, yield guarantees, and the project's timeline considered before the project is awarded. Once the project is given to the selected company, negotiations would occur between the two parties to minimize the project duration and reduce the overall cost while maintaining the requirements of quality and functionality and resolving any other relevant issue identified (Gevorkian, 2011). A legally binding agreement is signed between both parties, including all the agreed-upon guarantees. In addition to this, a Service Level Agreement (SLA) would be a contractual agreement between the two parties for maintaining the system after it has been commissioned. The conditions of the SLA, like the duration and what services would be included, are often decided in the negotiation phase of the project (Cavinato et al., 2006).

The third phase is where the overall detailed design for the project is developed. The requirements had been established in the contract, and the design changes were made from the initial tender proposal to meet these requirements in alignment with the regulatory requirements. The next phase would be construction phase where the detailed designs see the light through actual implementation. This phase includes the procurement of the approved equipment then followed by the mechanical and electrical installations until the utility point of connection. This phase is carried out by the Engineering, procurement and Construction companies (EPCs) (Mittal & Gorowara, 2020).

Once the systems are connected, then phase V for commissioning and testing starts. This phase includes client as well as grid service provider testing such as inverter commissioning, Harmonics verification, performance ration assurance, insulation resistance testing, polarity testing and current voltage (IV) curve testing. Additional testing and verifications could be carried out by the contracted company to ensure that the construction and installation carried out have been in line with the regulation and within the manufacturer's requirements. Once the commissioning is completed, the solar project will be ready for Operations and Maintenance (O&M) phase handover which constitutes the VI phase. The ownership is then transferred to the project owner, and in case the company has agreed to an SLA, they would be involved with the maintenance and ensuring that the operation of the PV system is going as expected at the agreed performance methodology. Routine maintenance would be done to ensure no breakdown and that all solar panels would be effective (van Vuuren et al., 2021). This section thus has explored the different phases in commercial solar PV construction.

2.2 Distinguishing Factors Between Solar PV and Traditional Construction Projects

There are significant differences in how the traditional and solar PV construction projects are being executed. Multiple varying requirements shall be considered in the decision-making. Some of them include:

- Tax exemptions
- Site selection

- Technical Capabilities
- Risks
- Increased communication requirement
- Feasibility analysis

One of the main differences would be the tax exemptions provided to solar PV projects, which are not available in regular construction projects. As per the KPMG survey on the policies and regulations on countries for renewable energy projects, it can be seen that the government provides incentives for solar projects, which is a part of the renewable energy project (Behrendt, 2015; KPMG international, 2013).

Another critical difference is the site selection. In the past, it has been said that the decision of the sites was based mainly on the financial and technical requirements of the project. Some of the main factors considered in the traditional construction site selection for commercial buildings are summarized in Figure 2 based on a study conducted to analyze which elements were crucial.

Figure 2: Factors influencing site selection

(Rikalovic et al., 2014)

The GIS method has been used to identify the most suitable site for commercial construction, which governments also use to develop industrial cities (Taibi & Atmani, 2017). The standard projects also conduct the study of the soil for the feasibility of the project and the firmness of the ground that would allow the construction or act as a barrier. While in the case of the solar PV construction projects though the factors in Figure 2 are critical, there is an increased need to focus on the geographic location of the site. Infrastructure availability, land cost, ecology, and climate are essential factors for both projects. Still, the site's selection criteria for solar PVs are also influenced by different social and environmental factors, as mentioned in the previous section. These factors would include annual irradiation, which would allow an understanding of the amount of solar power availability in the squared meter at a particular site. Other factors like the slope of the land, wind speed, air pressure, air humidity, surface temperature, and air temperature are to be considered when choosing the location as the efficiency of the solar cells depends on these selections (Türk et al., 2021). Thus, the site survey and study need to be more elaborate for solar PV construction than traditional construction. The design of the building would also be based on the solar PV type and how it needs to be installed, which means complete freedom will not be available for construction building designers to build in any shape. Like the site selection, measures must be taken to ensure that the solar panels can be placed at the correct height and angle to ensure optimal operation.

In addition to this, solar PV construction or renewable energy-based construction, in general, is considered an area where more technical knowledge is required to ensure the safe installation of solar PV cells. Unlike traditional projects where skilled labor is not highly needed, solar PV construction has specific guidelines and processes required to be carried out to ensure efficiency and quality (Bas et al., 2022). This means the project is to be done with more care and thus requires laborers who have undergone sufficient training to provide the best practices and follow the guidelines. The occupational risks that are associated with solar projects are also higher. These risks would include, falling from heights, heat stress, and electrical hazards the workers face when undertaking the solar PV project (Duroha et al., 2020; Duroha & Macht, 2021). The guidelines also cover the safety of the workers, but these require specific tools and uniforms, which make them different from standard construction projects. Other risks are considered for solar PV projects, like procurement risks (Guerin, 2017). The cost of the solar panels is reducing significantly, but these vary based on the change in demand, which means the variation could increase or decrease the project's overall cost (Barker, 2013; Vidyanandan, 2017). More decisions are required regarding the different components, primarily technical feasibility analysis and requirement checks that are often not considered in traditional projects. The conventional projects, the choices can be varied to include innovative systems. Still, the power calculations and other electrical component decision-making rely on the Solar PV construction feasibility analysis and not just the requirements. Figure 3 provides an overview of the different assumptions and costs drivers, inputs, and outputs of the solar PV model and the related cost categories (Fu et al., 2016).

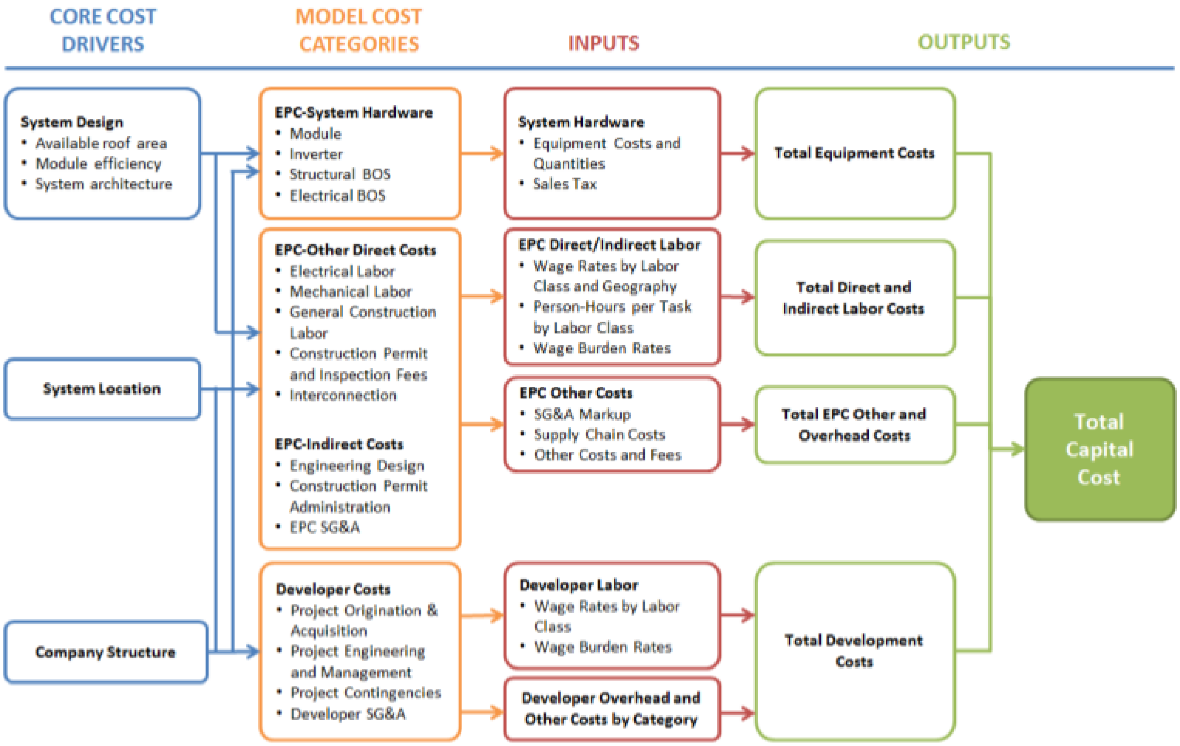


Figure 3: Commercial Solar PV model structure as per NREL

(Fu et al., 2016)

In solar PV construction, there needs to be increased communication with the utility companies to facilitate the integration of the project into the grid. Additional controls need to be placed to ensure the extra power is not sent to the primary grid or if there need to be intelligent systems to control and sell power (Azzopardi & Mutale, 2009; Duan & Deconinck, 2010), which is not considered in a traditional project. In solar PV construction, two-way communication or transfer of information is critical to facilitate improved metering in compliance with the grid requirements. The standard construction projects could require just the routine feasibility check and regulations that are to be considered that have been established for city contracts which means that there are strict guidelines on how each activity is to be carried out along with how much resources are sued like how much cement should be sued for each building block and many other such conditions that are to be satisfied. Compared with commercial solar PV projects, if it is a green project, then the building construction and solar PV construction guidelines are also used to find the optimal building design. Overall, more challenges are seen and more complications with Solar PV construction than traditional construction projects.

2.3 Barriers to Solar PV Construction

The literature available points to many barriers that limit the adoption of PV systems. These can be categorized under four dimensions which are socio-technical, economic, policy-based, and management (Karakaya & Sriwannawit, 2015). The technology for renewable energy sources is considered highly challenging, and the complexity leads to multiple connected factors. Some of these barriers include:

- Sociotechnical barriers
- Management barriers
- Policy barriers
- Economic barriers

Below section elaborates on each category in details:

2.3.1 Sociotechnical Barriers

Though there has been tremendous growth in PV systems technology in the recent decade, many barriers to this adoption fall under the sociotechnical category. One of the factors that are said to impact is the quality influenced by the local conditions where the project is undertaken (Müggenburg et al., 2012). There are also issues with the political and financial arrangement that affects the quality and the variation seen from country to country. An example of this can be seen in the study carried out by Palit (2013), who mentions that the quality standards used for the construction of PV systems are higher in emerging energy markets like India and

Bangladesh (Palit, 2013). Palit states, “In the south Asian region, India and Bangladesh have higher quality standards established for PV systems compared to other countries in the region.” On the other hand, D’Agositon et al. (2011) mention, “China has a high level of dissatisfaction caused by the low performance of the solar home systems.” It adds “The disappointment is not just due to the technical functionality but also because the repair locations are too far.”

The lack of knowledge that is present between the adopter and the non-adopters is considered to be a barrier too. The lack of knowledge among adopters would mean that there would be improper use of the system, creating a perception that is harmful to the system’s adoption (D’Agostino et al., 2011). In another study focusing on rural areas of Nicaragua, the people were very unaware of the PV system, which acted as a barrier (Rebane & Barham, 2011). A study undertaken in Austria mentions that lack of knowledge is a challenge not just on the adopter side but also on the supply side. It is said that the architects or planners often do not have complete knowledge and use different systems that fail or do not provide the required efficiency leading to mistrust in the system (Koinegg et al., 2013).The perception of the individuals is also said to play a crucial role as most feel, based on a survey done in the US, that the systems are complex and risky (Drury et al., 2012). The climate of the region is also considered to act as a barrier. Like in the US, the energy is different, and it varies from state to state, making the PV system suitable only in specific locations (Sarzynski et al., 2012). The technical site requirements also act as a barrier to the adoption. In the case of big cities like Hong Kong, the space required for the installation also becomes a challenge and acts as a battier (X. Zhang et al., 2012). Thus, the inadequate space available for installation is another critical barrier.

The local institutional dimension also acts as a barrier to specific countries. Like Bolivia, which relies on foreign financial aid, they are not in a position to do these projects unless they gain support from the foreign countries (Pansera, 2012). Thus, countries lack of financing funding or growth hinders the adoption. Another factor is the lack of electricity demand (Ondraczek, 2013). This could be due to the lack of requirements as there are minimal activities that need electricity, or it could be due to a lack of the customer base. Without the demand, the requirement for the system is not there, which becomes a barrier to adoption.

2.3.2 Management Barriers

When it comes to the management barriers, inappropriate business model adoption is a critical factor to technology adoption. Business models used in urban areas will not be helpful in rural areas with lower capacity and purchasing power (Palit, 2013; Pode, 2013). The companies need to market according to the requirement of each market instead of dumping the available products. Another barrier is the poor after-sales service provided by the companies. Without a solid after-sales service model to deal with the challenges, people would be reluctant to adopt the PV systems. If there is a need for maintenance, the lack of a service team could disrupt the system's use and lead to many downtime days (Palit, 2013). The existing infrastructure in the country could also play a role in the adoption, or it could act as a barrier. In a study that compared Japan to the Netherlands, it was found that Japan had better innovative capabilities that would support the PV systems (Vasseur et al., 2013). On the other hand, in the Netherlands, there is a lack of information sharing between developers and policymakers, which hinders the adoption.

2.3.3 Economic Barriers

When economic barriers are mentioned, it is often referring to the high cost of adoption for the PV modules. There is also the situation where other renewable energy systems could be available at a lower price (Sarzynski et al., 2012), leading to people choosing the more affordable solution like Wind Energy, which is significantly cheaper (Junior et al., 2019).

Another economic barrier has been seen to be the local challenges linked to the economy, like the financial crisis in Greece, where the banks are not willing to provide people with loans to adopt such systems (Karteris & Papadopoulos, 2013). Pode (2013) mentions that the low purchasing power in various countries is a barrier due to the high investment required for the projects. The lack of suitable financing mechanisms available in countries or the capability to provide such tools to businesses and citizens is a significant barrier that has lowered the adoption possibilities (Palit, 2013). The long payback period is also a cause of concern for many.

Kappagantu, Daniel and Venkatesh (2015) present how the rooftop solar PV projects could be adopted by governments to achieve strategic targets while endorsing fledged energy structures such as smart grids. The study presented that despite the high interest of participants to adopt solar PV rooftop project, the financial as well as the regulatory aspects of the projects constituted the main barriers for the project adoption. The upfront capital investment and the Levelized Cost of Electricity (LCOE) formed the bases of the investors to analyze the payback periods followed by the governmental electricity injection schemes of the surplus energy to the grid.

2.3.4 Policy Barriers

Though many countries have provided policies that support the adoption of renewable energies, some countries have shown that removing this policy support could send shock waves. One such example was seen in Spain, where an example was given that indicated the negative impact when the policy regarding the subsidy of the feed-in tariffs after the solar PV was adopted was reduced by the government (Brudermann et al., 2013; Movilla et al., 2013). Ineffective and insufficient policies could also act as a barrier. In the Netherlands, inconsistencies in the national subsidy led to the investors being discouraged regarding the adoption of the PV systems (Vasseur et al., 2013). The lack of proper support and participation between the different stakeholders in the project is also a barrier. Based on the study in Hong Kong, there was a lack of involvement in policy planning and a lack of incentives that would promote the adoption (X. Zhang et al., 2012). Without adequate and complete support and communication with all stakeholders, the process is inefficient. Overall, we have seen the different types of barriers to the adoption of PV technology.

2.4 Construction Project Timeline Management in Construction Industry

In the solar PV projects, project management is a demanding process carried out in practice by project managers, who track progress regularly, analyses plans, and take remedial action as needed. The goal of project management in the construction industry is to ensure that the project is completed on the agreed timeline and with the least cost variation possible while meeting the project objectives (Muneer, 2011).

The task’s expected starting and ending dates are part of the project's timeline performance throughout project management cycle. On adjustable time bases, depending on the project complexity and needs, the project managers must evaluate and compare the estimated timeline, percent completion, and overall work duration (Lawrence, 2015). According to Lekan and Dosunmu (2017), the primary reasons of project timeline delays and budget overruns are caused by lack of funding, poor planning, inaccurate predictions, changes in scope, and payment delays.

Addition consideration on the primary aspects that effects both time and cost performance has been proposed by Ismail, Aftab, Sasitharan and Qadir (2012). They found that the most significant affect is due to design adjustments, followed by management of financial resources which is resulted from resource procurement, payment delays and contract challenges. One of the methods that is used to perform Network Schedule Analysis is the Critical Chain Method (CCM) where the current project state is assessed based on the difference of buffer between the current time and the anticipated completion time (PMI, 2008). In order to measure the success of a project, the total float variance must be considered. MS Project and I-task are two popular project management tools, let could be used to keep track of planned and actual completion dates and anticipate the impact of schedule revisions.

Time management is considered as the process where the time spent on each activity by all the staff members who are part of the activities is recorded and controlled (Chin & Hamid, 2015; "Cost and Time Risk Management in Construction Projects," 2018). A project is deemed a collection of different activities, and the management of a project involves planning, managing, and monitoring. In project management, time and cost are considered the success parameters. Effective time management is considered to be critical for construction projects. Based on the PMBOK for time management, there are six standard processes for all the traditional projects, but for construction, the PMBOK, suggests the addition of three more activities (PMI, 2016). The nine activities are:

- Definition of activities
- Sequencing
- Resource estimation
- Duration estimation
- Schedule development
- Controls
- Activity weights
- S-Curve Development (Progress)
- Progress Monitoring

These activities could overlap during the project lifetime, or they could be run simultaneously. To better control the different phases, other authors have focused on reducing the number of processes to five: schedule management, time reporting, task changes, time approval, and reporting (McGraw & Leonoudakis, 2010). Schedule management is critical, and often, tools like Business Information Modelling (BIM) have been used to improve the schedule management capabilities of the construction (Barlish & Sullivan, 2012; Koseoglu & Nurtan-Gunes, 2018). BIM is a tool used even in complex projects and uses agile construction principles due to its ability to provide the required control and monitoring of projects (X. Li et al., 2017). Based on various studies, schedule management has been shown to impact the overall effectiveness of the project (Suresh & Sivakumar, 2019). Project scheduling allows tracking each activity and monitoring them to ensure that the project is on-time. At the same time, the scheduling also allows for a better understanding of the different activities in the project and how much duration would be required for each of these activities. The schedule thus created allows all stakeholders to be aware of their role in the project and assigned activities. It also provides for improved coordination among the different departments and stakeholders. It will enable the identification of critical activities that can be more important and monitored than the other activities. Schedule management allows for better control and allows the project owner to delay claims if required due to construction delays.

2.5 Project Delay Analysis Techniques

Delay in construction is said to be the overrun in time beyond the contractually agreed project completion date or could be linked to a particular activity that was completed in the specified time frame but was not completed due to some unforeseen circumstances (Durdyev & Hosseini, 2020; Marzouk & El-Rasas, 2014). Delay is considered the biggest challenge in all construction projects and often leads to disputes or claims. If a delay happens, the delay analysis techniques could be used to help quantify its impact. Over the years there have been different data analysis techniques have been developed. Delay analysis is always considered to be challenging. Over the years, various methods have been used in analyzing the delays and finding the impact and details behind those delays. The tools used for delay analysis are also often decided before the contract is agreed upon between the two parties. It could be written contractually, or it could be mutually agreed to use a particular technique. It is found that each delay analysis technique is said to have a different level of capabilities when it comes to providing the users with accurate results regarding the delay (Abouorban et al., 2018; Braimah, 2013; Shahsavand et al., 2018).

The analysis techniques could be summarized into prospective and retrospective techniques respectively, where the earlier considers the forward view of the project while the later investigates the backward view after the project is finished. Both techniques target the same goal of quantifying project delays. Below paragraphs explore these techniques and their capabilities as well as limitations.

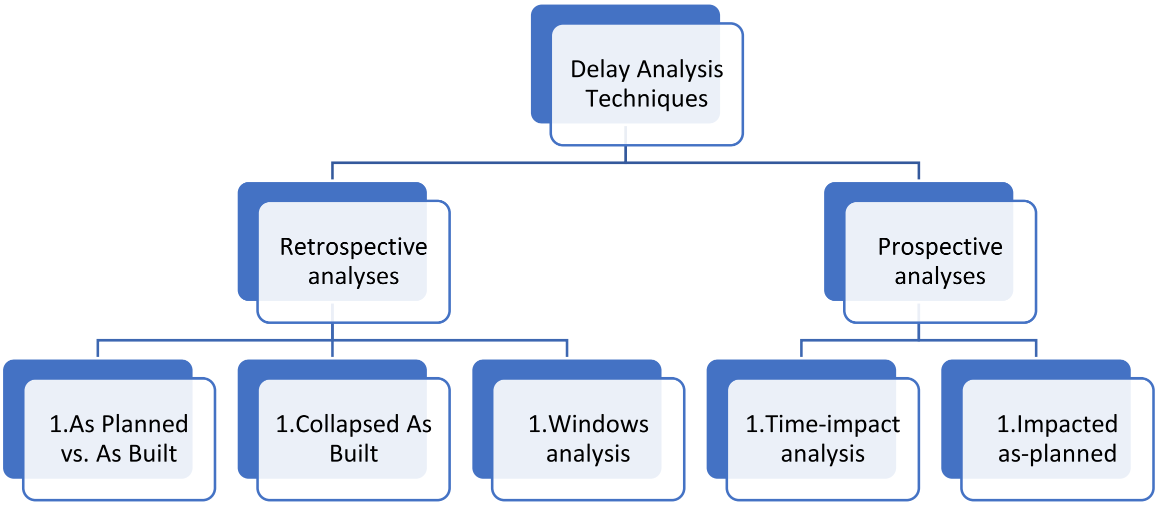


Figure 4: Delay Analysis Techniques

The first method is called the As Planned versus As Built delay analysis method. This tool compares what was planned in the project initial phase and what has happened actually in simple terms. The measure of the activities is undertaken based on the initial planned schedule or the most recent schedule plan where the changes or time frame has been updated due to a change. Under this technique, the different delaying events present in the projects are depicted in the As Built schedule. The delay-based activities are compared with As Planned completion dates, and the difference is calculated, which would be the difference in program tasks or delays. The observational technique is prevalent in the construction industry and is the most widely used tool for the delay analysis technique (Lyasko, 2008). The ease of use of these techniques has highlighted their attractiveness as it is mainly reliant on common sense. In most construction scenarios, construction contractors and consultants ranked the lack of proper project timeline records as the most predominate obstacle encountered in calculating delays.

Still, in the case of this method, there are no such issues as it relies on the start and finishes dates that were planned and that happened (Ghimire & Mishra, 2019; Ndekugri et al., 2008).

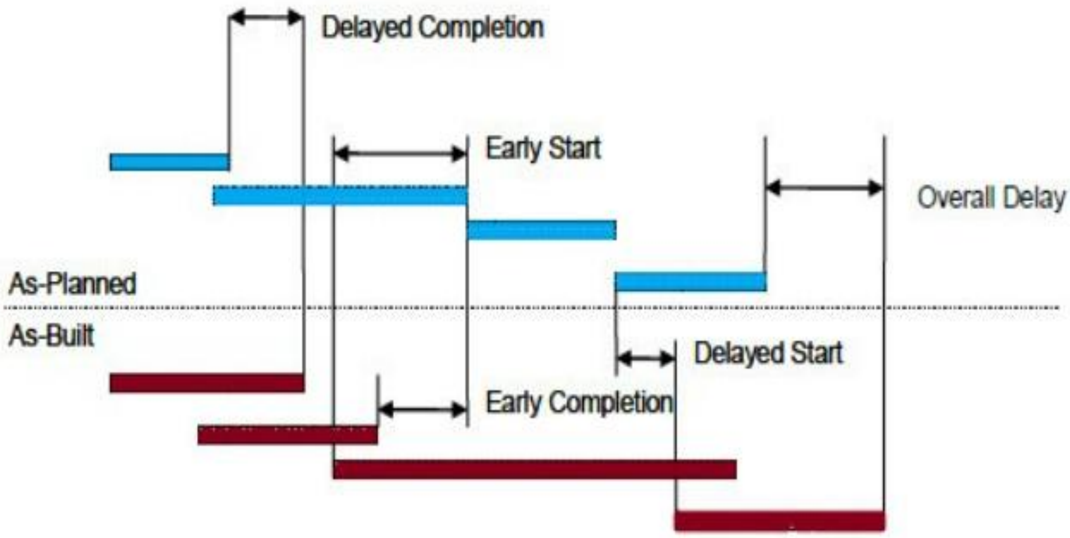


Figure 5: As Planned vs. As Built

(Vertex, 2020)

The main concern regarding the technique or limitations is that the method often does not scrutinize the delay and the type of delays, making it easy to be distorted to the bias of the individual carrying out the analysis. Another limitation of such a tool is that the overall dynamicity of the CPM is ignored, along with the changes in the scheduling system based on agreed modifications made by the two parties (Braimah, 2013). There is also no focus on understanding how each of the said delays would impact the project, and the technique is said to make use of all the net delays, including the identified delays in the non-critical paths.

Collapse As Built technique is considered as a retrospective tool that would start with an As Built schedule. Then it would slowly remove the activities that would represent the delays or make changes to the activities that would influence the completion date. The tool is often used in situations where the information regarding the As Built schedule is available, and the baseline schedule or the update schedules are not available or unreliable to provide an accurate analysis. This technique would involve the identification of the different delays in the project and the changes. The other activities linked to the changes and delays would then be subtracted from the overall schedule (Muhamad et al., 2016). This would result in the collapse of the program hence the name. The resultant schedule with the activities subtracted would demonstrate when a project should have been completed. It also analyzes and provides information on the different delays that caused the slowdown, what type of delays at which activities, and what changes were made can be gained from this analysis. The major limitation of this tool is that it fails to consider the dynamic characteristics of the project and its critical path. The tool is also highly subjective and easy to manipulate as required (Muhamad et al., 2016). Some of the other shortcomings of the technique are said to include (Braimah, 2013):

- In this type of analysis, the tool user must insert after-the-fact logic ties that would not reflect the actual values of the project executor.
- The removal of the delays could create a more unrealistic schedule
- This tool requires experience and capability to better judge the schedule, making the use of the tool a challenge.
- The circumstances due to which the delay occurred, and the dynamicity is often disregarded in this tool.

The next retrospective technique used for delay analysis as a would be the Window Analysis. The technique is different from others because it has an interim assessment of the delay for the updates made to the schedule at various intervals in the project. In this technique, at first, the complete project duration would be segmented into the different periods based on the planned changes or based on the milestones that have been established for the projects (Braimah, 2013). This division creates windows or snapshots of the project and based on this, the schedule within each of the windows would be updated that would reflect the actual duration as well as the sequence during the time of delay, while the remaining windows which are not a part of the current delay are not considered and kept as is. The analyses are carried out, which would help determine the delays and impact and develop a new date for completion. Then, the comparison is carried out for the new date calculated and the planned date just for the window period. The significant advantage of this technique is that it simplifies a complicated network into separate windows, making it manageable. It would also consider CPMs dynamicity, which is not considered in other tools (Braimah, 2013). That said, the method, even though it is deemed to be effective and accurate in its result, has several limitations. One major limitation is the time consumed, the cost involved in operating this tool, and the depth of information required. Another limitation is based on the fact that the difference in periods could impact the results and can vary. The periodic updates do not exist, leading the expert or analyst to carry out a more complicated analysis of the records to charter the update (Braimah, 2013).

The first prospective technique is the Time Impact analysis which is a critical path method used to determine to what extent an impact caused as a result of a change or delay in the project would have on the overall schedule or project timeline (Muhamad et al., 2016). This technique is said to be a forward-looking technique considering it analyses the events that have occurred or are occurring. The tool would compare the projected completion date when the delay event has not happened and the change after the delay. The analysis focuses on the delays in the project and not on the period that consists of the delay (Yang & Kao, 2012). This technique is recognized mainly in construction projects, even by boards and courts, as an effective tool that could measure the impact of delay. It is considered the prominent and most used tools in determining delays and their analysis.

The following technique is the Impacted As Planned delay analysis method. The technique is defined as a model technique that relies on the simulation of a specific scenario. The method is used to forecast a delay and its impact or effect on the completion date. The delay analysis technique would use the established or planned schedule timeline as the baseline. Into this baseline, created delays are added to simulate and measure the impact and influence on the completion of a project (Braimah, 2013). The impact-as planning is focused on quantifying the uncertainties that are sued for contemporaneous requests when there is a need for a time extension. The total delay would be calculated as the difference in the completion date between the various schedules after or before the impact of the uncertainty. This technique is seen to be effective in analyzing the delays that happen before and after the completion of the project. This technique, too, like the previous tool, is considered to be simple (Ghimire & Mishra, 2019; Ndekugri et al., 2008). Though unlike As Planted vs. As Built, the tool could be used to evaluate impacts based on assumptions or activities before the work. It could also be helpful in situations where the scheduling is not updated as required at the project time. When there is no other data other than the baseline schedule and the list of delays but not the complete data of the actual work, the impacted As Planned is a suitable tool.

As a supporting tools to assess the potential delay and effort tracking in the projects could use the s-curve analysis technique which is based on the non-critical path. The method is said to support a relationship between the time and cost of the project. In simple terms, S-Curve is used to plot the work carried out or the project's progress. Often, they are planned with the cumulative work or the project's costs over some time. The curve about the costs across the project's timeline would show the progress regarding the investment made right from the beginning of the project until its completion (Chao & Chen, 2015). The cumulative plotting leads to a curve that takes the shape of S, which is from where the name is gained. The angle is flatter right at the beginning and again after the project, while the curve is much steeper in the middle. This is valid for all construction projects considering that almost all projects have a quiet start as it is more planning work while in the middle, most of the implementation and actual work is carried out. An example of the S-curve is provided in Figure 6.

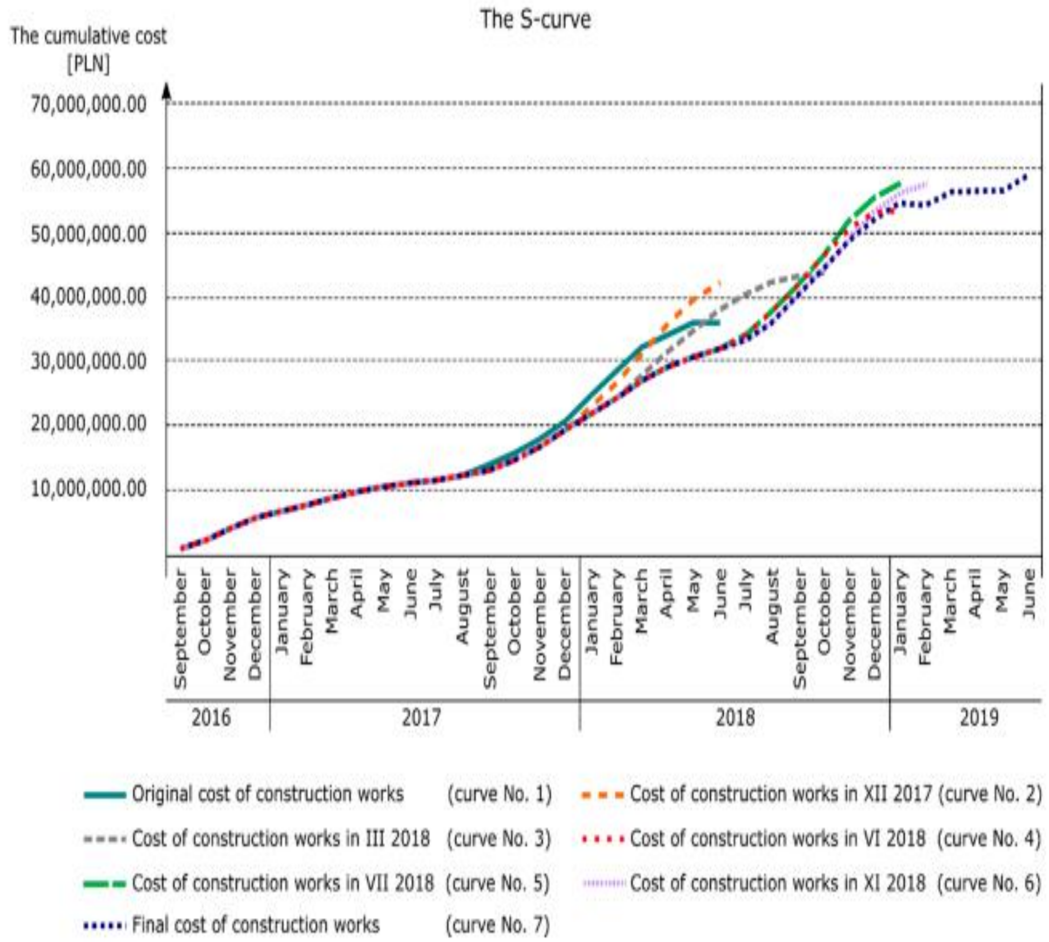


Figure 6: Sample S-curve

(Konior & Szóstak, 2020)

Another helpful technique is the Global Impact technique which is also a non-CPM method. Under this technique, all the delays experienced in the duration of the projects would be charted as bar graphs. The total delays are calculated from this, the sum of the individual delays in each activity (Muhamad et al., 2016). There is some limitation to this technique, which includes the possibility of overestimation of the actual uncertainty. In most cases, no allowance is made for the concurrent delays for the various activities running parallel. There is no scrutiny regarding such delays in activities. The net impact technique is another non-CPM tool used for delay analysis and is found to be broadly similar to the workings of the global impact tool. Compared to the Global Impact tool under this method, just the net effect is calculated in the same way as in the global impact tool using bar charts (Yang & Kao, 2012). The main difference is that the delays are plotted on the chart As Built schedule, while the global impact would be used as a planned schedule. The challenge with this technique is that it does not make use of networks, leading to some misinterpretation that would lead away from understanding the actual effect (Muhamad et al., 2016).

2.6 Causes of Delays in Construction Projects

Construction delays are pretty common in all projects, and this is caused by many reasons among which is the miscommunication between contractors, property owners, and subcontractors (Aditi, 2014). That said, the issue of delays is not limited to developed or developing countries and is found in all countries (Shah, 2016). In developed countries, the leading causes that were identified that have an impact on the delays are (Shah, 2016):

- Delays that arise due to the change in the client specifications and requirements.
- Different involved parties have different scope interpretations which creates a Scope creep
- Increase in inflation rates would incentivize the contractors to delay procurements hoping the prices would drop to meet the project cost requirement without increasing the overall budget.
- Underestimation of the time required and the assumption in procurement.

A case study is explored to understand better the impact and role of delays in the construction industry. Shah (2016) case study focused on the delays in Vale Malaysia Minerals Project. The paper undertook a qualitative approach with structured interviews with experts and staff involved in the project. Based on the study, it was found that the leading causes of delays are:

- Communication: the project had an international team with members from different parts of the world with different technical backgrounds, and each part of the project was assigned to a different team. This led to increasing virtual communication which resulted in communication gaps and scope ministration and also delays due to zone differences and the difficulties resulting from the contact not being face-to-face, all of which acted as barriers.
- Material: the material delivery delays occurred noticeably due to late order release, manufacturer's projection delays and supply chain logistical hurdles from countries like Germany and China.
- Labor: there were shortages and an increase in labor turnover, which caused delays as the number of employees required to meet the schedule was not available consistently, and the expected labor productivity was not achieved. This is directly linked to the learning curve of the newer team members.
- Project Management: poor control and management of the different activities in the project led to delays and the schedule not being met, which led to the replacement of the project management team who ties to retain some delays, but it was late at the moment of time.
- Equipment: Equipment like Crane and generators are required for large-scale projects, often unavailable unless scheduled earlier and available only for a fixed

time frame. The improper planning led to delays due to a shortage of such equipment.

Based on a case study, the above are some of the leading causes of delays. In another study by Hamzah et al., (2011) it was identified that there are two types of delays: excusable and non-excusable. Using this model of classification and the literature available on the topic, the causes of construction delays are grouped and divided as provided in figure 7.

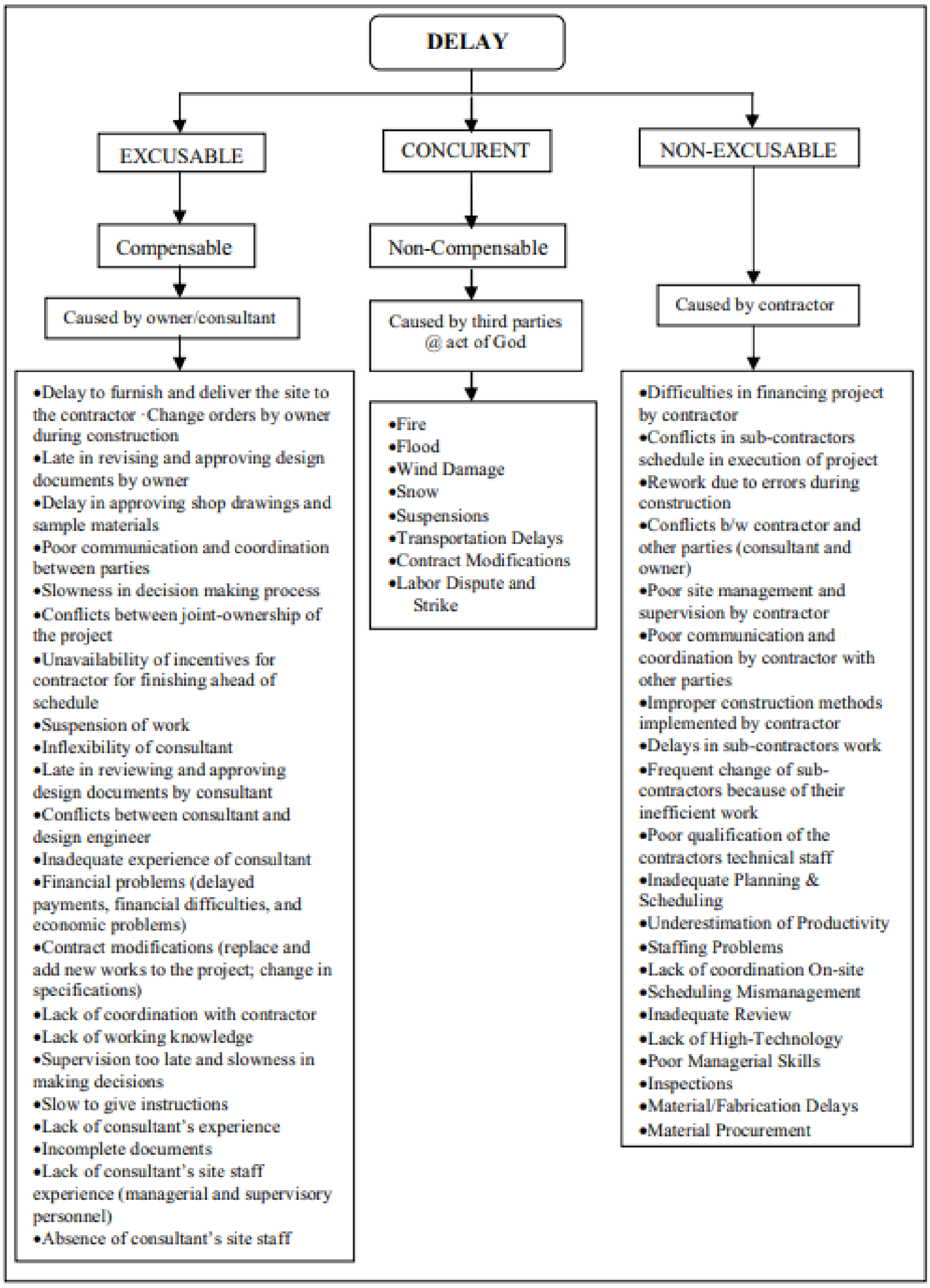


Figure 7: Causes for Delay

(Hamzah et al., 2011)

There are many Cause Analysis techniques that could be used to identify the main effecting factors in projects, among which is the Root Cause Analysis. All projects and businesses have some failures, and in the construction sector, the delay in the project completion is considered a major common failure. When such failures occur, there is a focus on understanding the reasons behind such an event, for which many tools are available. One such tool that can be sued is the Root Cause Analysis (RCA). RCA is considered an effective method that would help gain a better understanding of the chain of events that led to the undesired event, why it occurred, and what factors caused it (Aurisicchio et al., 2016; Hsu et al., 2017). Under the RCA, there are multiple steps that are often used in applying the root cause. The first step in the process would be to define the problem. Here the focus should be on identifying the event or issue to be analyzed. The data for this could be collected from different sources like incident reports or risk management reports (Charles et al., 2016; Morelli et al., 2013). The next step in the process is to identify and select a team or group of individuals responsible for analyzing the events and has experience in understanding the associated risks and possibilities. The next phase of the RCA would be to describe what happened by collecting information from different sources and exploring the issues from different perspectives. The next stage is to identify from the collected description of what happened the main factors that led to the situation or factors that contributed to the event occurring. The next step is to analyze these identified contributing factors and the underlying processes to identify the root causes of the event. Once the root cause has been identified, the changes can be made based on the most suitable solution.

There are many tools in RCA that can be used, like the Ishikawa diagram, also known as the fishbone diagram, which provide the causes and effects that would lead to a particular event. Below in Figure 8, we have a sample Ishikawa diagram for a construction project.

Figure 8: Sample Ishikawa diagram

(Muhadi & Yudoko, 2021)

2.7 Construction Projects Delay Case Studies

Thera are many cases study papers that highlights the construction project delays and in particular solar PV construction projects. Guerin (2017) presents a case study for a solar PV project in central West NSW. The project was constructed on a rural land situated on one land parcel. The plant capacity is 100 MW. Considering it is a remote location, the project required the construction of 132 kV transmission lines 4km in length. The project was reliant on the below main equipment:

- Solar photovoltaic modules that use thin-film technology
- Central inverters
- Electrical cabling and conduits (AC and DC cabling)
- Electrical switchgears (AC Solar PV combiners and grid interface connections)

- Transformer substation
- Transmission line connected to the national electric network
- Supervisory control and data acquisitions control system (SCADA)

The project had many benefits as it had no significant social or environmental negative impact, and all were beneficial. The study was able to identify critical areas of concern for solar construction projects. One of the first findings was discrepancies between planned and actual risks. These issues are present in all projects, though solar PV projects, especially those in rural areas, need to give significant thought regarding the logistics and waste management as to how the other wastes in the sites would be handled without influencing the environment. The study also found that the project's cost increased due to poor end-of-life packaging materials management. This highlights the importance of having a stable environment and community planning and approved commitments to ensure such additional compliance costs would not be a cause of risk and delay for the object. There was also the challenge of controlling the vegetation in the area as there was excessive growth. Due to improper planning, more time was spent clearing this vegetation and dust suppressing the ground cover for the project, which added to the cost and delays. The lack of planning taken into consideration regarding the reaction of the local community and their interest, who are also critical stakeholders, did hinder the progress as there were no plans in place to meet the requirement or interest expressed by the local community to visit the site when the platform was being constructed. Under this, based on the location and the community involvement in the project, this expectation might need to be considered and included in project planning. The project also faced several challenges related to regulation and concerns for pollution and environmental safety from the community and also use of local labor in their projects which were all regulatory measures that were enforced or required by the local government, which did hinder the progress and slow down the project where the project sponsors and managers had to explain and clear these regulatory hurdles. This project shows the various challenges faced by one single construction project in Australia, and the process and delays might differ from country to country. Still, some of these factors of uncertainty are consistent throughout the world.

Another research by Gohil et al. (2019) presented a case study from India with Charanka's 40 MWAC Solar PV Park, part of Gujarat Solar Park, to assess the key activities carried out by the Engineering, Procurement and Construction contractor (EPC) from the date of Letter of Intent (LOI) until the commercial operation Date (COD). The author highlighted the importance of proper project planning before any execution activity carried onsite. The project planning and scheduling as per the author should start with identifying the key milestones in the project, their sequence, the starting and ending date of each of these milestones then accordingly assess required workman force, system material and construction equipment. The project tracking visualization method used in this project was the commonly used S-Curve graph (Figure 9), where it represents the cumulative progress in comparison to the projected timeline including manhours and costs.

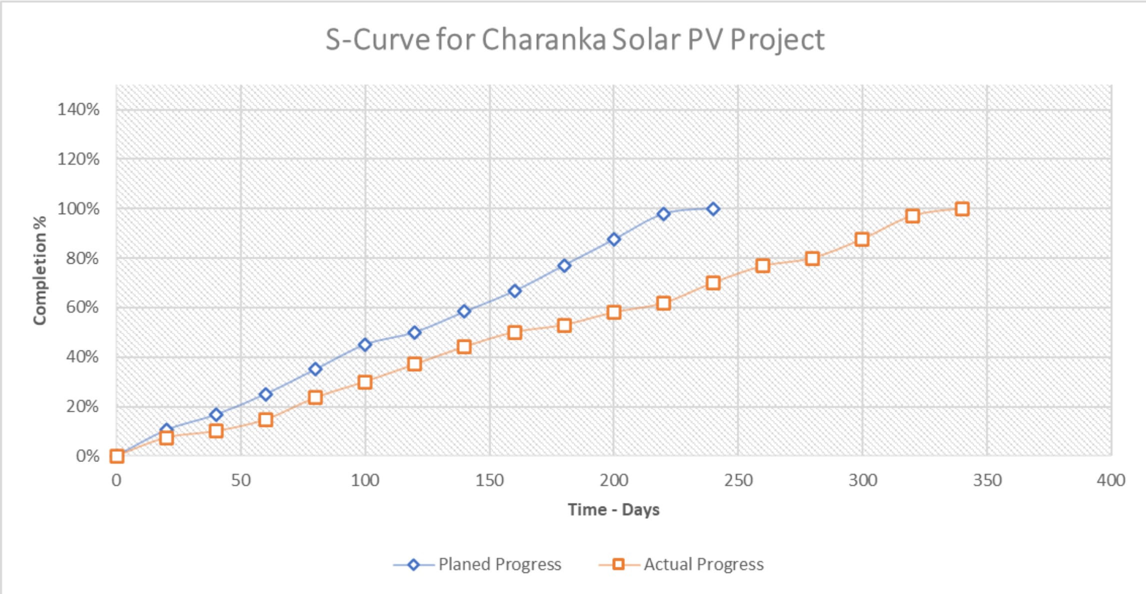


Figure 9: Charanka's 40 MWAC Solar PV Park S-Curve

The concluded causes of delay in the study were summarized into the below main reasons:

- Material delivery delays: the investigation showed that the EPC did not utilize a reliable and trustworthy network to procure the materials, also, the delivery timings were not synchronized with the work progress which resulted in a significant delay.
- Civil work delays: the EPC could have utilized the pre-casted foundation structures to install the transformers as well as the inverters rather than depending on the conventional civil techniques which consumes much time and effort.
- Construction technique: the adopted construction style in this project was to divide the project into smaller blocks then execute progressively. This is a common practice in similar size projects, but this would work best when having all the material available on time. Since the martial experienced some delays then a more agile management approach should have been adopted to work with the existing materials in different blocks rather than waiting for all material to be onsite.

- Legal Disputes: this is about the issues with contracts or local legal regulations that need to be addressed before the project begins with the help of an effective legal team that is an expert in the area. This would include delays in collecting the required permits and regulatory reviews (Guerin, 2017).
- Supervision and Management: the lack of supervision could lead to faulty work or work done at a sub-par quality, leading to reworks that would cause delays.
- Effective Communication --/ without proper communication between the different project stakeholders, there could be many misunderstandings regarding the requirements and resource acquisition, leading to increased costs and other delays.

Mittal and Gorowara (2020) emphasized that the solar PV construction projects are considered as complex projects when it comes to Engineering, Procumbent and Construction (EPC) phase which includes endways solar project services. The three main aspects that are used to evaluate solar PV project performance are Project Budget, Timeline and Quality. The budget and timeline are quantifiable metrics while the quality is relative. The author listed the delays and cost overruns dependent variables to the project geographical location, market industry, project category and time of execution. Project delays were observed to vary from the developing and developed regions seriously. Mittal and Gorowara (2020) concluded that the delays in solar PV projects are characterized by the following main aspects:

- Poor project management
- Limited team experience which leads to multiple design iterations
- Financial shortage and payment delays
- Logistical interruptions and delivery mismatch
- Authority approvals, legal disputes

No two projects are similar, and no two factors are the same as the impact of one factor might be more prominent when compared to other factors (Araújo-Rey & Sebastián, 2021). The literature has identified that the factors that cause delays in developing countries would be different from developed countries (Mittal & Gorowara, 2020). The weighting of the delays allows to identify those factors that are critical for the projects while eliminating or removing the other variables that do not add value or are significant concerns (Araujo-Rey & Sebastian, 2021), In the study undertaken by Mittal & Gorowara (2020), the identified six factors were reviewed based on a survey and rated based on a multiple-choice questionnaire to create an average score based on the Likert scale. This made an average rating for each factor identified as a critical delay factor. Based on this, the prominence of each element could be understood, and the project team or researchers could focus on those that are more critical to a specific project. Another technique used is ranking based on a weighted average of the delays based on the response from different groups with different priority levels. There would be multiple stakeholder groups who would make their ratings based on their experience with the various delays. A weighted average for each deal could be identified using the Overall Relative Importance Index (Aziz, 2013).

2.8 Management and Mitigation of Construction Delays

With the increase in different factors that delay the completion of the project over the years, various techniques have been developed that are focused on ensuring better management of these delays (Y. Zhang & Fan, 2014). Organizations must take a proactive role in mitigating the risks and ensuring the success or achieving the project's goals. A solid risk management framework capable of identifying the different internal and external threats and having associated mitigation strategies could help tackle and reduce the project delays (Wang et al., 2004). To help with this, other tools and models have been developed. One such study selected six risk factors linked to the target project and used a fuzzy logic system to measure the strategies' effectiveness in mitigating them (Kim et al., 2018). Based on the fuzzy model, it was seen that the process that has been identified to have the required capabilities in mitigating the delays has three critical characteristics, which are defined project mission, support from the top management, and effective scheduling. All these three are said to influence the project's different phases. A similar study was able to identify six factors that play a critical role in the success and reducing delays. This includes management competency, supply chain and leadership, project factors, practical methods for cost control, and availability of resources. Of these factors, management commitment and competence were the most critical factors (Tripathi & Jha, 2018). Some of the effective strategies that have been used in mitigating the risks based on existing literature have been provided below (Kim et al., 2018; Y. Li et al., 2019; Odeh & Battaineh, 2002; Tripathi & Jha, 2018; Wang et al., 2004; Y. Zhang & Fan, 2014):

- Using laborers with the required competency and experience working on similar projects.
- Having a solid and close supervision
- Ensuring that financial arrangements are appropriately planned, and risks identified.
- Making use of time estimation techniques
- Exploring the influence of the owner
- Training to increase the capacity of employees
- Proper communication protocols
- Timely site visits
- Risk identification and assessments

- Proper and detailed presentation of all information regarding the requirements at the initial stage
- Proper logistics control and management
- Increased use of technology like BIM could also help control delays (Koseoglu & Nurtan-Gunes, 2018; X. Li et al., 2017)

In successful projects, it was found that capacity building training is the primary mitigations strategy under successful projects. Using capacity building would improve the workers' performance, retention, and satisfaction and increase the number of skilled labor available to complete the projects (Banobi & Jung, 2019). In solar PV projects where highly skilled laborers are required, this would be critical and play an essential role in mitigating risks that are caused due to installation challenges. The availability of proper funding and support from the top management is also seen to have an essential influence on the project's success (Banobi & Jung, 2019). Ensuring the payments are made on time ensures that the contractors are motivated and would be committed to meeting their end of the bargain. When it comes to unsuccessful projects, it was found that the lack of timely payment was one of the main factors leading to the failure and delay (Banobi & Jung, 2019). Following this was an increased influence of the owner. The procurement of materials, lack of support, and lack of financial arrangements are also significant factors common in unsuccessful projects.

2.9 Case Study Analysis Techniques

Case studies are considered intensive studies that are in-depth studies that focus on a few units with different variables. The use of case studies provides a better picture of the situation. Case studies focus on units that could vary based on space and time (Cope, 2015; Joseph & Gupta, 2021; Noor, 2008). The unit that is focused on could be a group, an industry, or an individual. The case studies are used to understand better the different interactions that occur under a specific context or a particular phenomenon. One of the main reasons for its growing importance and popularity is that the researcher is more aware of the quantitative methods' limitation in providing a holistic approach to the topic or providing a better in-depth understanding of the situation or event or topic. The case study methodology offers the researcher the opportunity to move beyond the statistical results' limitations and allows them to explore the different variables and relationships from different perspectives.

Case studies are often considered a qualitative approach though there are instances where a quantitative mixed-method approach is also used. Irrespective of the case study design, qualitative or quantitative, the researcher can explore the identified phenomenon with different lenses. This capability to provide a multi-perspective outlook on the topic is considered a critical tool that matches the in-depth understanding requirement of case studies (Cope, 2015; Pearson et al., 2015). The case study has the flexibility to dive deeper into the different experiences and circumstances that would not have a fixed outcome. Case studies could be a suitable tool that could be used to serve the empirical purpose that would identify the different variables along with new hypotheses if any. There are very few techniques under qualitative studies that can generate new ideas (Starman, 2013). In addition, case studies can analyze highly complex events, and their flexibility, as mentioned, allows them to take in the different aspects of the event. Case studies could also investigate the causal mechanism for other cases. The approach could explore the different variables that would intervene and observe the various unexpected aspects of operations for a specific tool within a single point consecutively. It could also help highlight the different situations identified within a case that would lead to activation of the causal agent, which cannot be achieved through other qualitative methods as they lack the casualty. In addition to the causal approach, they, as mentioned, are capable of analyzing and accommodating the different challenging causal relations like equifinality (Starman, 2013).

It has been mentioned by critics of the case study methodology that the result findings of these studies cannot be validated. In contrast, it cannot be validated either in integrity or utility (Murphy, 2014). This is due to the nature of the case study. There are six commonly discussed disadvantages when it comes to disadvantages (Flyvbjerg, 2011). These are:

- Case studies often are said to contain specific bias toward verification
- The generalization cannot be achieved just from one study.
- The case study is helpful in hypothesis development but not for testing and theory building.
- Summarizing the specifics of the case study is challenging.
- Theoretical knowledge is often considered to be more critical and valuable when compared to practical knowledge.
- Quantitative vs. Qualitative research methodology

2.10 Conclusion

In conclusion, construction project delays are found to be a normal event and the same applies to the solar PV industry but with more criticality as it directly impact the national and international renewable targets. The solar PV projects follow a unique permitting progress based on the geographical location where the electrical and municipal requirements differ. Different countries were analyzed in the literature such as USA, China, Germany India etc. but nothing tackled the MENA (Middle East and North Africa.) region or Dubai form the United Arab Emirates. A Research gap has been identified in Solar PV commercial scale construction projects in Dubai and this research will bridge it.

CHAPTER III

RESEARCH METHODOLOGY

3.1 Introduction

The research methodology is a systematic way to gain answers to the research questions as presented in the previous section. The tools, techniques, and philosophies used to answer the research question could be defined as a research methodology. This section presents the details of the methodology that is adopted in this dissertation to describes how the data would be collected, how it would be analyzed, and how the results would be interpreted (Kothari, 2004; Kumar, 2017).

3.1.1 Qualitative Analysis

There are two common forms of research methodology classified based on the type of data used for the research. Qualitative research which is focused on non-numerical data and on the other hand the quantitative methodology depends on conclusive numerical data (Antwi & Hamza, 2015; Arghode, 2012). This research study will be using quantitative analysis to get the final delay recommendations.

3.2 Data Collection and Inputs

As described by Gaya and Smith (2016), case study research examines a single or series of cases to better understand a study's overall complexity. Additionally, a case study can be characterized as a complete, pragmatic assessment of a current event in its precise setting.

In this research, the case study will be constituted of three recently completed commercial scale solar PV projects, summing up to around 3,000 kWp, which will be analyzed from Shams Dubai Solar PV program to have a robust platform to analyze the status quo in the emirate.

The data collection in this study is divided in to the below primary and secondary sources:

- Primary Data:
    - Actual Project data: Data from Dubai solar PV portfolio, which are requested from a solar PV project development company in Dubai. Table 1 below presents the proposed projects that are involved in this dissertation, the project's actual names are evaded, yet the location and capacities are kept serving understanding the project categorization.
    - The collected data includes Contractual timelines, amended timelines, Minutes of Meeting, official letters, and mail communications.

Table 1: Selected Case Studies

Project Number	Project Location	Capacity (kWp)
Case Study 1 / Project 1	Dubai	800
Case Study 2 / Project 2	Dubai	900
Case Study 3 / Project 3	Dubai	1,250

- Secondary data: data collected form literature reviews, prior surveys, government publications, and technical documentations.

3.3 Analysis Steps

As presented in the methodology section, the delay analysis techniques could be summarized into two main categories, namely prospective and retrospective techniques, where the earlier considers the forward view of the project while the later looks into the backward view after the project is finished. Both techniques target the same goal of quantifying project delays.

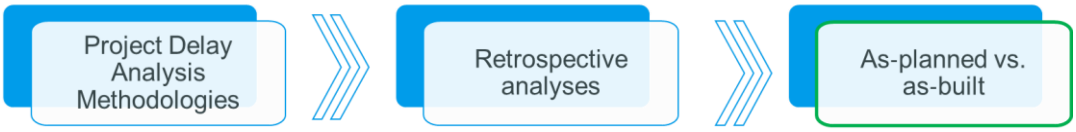


Figure 10: Delay Analysis Techniques

After analyzing the different delay analysis techniques and given the nature of the available data in addition to the industry common practice to identify and settle delays in the projects, the "As Planned vs. As Built" (APAB) technique will be used in this study analysis as shown in Figure 10. This technique is considered as an observational technique which makes it a common-sense and factual-based method as it relies on observing and comparing the actual progress with the original planned schedule.

Accordingly, the APAB delay analysis will follow the below sequential methodology:

- Collect the As Built and As Planned schedules for each of the identified projects alongside the delay claims, notification letters, minutes of meetings, mail chains and any other official communications between the contractor and the system owner that gives information about the schedules.
- After analyzing the schedules, tabulate and rearrange the schedule phases and key tasks that all projects experience in Dubai using Microsoft Project software as shown in Table 2 below:

Table 2: Dubai Solar PV Consolidated Project Plan

1. LOI & EPC Contract Signature Phase
1.1 EPC Contract Signature
2. Authority Permitting Phase
2.1 DEWA NOC
2.2 Building Permit
3. Design Approval & Engineering Phase
3.1 Detailed Design Approval (DEWA DA)
3.2 Limited Notice to Proceed (LNTP)
3.3 Notice to Proceed (NTP) Approval
4. Procurement Phase
4.1 PV Panel

4.2 Inverters
4.3 MMS
4.4 Cabling (AC/DC)
4.5 Switch Gears
4.6 Others
5. Construction & Installation Phase
5.1 Mechanical Installations
5.2 Electrical installation
6. Testing and commissioning Phase
6.1 DEWA Commissioning
6.2 System Energization
6.3 Municipal Commissioning
6.4 Client Commissioning and project Handover

- Using MS project, compile the As Planned and As Built schedules into a single Gant Chart to visualize the timelines and relationship intervals
- Assess and validate the As Planned schedule and its critical path (s)
- Assess and validate the As Built schedule and its critical path (s)
- Identify the total and subtotal delay durations in each project phase and task then quantify the significance of the delay
- Perform quantitative data analysis to evaluate the delays through the below equations aided by the list of abbreviations.

$$Project\ As\ Planned\ Duration\ (PAPD) = PAPFD - PAPSD$$

$$Project\ As\ Built\ Duration\ (PABD) = PABFD - PABSD$$

$$Task\ As\ Planned\ Duration\ (TAPD) = TAPSD - TAPFD$$

$$Task\ As\ Built\ Duration\ (TABD) = TABSD - TABFD$$

$$Task\ Overall\ Delay\ (TOD)\ \% = \frac{TABD - TAPD}{TAPD} * 100$$

$$Task\ Delay\ Contribution\ (TDC)\ \% = \frac{TABD - TAPD}{POD} * 100$$

$$Project\ Overall\ Delay\ \% = \frac{ABPD - APPD}{APPD} * 100$$

$$Task\ Weighted\ Average\ Delay\ Contribution\ (TWADC)\ \% = \frac{TOD\%}{\sum_{i=0}^{19} Task\ i\ (TOD\%)} * 100$$

- List down the delay causes for each of the identified delay phases and tasks then group into main delay categories
- Establish the root cause analysis of delays by analyzing the available data and information such as delay claim, official letters, minutes of meeting, official email communication
- Create Fish Bone diagram to visualize the delay root causes
- Propose a suitable delay mitigation strategy to help overcoming or reducing the impact of such recurrent events. The proposed mitigation strategy comes from the previous investigated literature review and the industry best practice.

3.3.1 Solar PV Project Phases

The identified project phases start with the contract negotiation where in some cases the Letter of Intent (LOI) is shared to the EPC company to carry on some early works until the contract is signed officially. Then moving to the preliminary authority approvals from the electricity service provider namely DEWA, then the municipal governing body which varies based on the project location to include Dubai Municipality (DM), Trakhees, Dubai South or Dubai Development Authority (DDA). The DEWA No Objection Certification (NOC) is a simple approval process from DEWA to the intended solar PV project where the total project capacity, total connected load capacity, location and grid availability matters are checked by

DEWA in couple of days as known in the industry and DEWA portal. The obtained DEWA NOC then is submitted to the municipal authority to issue the Solar PV Building Permit.

After both permits are achieved, the EPC could start with the Detailed Design as mandated by DEWA where all the technical permitters of the project are assessed before DEWA issues the Detailed Design Approval (DEWA DA). This stage of the project confirms that the material Bill of Quantity (BOQ) is finalized, and the procurement could start after obtaining the Notice to Proceed (NTP) by the client. In most cases, the contractors ask for an early procurement letter called Limited Notice to Proceed (LNTP) for some materials that are known not to be affected by DEWA comments for example purchasing solar PV modules or inverters or safety items such as lifelines. The LNTP request is directly linked to the expectance of the EPC project manager who assess the situation and request of procurement approval for the longer lead items to shortcut the foreseen complications or events.

The next phase is Procurement phase where all the required project equipment are ordered to satisfy the design conditions. The main procured items are PV Panels, Inverters, Module Mounting Structures (MMS), AC combiner panel and the metering cubical, AC and DC cabling and some other items that could vary from a project to another such as the monitoring platforms, cable trays, or the safety items such as roof lifelines, anchor points or roof guardrails.

The construction onsite phase could be divided into mechanical installations and electrical installations where the earlier interacts with the mechanical preparations onsite such as installing the mounting structures and modules etc. while the latter interacts with the electrical connection either on the DC side of the system or the AC side or the grid side of the system.

The final phase of the project execution is the Testing and commissioning phase, where it is divided into four main tasks. The first task is DEWA commissioning which includes the current and voltage testing (I V testing), insulation resistance (Megger) testing, earthing looping resistance or earth continuity resistance, Array Resistance and Harmonics testing which leads DEWA to issue the Final Status Connection Report (FSCR) to declare the plant complete energization and grid integration. This task is then followed by DEWA meter installation and system provisional energization. The third task in this phase is the municipal commissioning which includes the fire fighting and mechanical installation matters such as wind calculations and installation design from a municipal point of view regardless of the electrical side of the system which leads to Building Completion Certification issuance. Finally, the client commissioning task includes the parameters that falls in the interest of the client such as the Performance Ratio testing which is used to check the actual energy production and compare it to the forecasted plant performance. This task also includes the plant final documentation and handing over package which acts as the project master documentation package.

CHAPTER IV

RESEARCH RESULTS ANALYSIS AND DISCUSSION

4.1 Introduction

This section presents the findings realized after analyzing the commercial scale Solar PV project case studies from Dubai environment. All collected data inputs comes from completed projects and the findings are expressed for each case study separately in details. Furthermore, the findings are then tested against the literature review and industry best practices to formulate conclusions and explain the results in the context of Dubai's solar PV case studies.

4.2 Case Study 1

4.2.1 Project Description and Background

The first case study is a project that is constructed in 2021 over two warehouses with metallic rooftops for a heavy-duty construction machinery supplier in Dubai, with a total solar PV capacity of around 800 kWp. The plant is forecasted to cover up to 20% of the company's overall energy need for the next 20 years. The project has 2 DEWA grid interface connection points under the same municipal plot and more than 1,650 Nos. of tier one solar PV modules to power-up six inverters with some other technical parameters as shown in Figure 11.

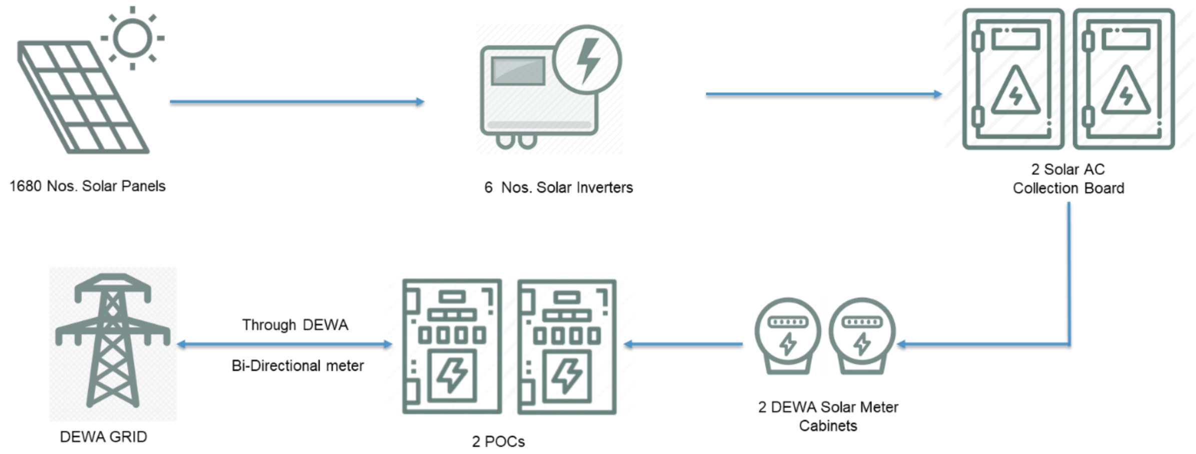


Figure 11: Case study 1 Overview

4.2.2 Case Study 1 Analysis

The collected and analyzed data for this case study started with analyzing the As Planned and As Built schedules for the Project which resulted in a significant time overrun with 28% (POD%) more time compared to the initial intended plan. The project was initially expected to be delivered in 251 days while it actually took 321 days. The different project task held different delay patterns and time shifting as presented in the below Gantt Chart, Figure 12. The chart compares the detailed As Planned durations, in gray bars and U shape brackets, and at the same time presents the As Built durations, in blue bars and inverted-U shape brackets, to visualize the delay as well as time shift of each of the tasks. Finally, the critical path tasks shown in red bars, plays a significant role in the project performance since some tasks could experience delays but not all of them would affect the overall project timeline, since those tasks had a spare slack time compared to the critical tasks which holds a zero slack. The analysis will consider the root cause of the delays despite if it is in the critical path or not as some delays could numerically deceive the root causes.

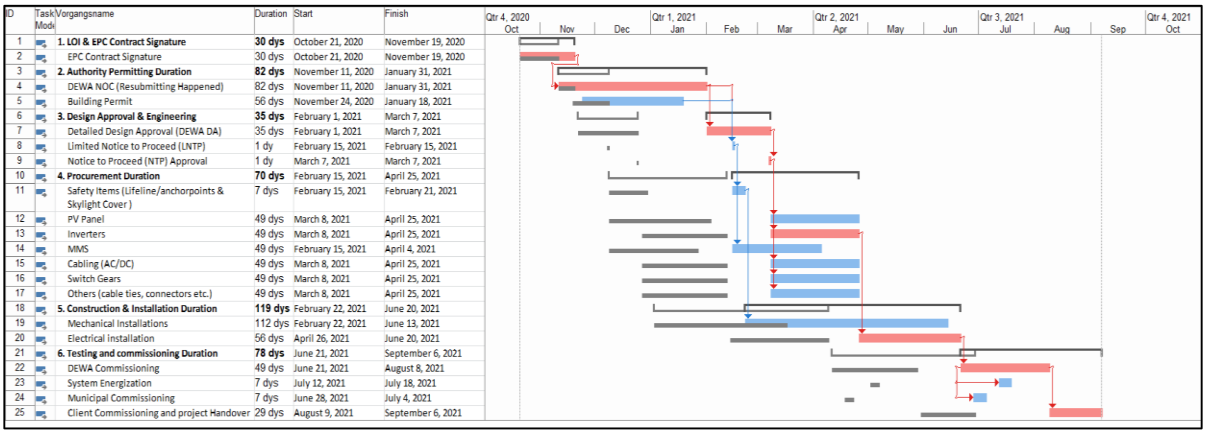


Figure 12: Case Study 1 - Gantt Chart Analysis

The project's network diagram below, Figure 13, shows the critical path tasks and correlate the interactions to the remaining project tasks.

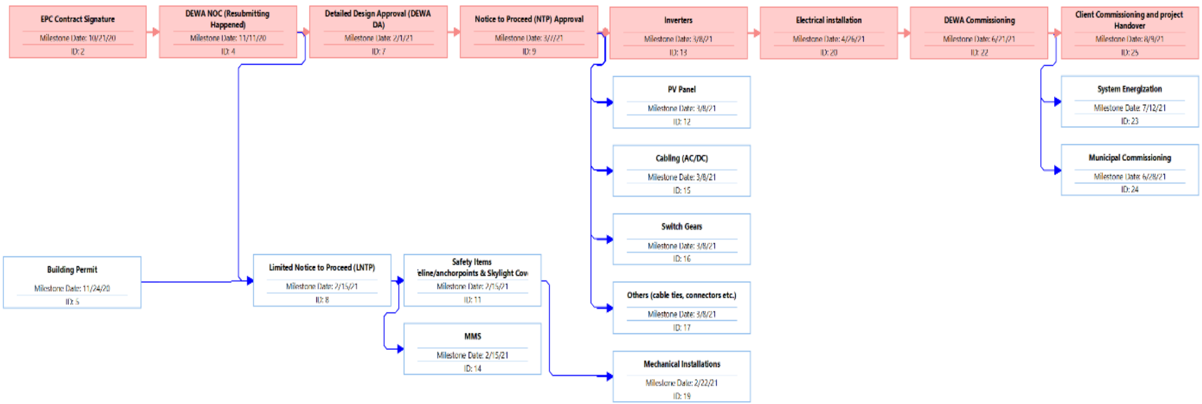


Figure 13: Case Study 1 - Network Diagram

Out of the major tasks that each solar PV project in Dubai passes through, this project has eight tasks falling in the critical path. Each of these tasks contributed differently to the overall delay percentage with the major delay caused by DEWA NOC application which made up 82% of the total delay in Case Study 1 as shown in Figure 14.

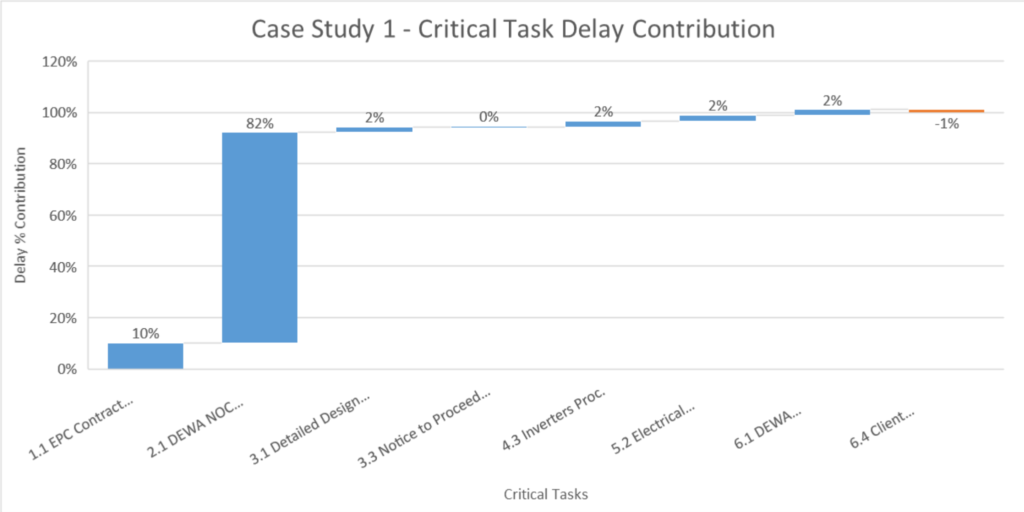


Figure 14: Case Study 1 - Critical Task Delay Contribution

Initially, when comparing the individual phases, the project shows a huge delay compared to the initial timeline with 28%. Tabulated Graph Figure 15, compares the delay significance in each of the phases compared to the As Planned schedule. The analysis resulted in a clear frontloading delay dominance specially in the Authority Permitting Phase, followed by the LOI and Contract Signature Phase then finally the construction and installation phase.

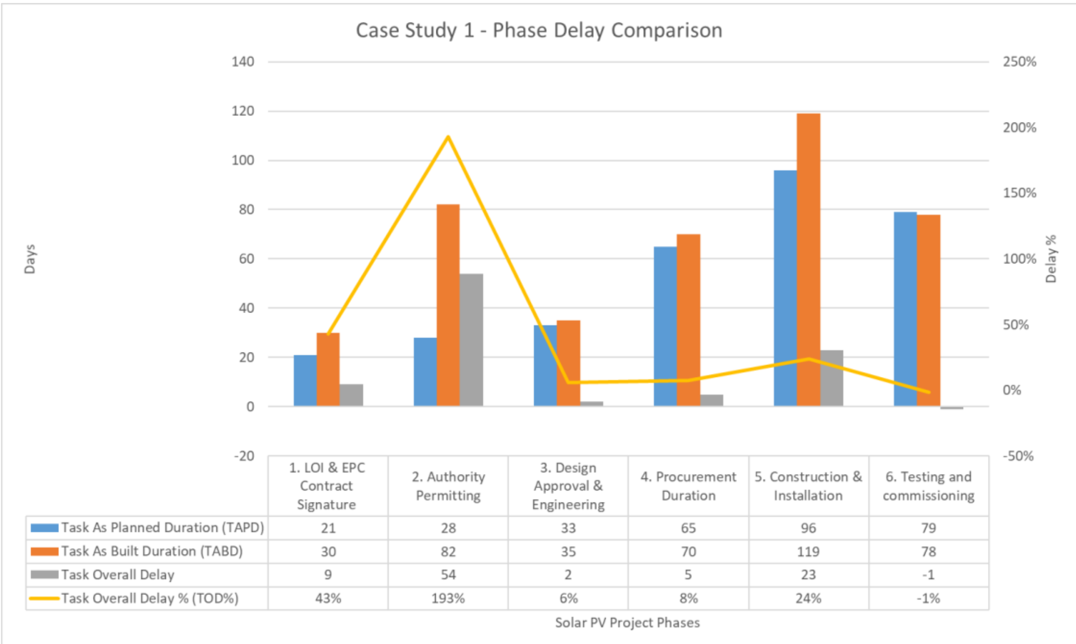
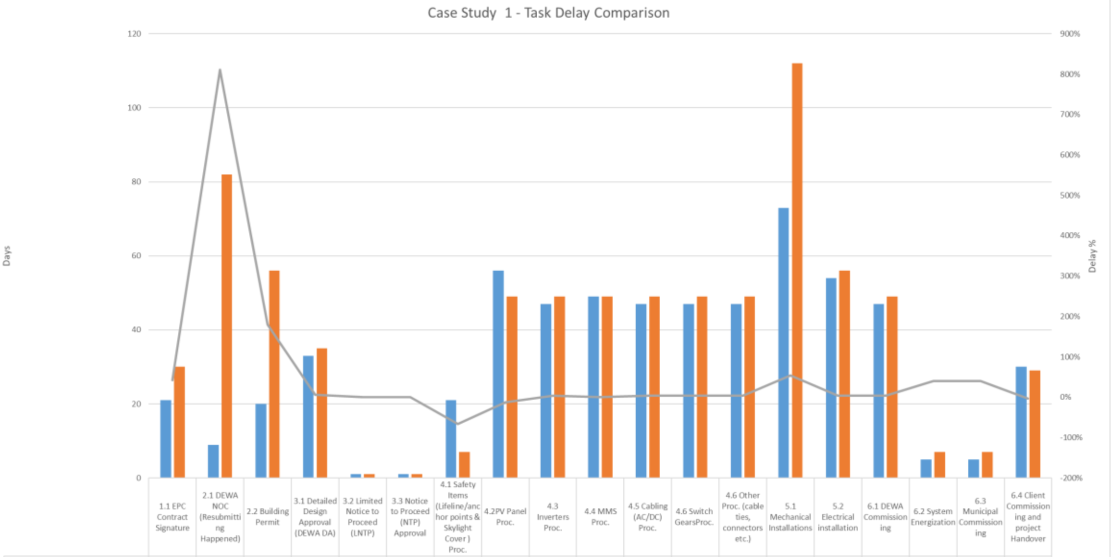


Figure 15: Case Study 1 - Phase Delay Comparison

Going a level down to the individual project tasks, Tabulated Figure 16, compares the task level delays. This analysis revealed more delay information and showed that the contract signature experienced almost 50% delay then DEWA NOC task took 811% more time compared to the initially planned time, which consequently held the municipal permitting task to 180% delay time. In the other side, it is observed that Safety equipment and Solar Panel Procurement have experienced a shortened timeline by 13% and 67% respectively. The next step is to go into the details of the delays to understand the root cause behind the numerical financings.



	1.1 EPC Contract Signature	2.1 DEWA NOC (Resubmitting Happened)	2.2 Building Permit	3.1 Detailed Design Approval (DEWA DA)	3.2 Limited Notice to Proceed (LNTP)	3.3 Notice to Proceed (NTP) Approval	4.1 Safety Items (Lifeline/anchor points & Skylight Cover) Proc.	4.2PV Panel Proc.	4.3 Inverters Proc.	4.4 MMS Proc.	4.5 Cabling (AC/DC) Proc.	4.6 Switch GearsProc.	4.6 Other Proc. (cable ties, connectors etc.)	5.1 Mechanical Installations	5.2 Electrical installation	6.1 DEWA Commissioning	6.2 System Energization	6.3 Municipal Commissioning	6.4 Client Commissioning and project Handover
Task As Planned Duration (TAPD)	21	9	20	33	1	1	21	56	47	49	47	47	47	73	54	47	5	5	30
Task As Built Duration (TABD)	30	82	56	35	1	1	7	49	49	49	49	49	49	112	56	49	7	7	29
Task Overall Delay % (TOD%)	43%	811%	180%	6%	0%	0%	-67%	-13%	4%	0%	4%	4%	4%	53%	4%	4%	40%	40%	-3%

Figure 16: Case Study 1 - Task Delay Comparison

The above analysis shows a significant improvement opportunity for similar solar PV projects in Dubai, which will consequently improve the renewable project deployment rate and increase the financial returns of all stakeholding parties.

The root cause analysis utilized the Ishikawa Diagram or the fish bone diagram, as in Figure 17, to reach to the root cause and the delay percentage of each category with elaborative explanation in Table 3.

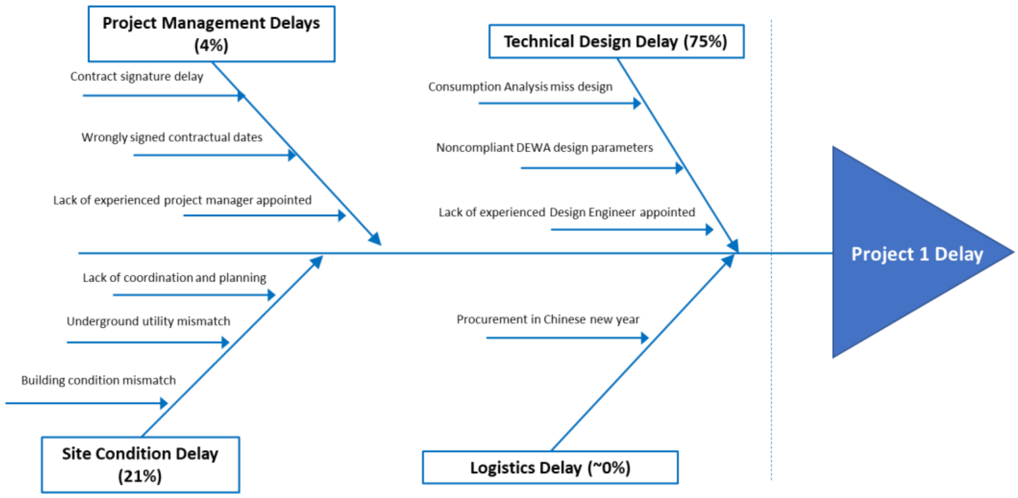


Figure 17: Case Study 1 - Ishikawa Diagram or Fish Bone Diagram

Table 3: Case Study 1 - Root Cause Delay Analysis Findings

Delay Task	Root Cause Explanation	Delay Category	Mitigation Strategy
Task 1.1, EPC Contract Signature	The multiple rounds of contract review are common in any construction project and in solar PV industry particularly. As in any other contract negotiation phase, the EPC and the project owner had multiple rounds of contract review regarding the bank guarantees, material specifications, warranty periods, applicable standards, and project deadlines. The overall delay in this task was 9 days which was not reflected on the signed schedules. This delay is related to the project management experience of the team to handle such delay or at lease to	Project Management Delay (Contract management)	- Train the project managers to develop contract signature checklist which mandates the timeline update specially for the long negotiation periods. - Limiting the mail contract review to maximum two rounds and try to agree on online or face to face meeting to close most of the points on-spot rather than extending to lengthy mail

	reflect it in the signed contract. (3.9% delay contribution)		chains and delay. The discussed points in such meetings shall be recorded in Minutes of Meeting (MoM) and signed by both parties to document the process and to shortcut time.

Task 2.1 DEWA NOC (Resubmitting Happened)	In the first glance, the analyzer could be deceived by the raw schedule data and shift the delay responsibility to the authorities but in the root cause analysis done and after reviewing the provided mails, letters and minutes of meeting, the delay reasons are from: Contractor: DEWA NOC is very simple step that could be triggered even if the contract signature is not yet finalized since it is very fast, simple and has no monetary cost. Through DEWA NOC stage, the main information that shall be provided is the maximum connection capacity in the plot and the expected electrical point of connection. The contactor in this project did a consumption analysis mistake	Technical Design Delay	- Adding proper internal review layers before any DEWA NOC application submission could prevent this time loss due to simple calculation work and help as a Quality Assurance / Control (QA/QC) measure before submission.

	which led to wrong electrical point of connection. This issue was discovered by the project owner randomly after reviewing the linked consumption account which led to resubmission in January 2021. In summary NOC resubmission due to wrong designing calculations. (73.9 % delay contribution)		

Task 2.2 Building Permit	In the first glance, the analyzer could be deceived by the raw schedule data and shift the delay responsibility to the authorities but in the root cause analysis done and after reviewing the provided mails, letters and minutes of meeting, the delay reasons are from: Client: Another delay which was not part of the critical delays fortunately is the municipal permit delay. This delay was shaded by DEWA NOC resubmission above, elsewise it could be the major delay in this phase. The EPC alongside the Structural consultant witnessed that the As Built drawings submitted by the client for the structural analysis of the buildings did not match the actual onsite	- Site Condition Delay	- Prioritize checking the submitted building drawings with the onsite condition before contract signature to discover the discrepancy very early before the contract signature. This would help having much accurate assumptions and project time performance overall.

	condition and hence the client was asked to do the structural reinforcement for the building before applying for the building permit. This analysis is critical since it gives the green or red light for the project by assessing the building roof capacity to withstand the solar PV loading over the roof. In many cases the project is canceled if this study is found failing. Since the client is working in the construction industry, he commenced the reinforcement work directly without further time loss compared to other clients. In summary, Building reinforcement work due to drawing discrepancy with the onsite condition. (16.4 % delay contribution)		

Task 3.1 Detailed Design Approval (DEWA DA)	- Minor delay due to design requirement from the project developer to comply with DEWA AC cabling requirements which was influenced by the site condition. This delay is linked to the issuance of the Notice to Proceed (NTP) letter which gives the green light for the material procurements. In summary, Re-designing due to DEWA requirement. (0.6 % delay contribution)	- Technical Design Delay	- Providing specific training for the design team to comply with DEWA requirements. - Creating DEWA design checklist controlling measure before submitting to DEWA.

Task 4.4 MMS Procurement & 4.3 Inverters Proc.	- Since the timeline was shifted due to the above reasons, procurement was forced to be during the Chinese New Year (starting on 12th Feb) where all companies close for 16 days, this creates production stacked delay if orders are not placed well in advanced. The major component delayed was Module Mounting Structures. The As Planned procurement schedule was protective in terms of durations since this period was rich with Covid-19 restrictions and the contractors added a decent time buffer for each of the items, hence the delay affect was not clearly observed even after all the above delays occurrence. The	- Logistics Delay	- Having a better and more transparent communication between the EPC contractor and the client to issue the LNTP (Limited Notice to Proceed) and overcome this delay for the critical items. This is directly linked to the experience and awareness of the EPC project manager hence a proper internal training shall be done for the project managers.

	Limited Notice to Proceed was (LNTP) was not requested for the long lead time equipment. This delay was not clear in the schedules since some other delays have shadowed it, but it was observed to be captured in the minutes of meeting to be one of the significant factors that could have shortened the overall duration. In summary, Procurement delays due to LNTP shifting during Chinese New Year holidays. (0.4% delay contribution)		

Task 5.1 Mechanical Installations	- The project included excavation trenching from roof 1 till the first grid point of connection. The client discussed with the EPC during the construction that he has spare buried conduits existing, and the excavation could be avoided. The EPC did not check the readiness of the conduits and before the AC cable pulling, he discovered that the conduits were damaged and had to do the excavation work on urgent bases and delay was experienced. In summary, Delay due to EPC site condition verification. (4.9 % delay contribution)	- Site Condition Delay	- This delay should never happen in reality since the conduits shall be checked since day 1 of the installation work as underground conduit damage is always expected. The contractor shall have a work commencement checklist that includes the existing trench/conduit checking.

4.3 Case Study 2

4.3.1 Project Description and Background

The second case study is a solar PV project in an educational facility in Dubai. The project consists of four installation areas namely Buss Parking, Normal Car Parking and two standing seam roofs. The total project capacity is around 900 kWp of distributed solar PV installation with the major project components shown in Figure 18. The educational facility considered solar PV since the architectural building design and the solar designers were involved since day one of the facility construction plan. The electrical design was forecasted to cover 18-20% of the forecasted the facility's energy need. The project took a very close attention and had very tight timeline since the owner wanted to have the facility completely operational before the schooling season start in September 2021, hence all contractors had to handover the specific parts before that date. The owner came to know through the EPC contractor of the possibility of financing the solar PV project through a project developer and decided to go with this option which adds one more stakeholder to the project value chain. Authority permitting in this project was combined with the complete building permit which eased the process of getting the approvals from DEWA and the municipal authority. The project was planned to be completed by 19th of July 2021 but in reality, it took much more than that as explained in the below sections.

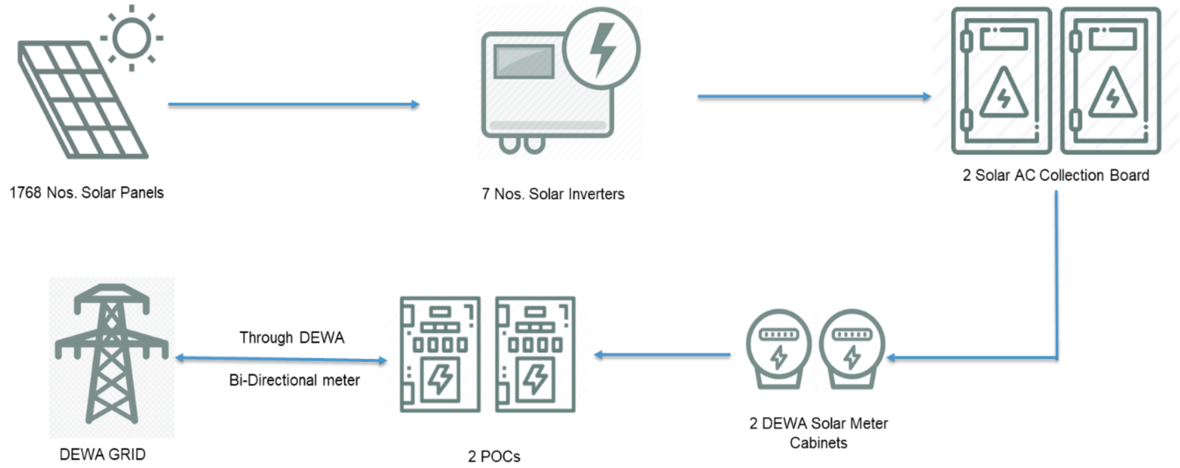
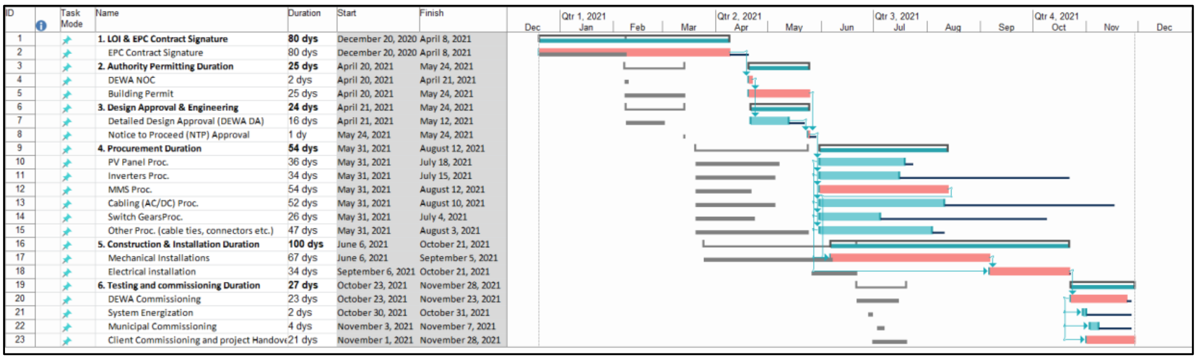


Figure 18: Case Study 2 Overview

4.3.2 Case Study 2 Analysis

The collected and analyzed data for this case study started with analyzing the As Planned and As Built schedules for the Project which resulted in a significant time overrun with 62% (POD%) more time compared to the initial intended plan. The project was initially planned to be delivered by 212 days while it actually took 344 days. The different phases and tasks held different delay patterns and time shifting as presented in the below Gantt Chart Figure 19. The chart compares the detailed As Planned durations, in gray bars and U shape brackets, and at the same time the As Built durations, in blue bars and inverted U shape brackets, to visualize the delay as well as shift of each of the tasks. The critical path, shown in red bars, plays an important role in the delay analysis since many tasks could experience delays but not all of them would affect the overall project timeline, since those tasks had a spare slack time compared to the critical tasks which holds a zero-slack time. The analysis will consider the root cause of the delays despite if it is in the critical path or not as some delays could numerically deceive the root causes.



ID		Task Mode	Name	Duration	Start	Finish
1			**1. LOI & EPC Contract Signature**	**80 dys**	December 20, 2020	April 8, 2021
2			EPC Contract Signature	80 dys	December 20, 2020	April 8, 2021
3			**2. Authority Permitting Duration**	**25 dys**	April 20, 2021	May 24, 2021
4			DEWA NOC	2 dys	April 20, 2021	April 21, 2021
5			Building Permit	25 dys	April 20, 2021	May 24, 2021
6			**3. Design Approval & Engineering**	**24 dys**	April 21, 2021	May 24, 2021
7			Detailed Design Approval (DEWA DA)	16 dys	April 21, 2021	May 12, 2021
8			Notice to Proceed (NTP) Approval	1 dy	May 24, 2021	May 24, 2021
9			**4. Procurement Duration**	**54 dys**	May 31, 2021	August 12, 2021
10			PV Panel Proc.	36 dys	May 31, 2021	July 18, 2021
11			Inverters Proc.	34 dys	May 31, 2021	July 15, 2021
12			MMS Proc.	54 dys	May 31, 2021	August 12, 2021
13			Cabling (AC/DC) Proc.	52 dys	May 31, 2021	August 10, 2021
14			Switch GearsProc.	26 dys	May 31, 2021	July 4, 2021
15			Other Proc. (cable ties, connectors etc.)	47 dys	May 31, 2021	August 3, 2021
16			**5. Construction & Installation Duration**	**100 dys**	June 6, 2021	October 21, 2021
17			Mechanical Installations	67 dys	June 6, 2021	September 5, 2021
18			Electrical installation	34 dys	September 6, 2021	October 21, 2021
19			**6. Testing and commissioning Duration**	**27 dys**	October 23, 2021	November 28, 2021
20			DEWA Commissioning	23 dys	October 23, 2021	November 23, 2021
21			System Energization	2 dys	October 30, 2021	October 31, 2021
22			Municipal Commissioning	4 dys	November 3, 2021	November 7, 2021
23			Client Commissioning and project Handove	21 dys	November 1, 2021	November 28, 2021

Figure 19: Case Study 2 - Gantt Chart Analysis

The network diagram below, Figure 20, shows the critical tasks in project 2 and correlate the interactions to the total project tasks.

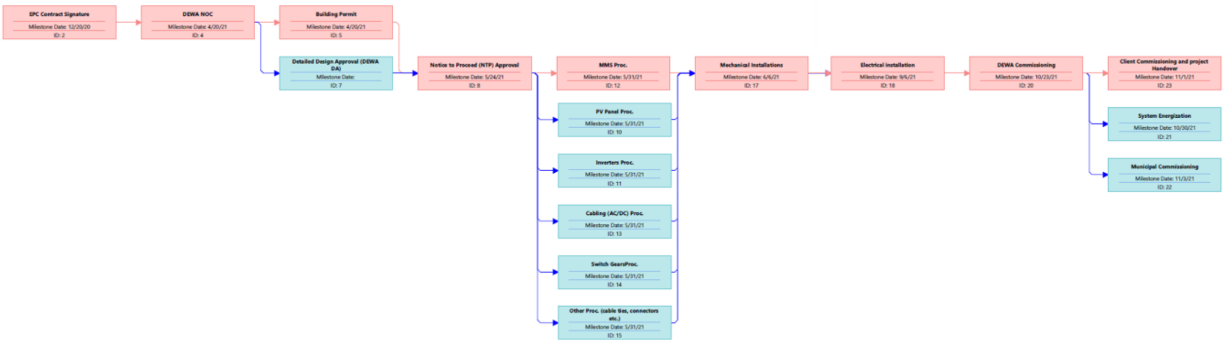


Figure 20: Case Study 2 - Network Diagram

Out of the project's major tasks that solar PV projects in Dubai go through, this project had nine tasks falling in the critical path. Each of these tasks contributed differently to the overall delay percentage, as shown in Figure 21, with the major delay caused by contract signature and Module Mounting System (MMS) procurement which formed together 65% of the critical delay. Electrical and mechanical installation during the construction phase shaped another 25% of delay in the project.

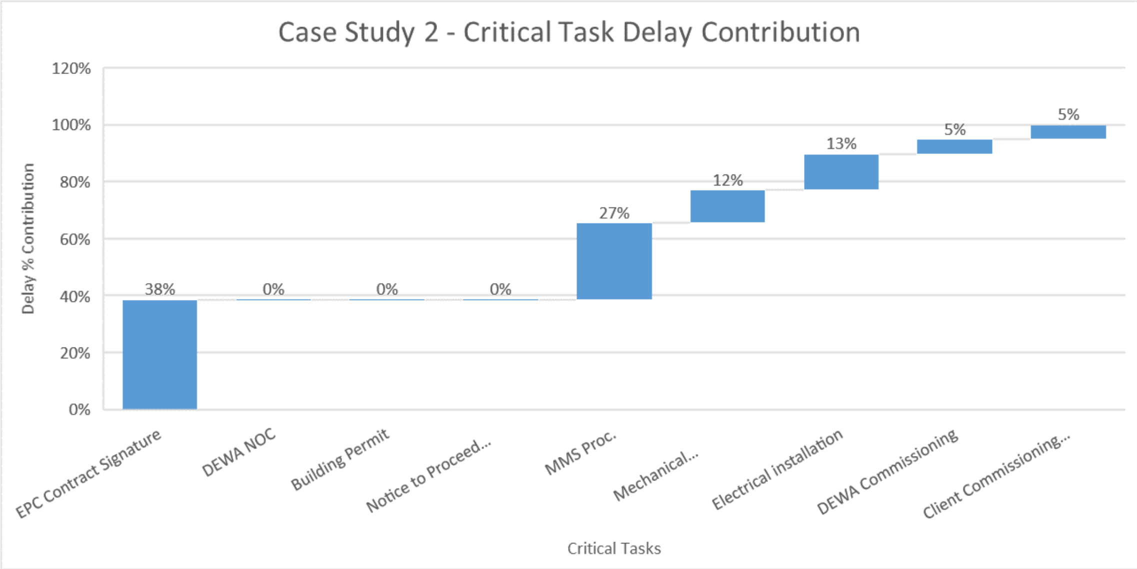


Figure 21: Case Study 2 - Critical Task Delay Contribution

When comparing the individual phases, the project shows a significant delay compared to the initial timeline. The Tabulated Figure 22, compares the delay significance in each of the phases compared to the As Planned schedule. The analysis resulted in a clear frontloading delay dominance in the contracting phase with 120%-time requirement compared to the initial plan. The procurement phase overall showed a moderate delay of 14% more time which was reflected on the construction phase prolonging resulting in 57% more time and finally the testing and commissioning phase at 28%.

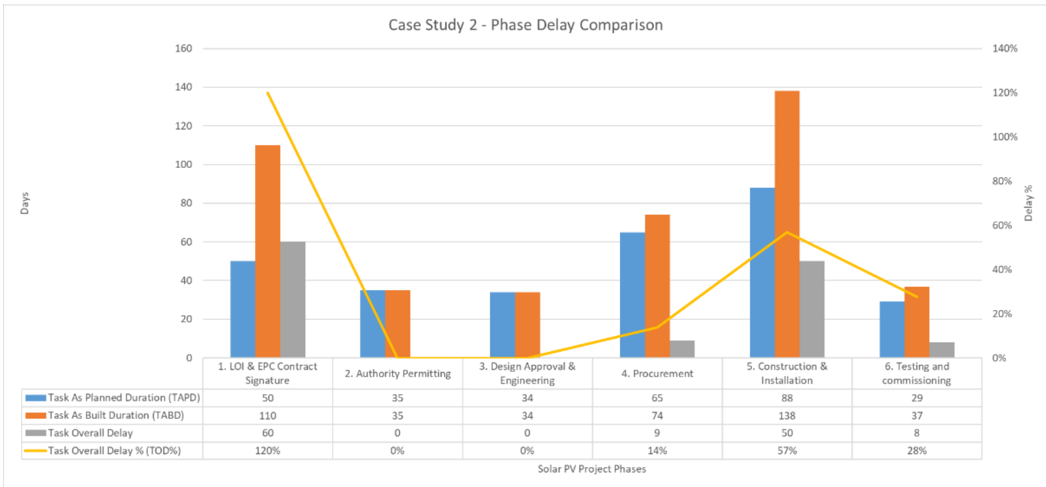
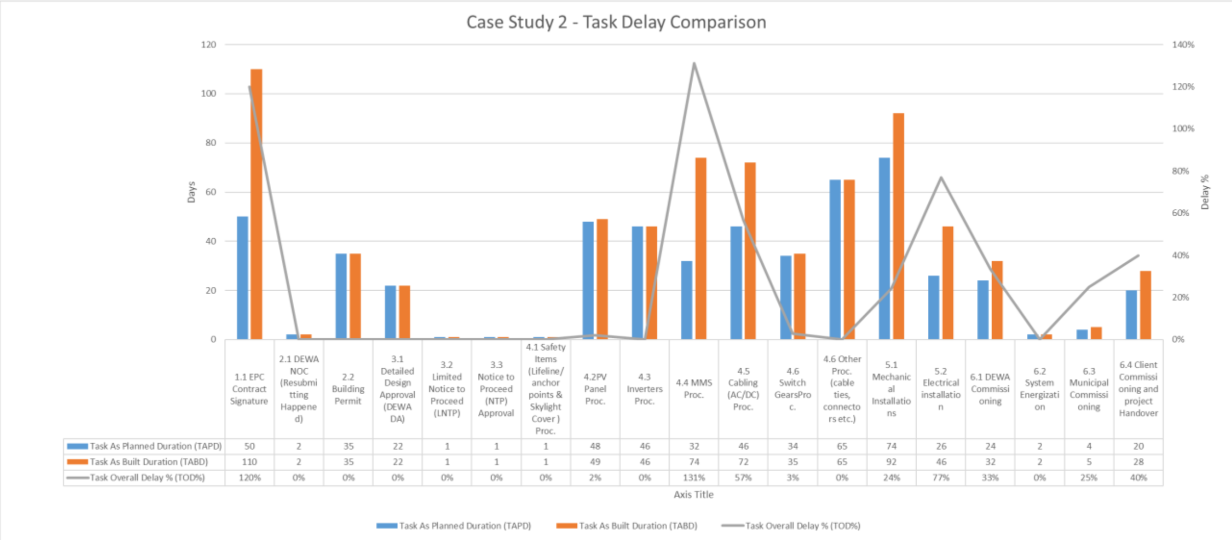


Figure 22: Case Study 2 - Phase Delay Comparison

Going a level down to the individual project tasks, Tabulated Figure 23, compares the task level delays. This deep diving revealed more delay information and showed that the project started with a 120% delay for the contract signature, then a steady progress with no delay until the procurement of the Module Mounting Structure (MMS) and DC cabling tasks with 131% and 57% more time compared to the initially planned time, respectively. In the other side, it is observed that electrical construction superseded the planned timing with 77% delay and mechanical construction which took 24% more time. The next step is to go into the details of the delays to understand the root cause behind the numerical findings.

Permitting tasks in this project did not create any direct delay impact since it was imbedded in the overall building permit since this building was constructed from scratch. DEWA permitting had a minor indirect delay impact by enforcing the usage of DC armored cabling in this project which was not imposed by DEWA before. The same goes to the design tasks that did not create any delay impact since it was imbedded in the overall building design since this building was constructed from scratch considering solar PV project.



	1.1 EPC Contract Signature	2.1 DEWA NOC (Resubmitting Happened)	2.2 Building Permit	3.1 Detailed Design Approval (DEWA DA)	3.2 Limited Notice to Proceed (LNTP)	3.3 Notice to Proceed (NTP) Approval	4.1 Safety Items (Lifeline/ anchor points & Skylight Cover) Proc.	4.2PV Panel Proc.	4.3 Inverters Proc.	4.4 MMS Proc.	4.5 Cabling (AC/DC) Proc.	4.6 Switch GearsProc.	4.6 Other Proc. (cable ties, connectors etc.)	5.1 Mechanical Installations	5.2 Electrical installation	6.1 DEWA Commissioning	6.2 System Energization	6.3 Municipal Commissioning	6.4 Client Commissioning and project Handover
Task As Planned Duration (TAPD)	50	2	35	22	1	1	1	48	46	32	46	34	65	74	26	24	2	4	20
Task As Built Duration (TABD)	110	2	35	22	1	1	1	49	46	74	72	35	65	92	46	32	2	5	28
Task Overall Delay % (TOD%)	120%	0%	0%	0%	0%	0%	0%	2%	0%	131%	57%	3%	0%	24%	77%	33%	0%	25%	40%

Figure 23: Case Study 2 - Task Delay Comparison

The above analysis shows a significant improvement opportunity for similar solar PV projects in Dubai, which will consequently improve the renewable project deployment rate and increase the financial returns of all stakeholding parties.

The root cause analysis utilized the Ishikawa Diagram or the fish bone diagram, as in Figure 24, to reach to the root cause and the delay percentage of each category with elaborative explanation in Table 4.

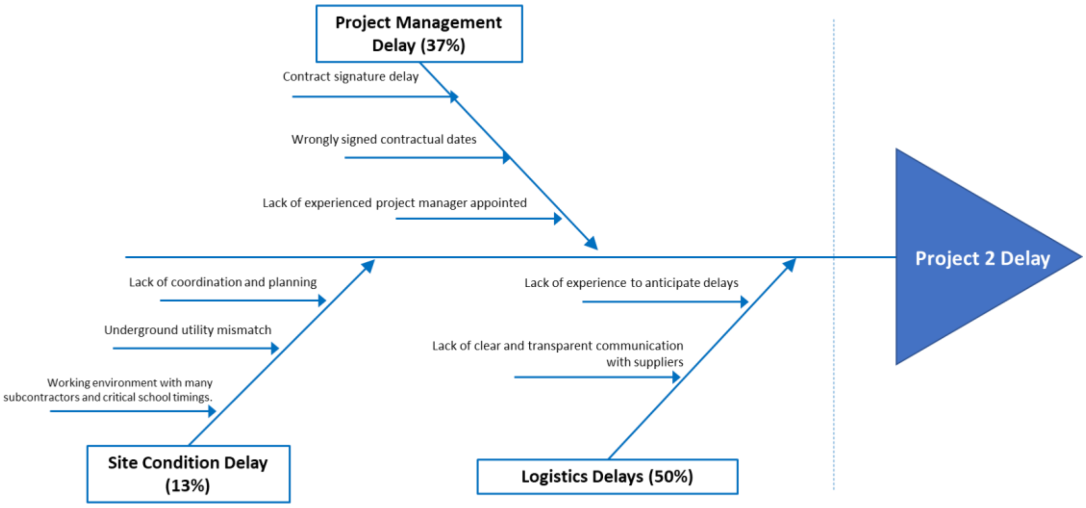


Figure 24: Case Study 2- Ishikawa Diagram/Fish bone diagram

Table 4: Case Study 2- Root Cause Delay Analysis

Delay Task	Root Cause Explanation	Delay Category	Mitigation Strategy
Task 1.1 EPC Contract Signature	The project owner initially intended to self-finance the project then saw an attractive financing opportunity through the project development company. The project's technical aspects were almost fully agreed-on since the building construction considered the solar since day one of the building construction plan. The expectation was to sign the contract in a fast-track way, but the negotiations took much more than expected specially for the Car Parking structure, which was heavily affecting the project financial offer, hence negotiation was prolonged. (32% delay contribution)	Project Management Delay (Contract management)	- Having a contract signature checklist which mandates the timeline update specially for the long negotiation periods. - Limiting the mail contract review to maximum 2 rounds and try to agree on online or face to face meeting to close most of the points on-spot rather than extending to lengthy mail chains and delay. The

	Even though the discussions took 60 days more compared to the initially planned EPC contract package, the final signed contract kept the old project schedule with the older dates instead of amending it with the updated dates as a common contract signing practice. The overall delay in this phase was 60 days.		discussed points in such meetings shall be recorded in Minutes of Meeting (MoM) and signed by both parties to document the process and to shortcut time.

Task 4.4 MMS Procurement	The procurement period was very critical since the COVID-19 impact on the intranational supply chain started to surface out during the project period. The Module Mounting Structure in this project was divided into two batches, one coming from a local supplier for the car parking zones of the project and the other part for the standing seam roofs which comes from Europe through an international supplier. The production and shipping of standing seam rooftop MMS took much more than planned although partial shipment happened by air freight to cut time lost. This delay added 18 delay days. (35% delay contribution)	- Logistics Delay	- Better and more transparent communication between the contractor and manufacturers to better anticipation such delays. - Early order placement for such critical items given the Limited Notice to Proceed (LNTP) was issued by end of May 2021, but it could have been requested earlier since the project was signed in April with all technical aspects agreed on. This is directly linked to the

			experience and awareness of the EPC project manager; hence, proper project management training shall be given to the PMs.
Task 4.5 Cabling (AC/DC) Proc.	The procurement period was very critical since the COVID-19 impact on the intranational supply chain started to surface out during the project period. Since DEWA imposed the DC armored cabling, which is not a standard practice in	Logistics Delay	- Better and more transparent communication between the contractor and manufacturers to better anticipation such delays.

	Dubai, the EPC had to make a special order from the local cable manufacturer in Abu Dhabi. The manufacturing of this type of cables took more than planned, and before the shipment day, the whole plant was shut down due to COVID spreading among the workers. This totally added 12 days of delay in this procurement which was critical since construction finalization completely depended on it. (15 % delay contribution)		- Early order placement for such critical items given the Limited Notice to Proceed (LNTP) was issued by end of May 2021, but it could have been requested earlier since the project was signed in April with all technical aspects agreed on. This is directly linked to the experience and awareness of the EPC project manager; hence, proper project management training shall be given to the PMs.

Task 5.1 Mechanical Installation and Task 5.2 Electrical installation	- Work environment: Since the facility was constructed from scratch, the site was with a lot more contractors compared to retrofit projects. The solar PV EPC contractor had many limitations such as working location restrictions and time of duty following the Civil Contractor orders (usually called the main contractor). Additionally, since the educational facility has opened its doors for students in September and solar construction was not finished in the electrical part of the project, working overnight was the only option to carry on the remaining work without effecting the	- Site Condition Delay	- Close and transparent work forecast schedule could be given to the main contractor to properly allocate the time and area for the solar PV team rather than planning each activity by its own would completely eliminate the delay caused due to congested working environment. - Site readiness (concerning solar work) falls directly under the responsibility of the contractor and this issue

	Business-as-usual activities onsite. (6% delay contribution) - Car parking conduit blockage: after the delay seen in DC armored cable delivery, the team had an unpleasant event where some DC cable conduits in the car parking columns (which was of a pre-casted concert material) were blocked and a tedious work took place to clear the conduits to run the cables. This resulted in 16 delay days in the project. Worth mentioning that the team was working overtime in all holidays to bridge the delay. (1% delay contribution)		should have been spotted out way before the cabling reach the site. Any conduit should have the tracking line that should be checked by the solar contractor since day one of the column installation. A checklist shall be adopted by the contractor to avoid similar incident in the future.

Task 6.4 Client Commissioning and project Handover	- Performance Ratio (PR) testing is a very critical test which takes place for a continuous 14 days after the system is completely ready for use to check its actual performance compared to the design performance. The test had couple of interruptions such as client imposition of 1 day-off due to student event. Then another 12 delay days dur to contractor miscalculation since the PR included 4 different areas and miss canulations occurred during the result presentation. This added 13 delay days to the project. (10% delay contribution)	- Site Condition - Project Management	- Having a weekly meeting with the client to inform him about the planned tasks would help minimizing the communication gap that led to PR starting delay of 1 day. - PR testing is a redundant testing in each project, having a ready-made template with the general requirements to completer such testing without miscalculation should be with the contractor to avoid

			reinventing the wheel and adding higher probability of doing calculation mistakes.

4.4 Case Study 3

4.4.1 Project Description and Background

The third case study is considered as, one of a type project, in Dubai due to its huge size, yet it is constructed under a single roof of a huge industrial manufacturing company in Dubai which supplies many counties in GCC region. The total project capacity is around 1,250 kWp of distributed solar PV installation which is expected to cover 45% of the facility consumption as shown in Figure 25. The plant is surrounded by three cement factories which gives a unique challenge to the operations and maintenance in the next 20 years.

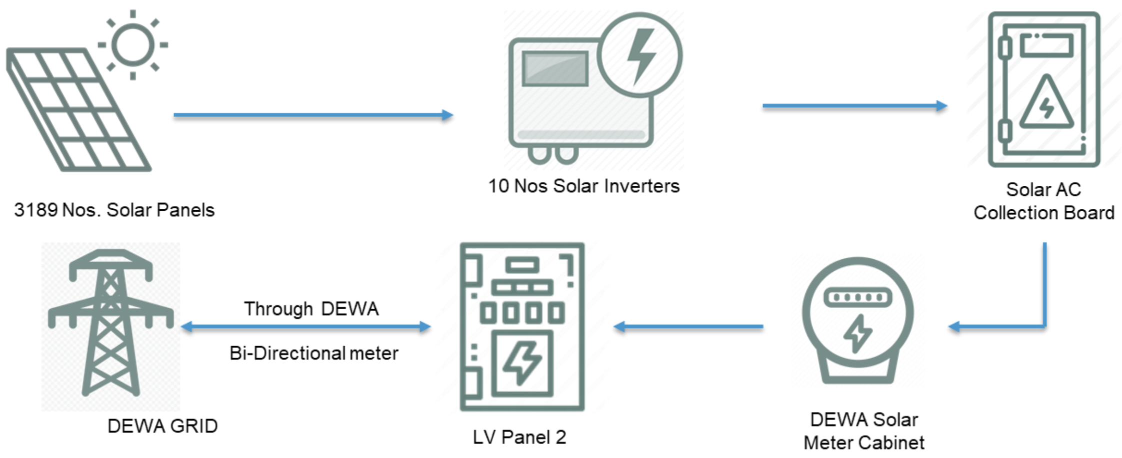
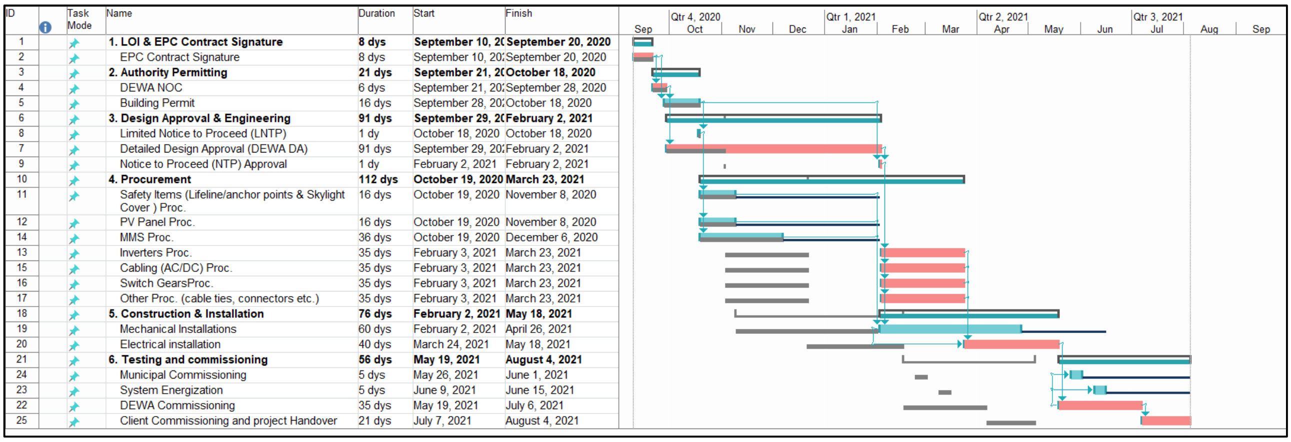


Figure 25: Case Study 3 Overview

4.4.2 Case Study Analysis

The collected and analyzed data for this case study started with analyzing the As Planned and As Built schedules for the Project which resulted in a significant time overrun with 38.8% (POD%) more time compared to the initial intended plan, where the project was initially planned to be delivered in 237 days while it actually took 329 days. The different phases held different delay patterns and time shifting as presented in the below Gantt Chart, Figure 26. The chart compares the detailed As Planned durations, in gray bars and U shape brackets, and at the same time the As Built durations, in blue bars and inverted U shape brackets, to visualize the delay as well as shift of each of the tasks. The critical path, shown in red bars, plays an important role in the delay analysis since many tasks could experience delays but not all of them would affect the overall project timeline, since those tasks had a spare slack time compared to the critical tasks which holds a zero-slack time. The analysis will consider the root cause of the delays despite if it is in the critical path or not as some delays could numerically deceive the root causes.



ID	Task Mode	Name	Duration	Start	Finish
1		**1. LOI & EPC Contract Signature**	**8 dys**	**September 10, 2(**	**September 20, 2020**
2		EPC Contract Signature	8 dys	September 10, 20:	September 20, 2020
3		**2. Authority Permitting**	**21 dys**	**September 21, 2(**	**October 18, 2020**
4		DEWA NOC	6 dys	September 21, 20:	September 28, 2020
5		Building Permit	16 dys	September 28, 20:	October 18, 2020
6		**3. Design Approval & Engineering**	**91 dys**	**September 29, 2(**	**February 2, 2021**
8		Limited Notice to Proceed (LNTP)	1 dy	October 18, 2020	October 18, 2020
7		Detailed Design Approval (DEWA DA)	91 dys	September 29, 20:	February 2, 2021
9		Notice to Proceed (NTP) Approval	1 dy	February 2, 2021	February 2, 2021
10		**4. Procurement**	**112 dys**	**October 19, 2020**	**March 23, 2021**
11		Safety Items (Lifeline/anchor points & Skylight Cover) Proc.	16 dys	October 19, 2020	November 8, 2020
12		PV Panel Proc.	16 dys	October 19, 2020	November 8, 2020
14		MMS Proc.	36 dys	October 19, 2020	December 6, 2020
13		Inverters Proc.	35 dys	February 3, 2021	March 23, 2021
15		Cabling (AC/DC) Proc.	35 dys	February 3, 2021	March 23, 2021
16		Switch GearsProc.	35 dys	February 3, 2021	March 23, 2021
17		Other Proc. (cable ties, connectors etc.)	35 dys	February 3, 2021	March 23, 2021
18		**5. Construction & Installation**	**76 dys**	**February 2, 2021**	**May 18, 2021**
19		Mechanical Installations	60 dys	February 2, 2021	April 26, 2021
20		Electrical installation	40 dys	March 24, 2021	May 18, 2021
21		**6. Testing and commissioning**	**56 dys**	**May 19, 2021**	**August 4, 2021**
24		Municipal Commissioning	5 dys	May 26, 2021	June 1, 2021
23		System Energization	5 dys	June 9, 2021	June 15, 2021
22		DEWA Commissioning	35 dys	May 19, 2021	July 6, 2021
25		Client Commissioning and project Handover	21 dys	July 7, 2021	August 4, 2021

Figure 26: Case Study 3 - Gantt Chart Analysis

The network diagram below, Figure 27, shows the critical tasks in project 3 and correlate the interactions to the total project tasks.

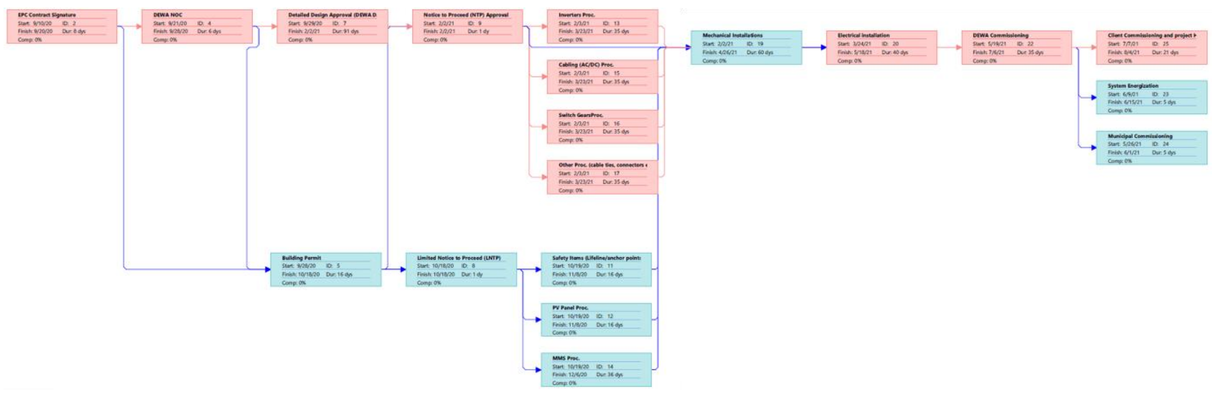


Figure 27: Case Study 3 - Network Diagram

Out of the 19 major tasks that solar PV projects in Dubai go through, this project had 10 tasks falling in the critical path. Only one task created all the delay, as shown in Figure 28, observed in this project which is DEWA design approval. This does not mean that no other delays were observed during the project, but this acted as a shadow to cover other unreported delay in procurement and construction.

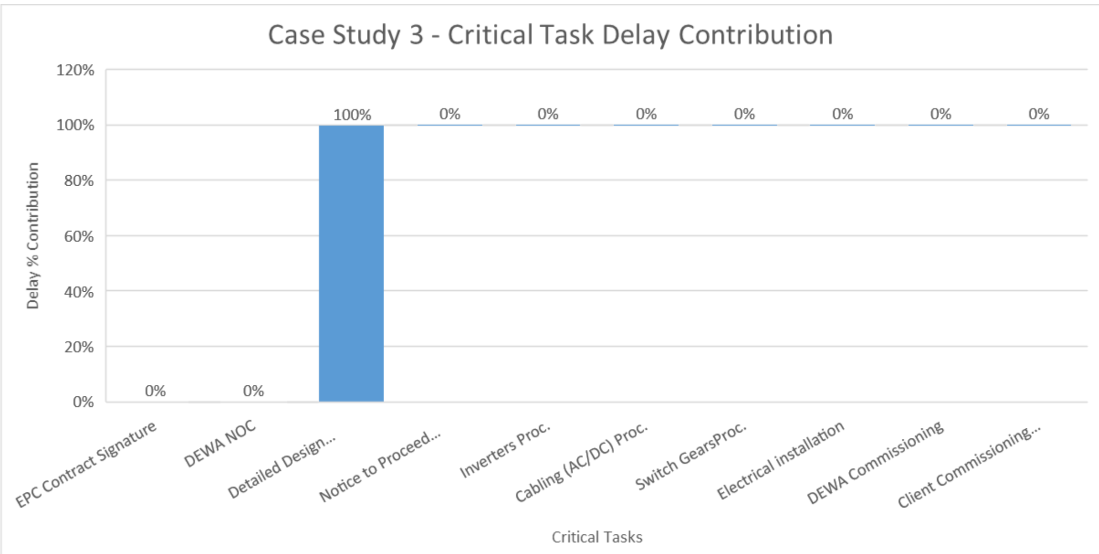


Figure 28: Case Study 3 - Critical Task Delay Contribution

When comparing the individual phases, without considering the critical path, the project shows a significant delay compared to the initial timeline. Tabulated Figure 29, compares the delay significance in each of the phases compared to the As Planned schedule. The analysis resulted in a mid-loading delay dominance in the design approval phase with 236% more-time requirement compared to the initial plan. The procurement phase overall showed a big delay too with 144%.

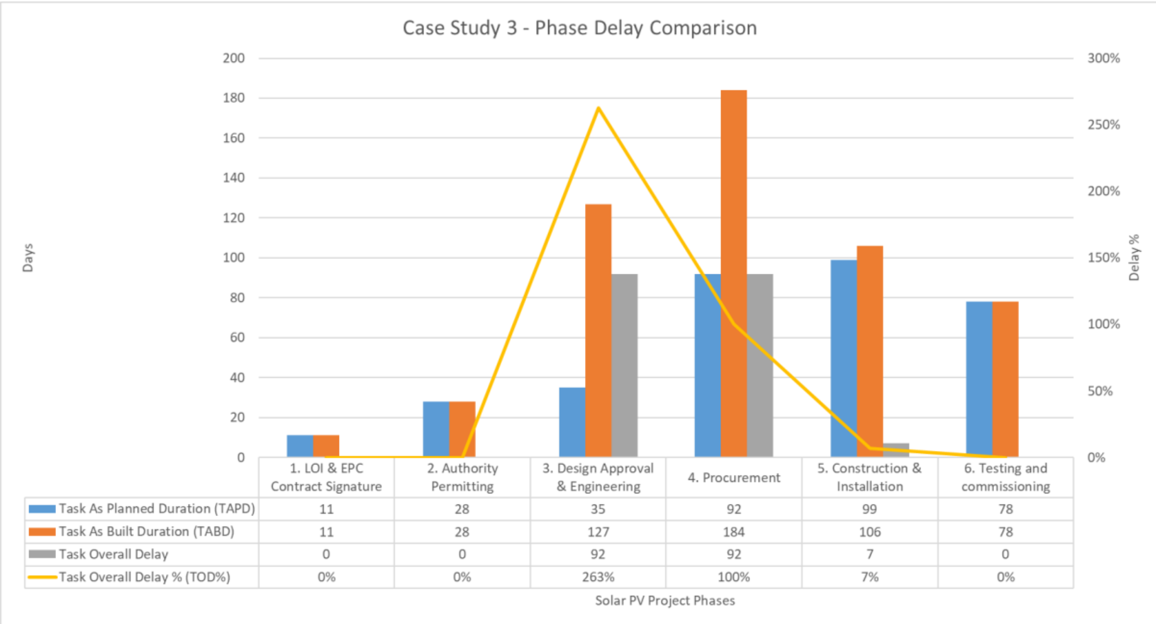


Figure 29: Case Study 3 - Phase Delay Comparison

Going a level down to the individual project tasks, Tabulated Figure 30, compares the task level delays. This deep diving revealed more information and showed that the project has a sole delay task which is DEWA Design Approval with 263%. The next step is finding the actuals and to go into the details of the delays to understand the root cause behind the numerical financings.

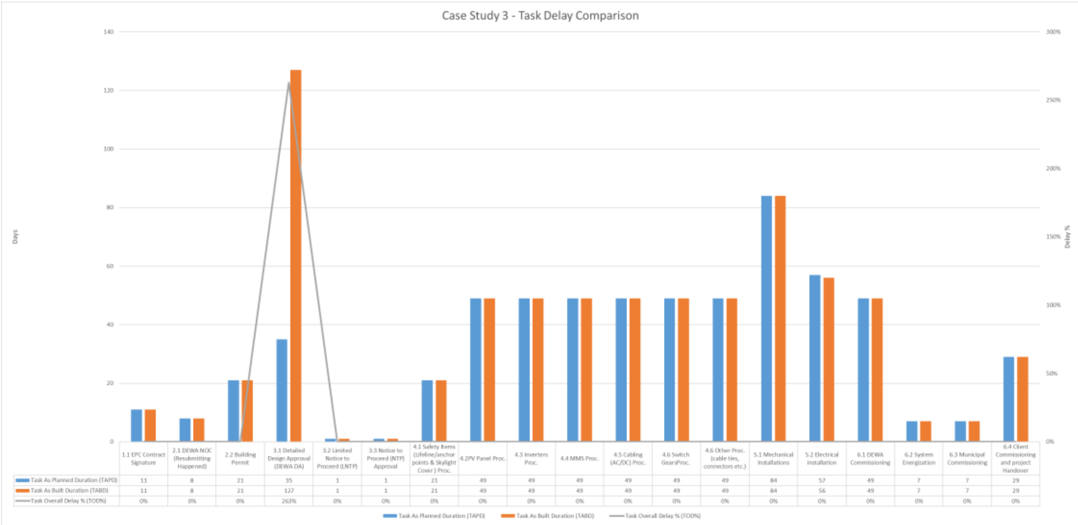


Figure 30: Case Study 3 - Task Delay Comparison

The above analysis shows a significant improvement opportunity for similar solar PV projects in Dubai, which will consequently improve the renewable project deployment rate and increase the financial returns of all stakeholding parties.

The root cause analysis utilized the Ishikawa Diagram or the fish bone diagram, as in Figure 31, to reach to the root cause and the delay percentage of each category with elaborative explanation in Table 5

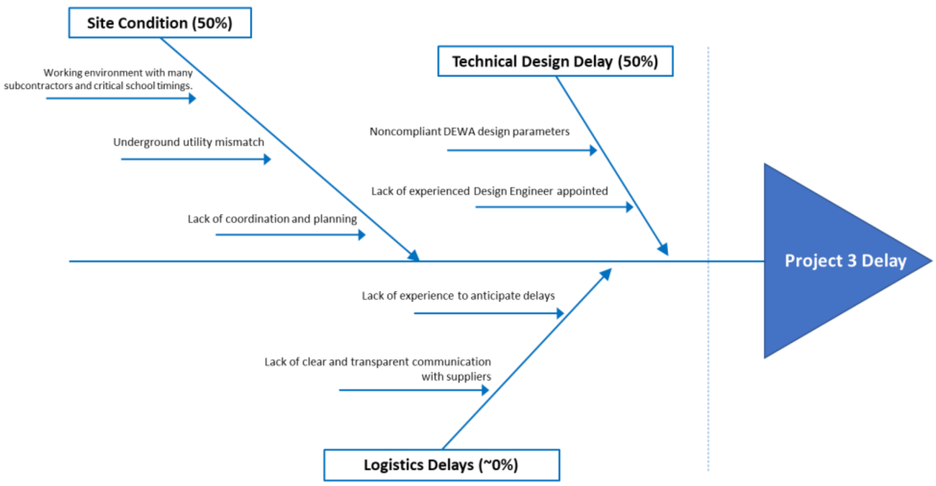


Figure 31: Case Study 3 - Ishikawa Diagram/Fish bone diagram

Table 5: Case Study 3 - Root Cause Delay Analysis Findings

Delay Task	Root Cause Explanation	Delay Category	Mitigation Strategy
Task 3.1 Detailed Design Approval (DEWA DA)	- DEWA DA approval was delayed tremendously due to client's electrical connection level on MV/LV point of connection, the issue linked to their load scheduling. The client had to approach DEWA to correct the issue before any solar PV design approval could be obtained. In summary, documentation mismatch between the drawings and As Built condition - DEWA asked for a round of review since the Solar electrical point of connection was proposed to be installed indoor initially	- Site Condition - Technical Design delay	- Client documentation shall be checked in much earlier stage e.g., during the contract negotiation stage since this is a simple task and is mandatory to do proper design proposals. A simple document verification checklist can be developed to overcome this issue in the future. - Initial site visit shall be conducted by a competent

	then the location was shifted to outdoor which is not preferred by DEWA. The contractor had to redo some calculations and issued a letter to DEWA informing them that it is not possible to install inside the LV room due to space restrictions. (99% delay contribution)		person by EPC before any proposal is made to DEWA in the Design approval stage with justification of uncommon installations. This would save the EPC the reviewing time and DEWA processing time.

Task 4.3 Inverters Proc.	- Since the timeline was shifted due to the above reason, procurement was forced to be during the Chinese New Year (starting on 12th Feb) where all companies close for 16 days, this creates production stacked delay if orders are not placed well in advanced. The major delayed component was Solar PV inverters. The As Planned procurement schedule was protective in terms of durations since this period was rich with Covid-19 restrictions and the contractors added a decent time buffer for each of the items, hence the delay affect was minimized even after all the above delays occurrence. The Limited Notice to	- Logistics Delay	- Better and more transparent communication between the contractor, system owner and manufacturers to better anticipation such delays and placing orders before the Chinese New Year. - Early order placement for some critical equipment given only one LNTP was issued, and much more could have been requested by the EPC to accommodate order placement before the Chinese New Year.

	Proceed was (LNTP) was not requested for the long lead time equipment. (1% delay contribution)		

CHAPTER V

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

Even though construction schedule delays are considered universal, those that occur in the commercial scale solar PV industry are particularly unique. This is due to the environment in which the construction is carried out, requirement for specialized materials, required manpower skillsets, relatively complex time schedules, and the associated unique authority permitting processes. The purpose of this study is to identify the delays observed in Dubai's solar PV construction industry, the primary reasons of delays, and how to overcome such events in the future. After analyzing the results, it can be concluded that the research objectives are achieved; the actual project delays were assessed, delay causes are identified, and mitigation strategies proposed. After conducting an in-depth multi case-study analysis and reviewing the relevant literature, a conceptual framework was constructed to outline the reasons for delay, along with their primary categories, and the significance of these factors.

The quantitative method was adopted, as opposed to the qualitative method, to establish evidence for the existence of these delays in Dubai's commercial scale solar PV projects, as well quantifying the impact and the mitigation techniques. The study's primary data is collected through actual and recent project data from the Dubai commercial solar PV construction industry. Furthermore, the secondary data is collected from literature reviews, prior surveys conducted, government publications, and technical documentation. As expected, the delays that surrounded the management of restrictive schedules in the solar PV industry and the factors that led to delays had deeper root causes than what is reported in the literature, hence root cause analysis was conducted.

The conclusion of the above-mentioned quantitative case study analysis could be summarized into the items listed below :

The analyzed case studies from Dubai's solar PV industry experienced significant delay with an average of 43% delay compared to the initial planned schedules, which is quite significant in the agile renewable environment. All three case studies experienced a common delay in three main phases namely LOI & EPC Contract Signature, Authority Permitting, and Procurement while the other phases showed delay in 1 or 2 of the case studies.

Task level analysis, expressed by the Pareto Chart in Figure 32, confirmed that 80% of delays were related to utility (DEWA) and municipal permitting which summed up to 67% (43% due to DEWA NOC, 14% due to DEWA Design Approval, and 10% due to Building Permit) of the total delay. These delays were due to client site condition issues and technical design mistakes. The contract signature without validated contractual timelines constituted 9% of the total delay, reason being the lack of project management experience and quality assurance processes. Finally, logistical delay, which formed 7% of the delay, was due to Module Mounting Structure (MMS) procurement shifting to be in the manufacture's public holidays and Covid-19 pandemic lockdown.

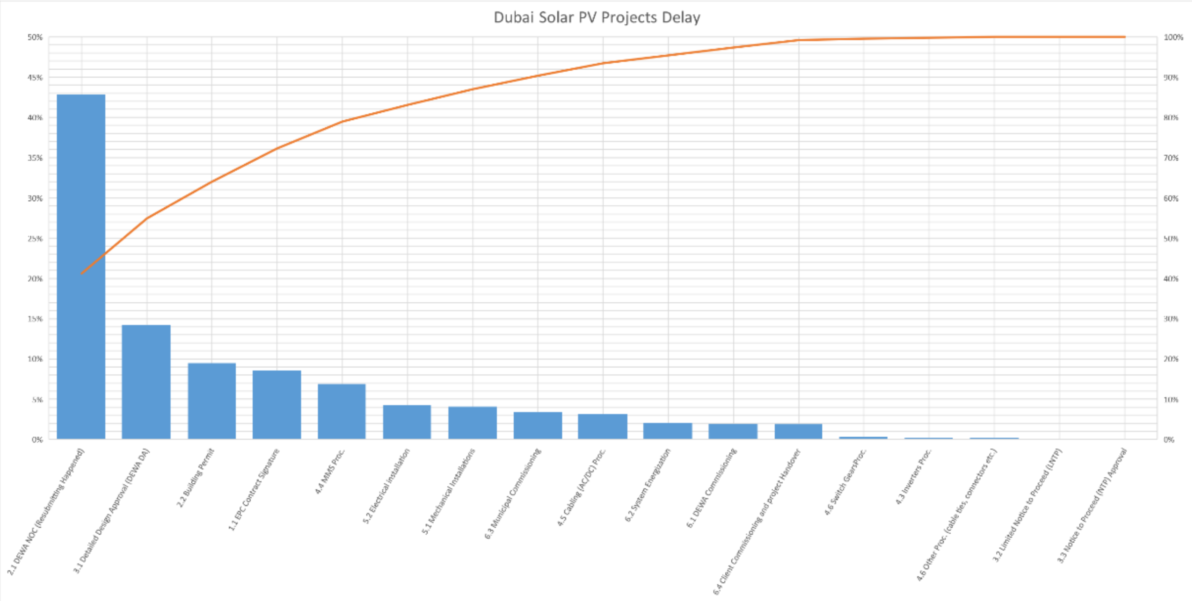


Figure 32: Dubai Solar PV Delays - Pareto Chart

The detailed root cause analysis and above-mentioned delays in Dubai's solar PV commercial scale projects resulted in four main delay categories starting with Site Condition Delays, Project Management Delays, Technical Design Delays, and Logistical Delays. The technical Design Delay constituted the most dominant cause of delay with 41.6%, followed by Site Condition Delay with 28.0%, then logistical delay of 16.7%, and finally project management delay with 13.7% as shown in Figure 33.

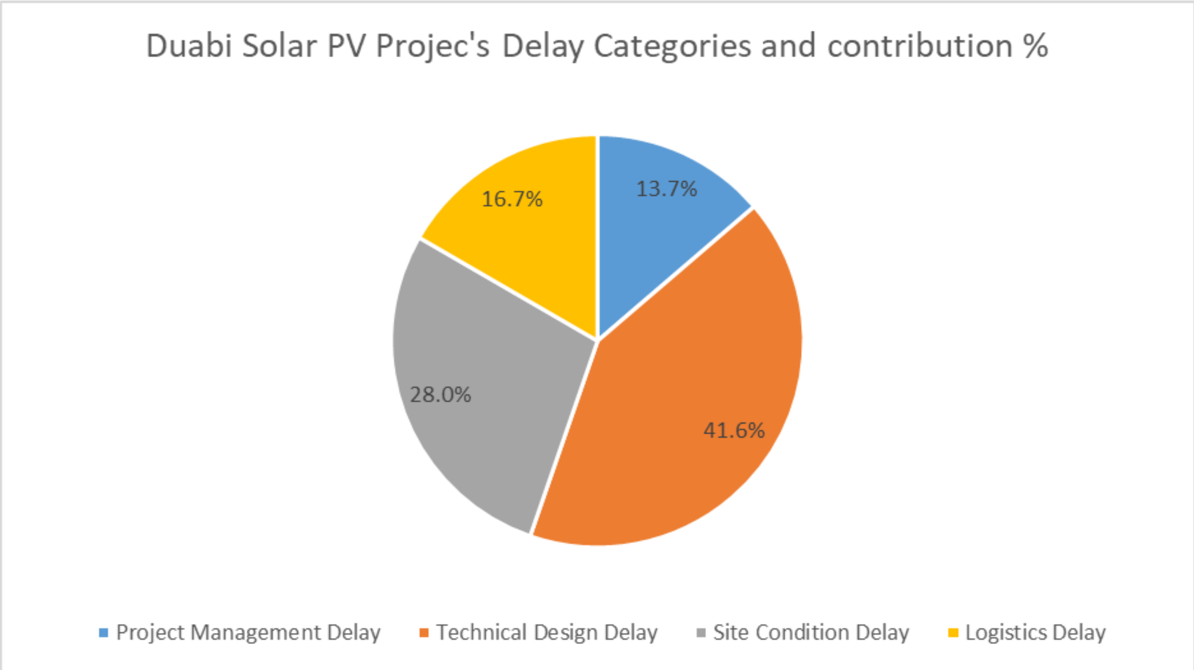


Figure 33: Dubai Solar PV Project's Delay Categories

The main causes of the Technical Design Delay (41.6%) were related to Consumption analysis mistakes in the early stage of permitting, incorrect AC cable sizing in compliance with DEWA requirements, and AC combiner switchgear design noncompliance with DEWA requirements. Despite that, all designers working on the authority submittals should be certified by the Authority. It has been concluded that quality assurance practices need to be adopted by the designer's companies to avoid such delays, which could be pretty much controllable through additional review layers, quality assurance checklists, and refreshment trainings.

The analyzed case studies showed that Site Condition Delay formed 28% of the total delay observed in Dubai's solar PV projects. This delay is a result of client's site drawing discrepancy with the As-Built conditions, either electrically or structurally, which mandate site rectification and consequently prolong the task duration more than planned. Such mismatch impacts the permitting tasks directly which is unsophisticated in nature but tightly linked the quality of the submitted documentation. In return, that could shorten the permitting time to couple of days or extend it to couple of months as it has been observed. The mitigation strategy that should be adopted is having a Quality Assurance procedure before the final submissions, to confirm site conditions with the available Site As-Built drawings. This QA task could take place as early as the contract negotiation stage, keeping in mind this is not a time or labor-intensive task, and could be done in a very short time given that proper training is provided.

The logistical delays constituted 16.7% of the total delay in Dubai's solar PV projects this is mainly linked to procurement shifting to take place during the public holidays, for instance the Chinese New Year when all manufacturers halt working for a period of two weeks. Moreover, another factor is linked to force majeure events like COVID-19 or the intranational logistical crises impact. The mitigation strategies are directly linked to the experience of the project manager who hold the responsibly of anticipating such events earlier and take corrective actions such as requesting an early LNTP for items with long lead time that fall in the project's critical path. This would be more feasible through establishing a transparent communication between the EPC and the client to overcome this expected event.

Finally, project management delays, which formed 13.7% of the total delays, are due to contract signature with wrong dates after lengthy negotiation rounds and significant time that doesn't get reflected on the final signed contract and not even requested through a contract timeline amendment early in the project lifetime. This makes the project commence with an existing delay which pressures the team to deliver results within a shortened time period. This ultimately could lead into mistakes or quality compromise, keeping in mind that any delay would impose liquidity damages penalties. Such delays could be mitigated by implementing a Quality Assurance (QA) procedure where the contract signature checklist is utilized to mandate updating the timeline before the official signatures. Additionally, proving efficient training for project managers to explain the importance of this action and how it impacts the project performance.

The results presented above links to the previously identified common construction delays in the literature review, where the main delay categories are linked to Site coordination and communication, material procurement and delivery, labor skillset, project management practices, and finally equipment availability. The site condition delay category is a newly highlighted category in the solar PV projects since mostly the commercial scale projects comes after the building completion and site condition plays a vital role in it.

5.2 Recommendation

The delays in Dubai's solar PV construction projects exhibited a significant enhancement opportunity. The recommendations that this research resulted in are listed in Table 6, where delay mitigation strategies are recommended for each of the identified delay categories.

Table 6: Delay Recommended Mitigation Strategies

Delay Category	Recommended Mitigation Strategy
Technical Design Delay	- Adding a QA review layer/level before any authority submittal - Formulation of QA checklist that shall be checked before any authority submittal - Conduct refreshment trainings annually with the updated authority requirements (electrical/structural)
Site Condition Delay	- Formulating a QA procedure to do site electrical and structural condition check right after the EPC contract signature
Logistics Delay	- Conducting trainings for PMs to request LNTPs/NTPs whenever any delay is anticipated

	- Adding the procurement status review in all weekly project follow up meetings
Project Management Delay	- Enforcing pre-EPC contract signature checklist to validate the timeline before signature - Conducting timeline management trainings to the PMs

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ANNEXES

7.1 Case Study 1 Tables

Project Phase	As Planned Schedule - Phase Starting Date	As Planned Schedule - Phase Finishing Date	As Built Schedule- Starting Date	As Built Schedule - Finishing Date	Task As Planned Duration (TAPD)	Task As Built Duration (TABD)	Task Overall Delay	Task Overall Delay % (TOD%)
1. LOI & EPC Contract Signature	October 21, 2020	November 10, 2020	October 21, 2020	November 19, 2020	21	30	9	43%
1.1 EPC Contract Signature	October 21, 2020	November 10, 2020	October 21, 2020	November 19, 2020	21	30	9	43%
2. Authority Permitting	November 11, 2020	December 8, 2020	November 11, 2020	January 31, 2021	28	82	54	193%
2.1 DEWA NOC (Resubmitting Happened)	November 11, 2020	November 19, 2020	November 11, 2020	January 31, 2021	9	82	73	811%
2.2 Building Permit	November 19, 2020	December 8, 2020	November 24, 2020	January 18, 2021	20	56	36	180%
3. Design Approval & Engineering	November 22, 2020	December 24, 2020	February 1, 2021	March 7, 2021	33	35	2	6%
3.1 Detailed Design Approval (DEWA DA)	November 22, 2020	December 24, 2020	February 1, 2021	March 7, 2021	33	35	2	6%

3.2 Limited Notice to Proceed (LNTP)	December 8, 2020	December 8, 2020	February 15, 2021	February 15, 2021	1	1	0	0%
3.3 Notice to Proceed (NTP) Approval	December 24, 2020	December 24, 2020	March 7, 2021	March 7, 2021	1	1	0	0%
4. Procurement Duration	December 9, 2020	February 11, 2021	February 15, 2021	April 25, 2021	65	70	5	8%
4.1 Safety Items (Lifeline/anchor points & Skylight Cover) Proc.	December 9, 2020	December 29, 2020	February 15, 2021	February 21, 2021	21	7	-14	-67%
4.2PV Panel Proc.	December 9, 2020	February 2, 2021	March 8, 2021	April 25, 2021	56	49	-7	-13%
4.3 Inverters Proc.	December 27, 2020	February 11, 2021	March 8, 2021	April 25, 2021	47	49	2	4%
4.4 MMS Proc.	December 9, 2020	January 26, 2021	February 15, 2021	April 4, 2021	49	49	0	0%
4.5 Cabling (AC/DC) Proc.	December 27, 2020	February 11, 2021	March 8, 2021	April 25, 2021	47	49	2	4%
4.6 Switch GearsProc.	December 27, 2020	February 11, 2021	March 8, 2021	April 25, 2021	47	49	2	4%
4.6 Other Proc. (cable ties, connectors etc.)	December 27, 2020	February 11, 2021	March 8, 2021	April 25, 2021	47	49	2	4%
5. Construction & Installation	January 3, 2021	April 8, 2021	February 22, 2021	June 20, 2021	96	119	23	24%

5.1 Mechanical Installations	January 3, 2021	March 16, 2021	February 22, 2021	June 13, 2021	73	112	39	53%
5.2 Electrical installation	February 14, 2021	April 8, 2021	April 26, 2021	June 20, 2021	54	56	2	4%
6. Testing and commissioning	April 11, 2021	June 28, 2021	June 21, 2021	September 6, 2021	79	78	-1	-1%
6.1 DEWA Commissioning	April 11, 2021	May 27, 2021	June 21, 2021	August 8, 2021	47	49	2	4%
6.2 System Energization	May 2, 2021	May 6, 2021	July 12, 2021	July 18, 2021	5	7	2	40%
6.3 Municipal Commissioning	April 18, 2021	April 22, 2021	June 28, 2021	July 4, 2021	5	7	2	40%
6.4 Client Commissioning and project Handover	May 30, 2021	June 28, 2021	August 9, 2021	September 6, 2021	30	29	-1	-3%

7.2 Case Study 2 Tables

Project Phase	As Planned Schedule - Phase Starting Date	As Planned Schedule - Phase Finishing Date	As Built Schedule- Starting Date	As Built Schedule - Finishing Date	Task As Planned Duration (TAPD)	Task As Built Duration (TABD)	Task Overall Delay	Task Overall Delay % (TOD%)
1. LOI & EPC Contract Signature	December 20, 2020	February 7, 2021	December 20, 2020	April 8, 2021	50	110	60	120%
EPC Contract Signature	December 20, 2020	February 7, 2021	December 20, 2020	April 8, 2021	50	110	60	120%
2. Authority Permitting	February 7, 2021	March 13, 2021	April 20, 2021	May 24, 2021	35	35	0	0%
DEWA NOC	February 7, 2021	February 8, 2021	April 20, 2021	April 21, 2021	2	2	0	0%
Building Permit	February 7, 2021	March 13, 2021	April 20, 2021	May 24, 2021	35	35	0	0%
3. Design Approval & Engineering	February 8, 2021	March 13, 2021	April 21, 2021	May 24, 2021	34	34	0	0%
Detailed Design Approval (DEWA DA)	February 8, 2021	March 1, 2021	April 21, 2021	May 12, 2021	22	22	0	0%
Limited Notice to Proceed (LNTP)					1	1	0	0%

Notice to Proceed (NTP) Approval	March 13, 2021	March 13, 2021	May 24, 2021	May 24, 2021	1	1	0	0%
4. Procurement	March 20, 2021	May 23, 2021	May 31, 2021	August 12, 2021	65	74	9	14%
Safety Items (Lifeline/anchor points & Skylight Cover) Proc.					1	1	0	0%
PV Panel Proc.	March 20, 2021	May 6, 2021	May 31, 2021	July 18, 2021	48	49	1	2%
Inverters Proc.	March 20, 2021	May 4, 2021	May 31, 2021	July 15, 2021	46	46	0	0%
MMS Proc.	March 20, 2021	April 20, 2021	May 31, 2021	August 12, 2021	32	74	42	131%
Cabling (AC/DC) Proc.	March 20, 2021	May 4, 2021	May 31, 2021	August 10, 2021	46	72	26	57%
Switch GearsProc.	March 20, 2021	April 22, 2021	May 31, 2021	July 4, 2021	34	35	1	3%
Other Proc. (cable ties, connectors etc.)	March 20, 2021	May 23, 2021	May 31, 2021	August 3, 2021	65	65	0	0%
5. Construction & Installation	March 25, 2021	June 20, 2021	June 6, 2021	October 21, 2021	88	138	50	57%

Mechanical Installations	March 25, 2021	June 6, 2021	June 6, 2021	September 5, 2021	74	92	18	24%
Electrical installation	May 26, 2021	June 20, 2021	September 6, 2021	October 21, 2021	26	46	20	77%
6. Testing and commissioning	June 21, 2021	July 19, 2021	October 23, 2021	November 28, 2021	29	37	8	28%
DEWA Commissioning	June 21, 2021	July 14, 2021	October 23, 2021	November 23, 2021	24	32	8	33%
System Energization	June 28, 2021	June 29, 2021	October 30, 2021	October 31, 2021	2	2	0	0%
Municipal Commissioning	July 3, 2021	July 6, 2021	November 3, 2021	November 7, 2021	4	5	1	25%
Client Commissioning and project Handover	June 30, 2021	July 19, 2021	November 1, 2021	November 28, 2021	20	28	8	40%

7.3 Case study 3 Tables

Project Phase	As Planned Schedule - Phase Starting Date	As Planned Schedule - Phase Finishing Date	As Built Schedule- Starting Date	As Built Schedule - Finishing Date	Task As Planned Duration (TAPD)	Task As Built Duration (TABD)	Task Overall Delay	Task Overall Delay % (TOD%)
1. LOI & EPC Contract Signature	September 10, 2020	September 20, 2020	September 10, 2020	September 20, 2020	11	11	0	0%
EPC Contract Signature	September 10, 2020	September 20, 2020	September 10, 2020	September 20, 2020	11	11	0	0%
2. Authority Permitting	September 21, 2020	October 18, 2020	September 21, 2020	October 18, 2020	28	28	0	0%
DEWA NOC	September 21, 2020	September 28, 2020	September 21, 2020	September 28, 2020	8	8	0	0%
Building Permit	September 28, 2020	October 18, 2020	September 28, 2020	October 18, 2020	21	21	0	0%
3. Design Approval & Engineering	September 29, 2020	November 2, 2020	September 29, 2020	February 2, 2021	35	127	92	263%
Detailed Design Approval (DEWA DA)	September 29, 2020	November 2, 2020	September 29, 2020	February 2, 2021	35	127	92	263%
Limited Notice to Proceed (LNTP)	October 18, 2020	October 18, 2020	October 18, 2020	October 18, 2020	1	1	0	0%

Notice to Proceed (NTP) Approval	November 2, 2020	November 2, 2020	February 2, 2021	February 2, 2021	1	1	0	0%
4. Procurement	September 21, 2020	December 21, 2020	September 21, 2020	March 23, 2021	92	184	92	100%
Safety Items (Lifeline/anchor points & Skylight Cover) Proc.	October 19, 2020	November 8, 2020	October 19, 2020	November 8, 2020	21	21	0	0%
PV Panel Proc.	September 21, 2020	November 8, 2020	September 21, 2020	November 8, 2020	49	49	0	0%
Inverters Proc.	November 3, 2020	December 21, 2020	February 3, 2021	March 23, 2021	49	49	0	0%
MMS Proc.	October 19, 2020	December 6, 2020	October 19, 2020	December 6, 2020	49	49	0	0%
Cabling (AC/DC) Proc.	November 3, 2020	December 21, 2020	February 3, 2021	March 23, 2021	49	49	0	0%
Switch GearsProc.	November 3, 2020	December 21, 2020	February 3, 2021	March 23, 2021	49	49	0	0%
Other Proc. (cable ties, connectors etc.)	November 3, 2020	December 21, 2020	February 3, 2021	March 23, 2021	49	49	0	0%
5. Construction & Installation	November 9, 2020	February 15, 2021	February 2, 2021	May 18, 2021	99	106	7	7%

Mechanical Installations	November 9, 2020	January 31, 2021	February 2, 2021	April 26, 2021	84	84	0	0%
Electrical installation	December 21, 2020	February 15, 2021	March 24, 2021	May 18, 2021	57	56	0	0%
6. Testing and commissioning	February 16, 2021	May 4, 2021	May 19, 2021	August 4, 2021	78	78	0	0%
DEWA Commissioning	February 16, 2021	April 5, 2021	May 19, 2021	July 6, 2021	49	49	0	0%
System Energization	March 9, 2021	March 15, 2021	June 9, 2021	June 15, 2021	7	7	0	0%
Municipal Commissioning	February 23, 2021	March 1, 2021	May 26, 2021	June 1, 2021	7	7	0	0%
Client Commissioning and project Handover	April 6, 2021	May 4, 2021	July 7, 2021	August 4, 2021	29	29	0	0%