

LIGHTING THE PATH

The next stage in utility-scale solar development



EXECUTIVE SUMMARY

Solar is currently the fastest-growing generation technology in the world, with a continuously decreasing levelized cost of electricity (LCOE). Today, approximately half of global installed solar generation is from utility-scale plants, defined as grid-connected, ground-mounted plants of 5 MW DC (direct current) or larger. At approximately 2,500 to 4,000 panels per MW, the large number of panels, inverters, material movements, projects, contracts, stakeholders, and suppliers and repetitive nature of construction make solar a strong candidate for digital transformation.

The most significant challenge for solar generators is managing the end-to-end development process to meet the target cost, timeline and LCOE, given the different transitions and parties involved in the process. In origination and business development, the primary challenges are finding, financing and competing for the most appealing projects, given the variety of technology options and cost and resource yield implications. In engineering, it's designing the most commercially competitive solution, including the technology choices and delivery model. In project and contract management, it's commercial and operational management of the contracts including schedule, cost and project control structures. In construction, it's the management of the large numbers of people and materials on the field to verify safe, efficient operations and an effective handover to operations and maintenance (O&M).

Solar is an incredibly competitive market with low barriers to entry and many different players that enter and exit projects at various stages of development. This has led to a variety of operating models and significant differences in investment practices.

We set out to uncover approaches to address the challenges solar generators face and what they need to do to drive greater performance in solar development going forward. We leveraged Accenture project experience, research and interviews with six leading players in solar project development around the world, and from this analysis identified six themes and related opportunities. Our study also draws on lessons from other industries with similar repetitive small project and construction processes, such as industrial manufacturing and unconventional resource development, to bring to life some of the opportunities captured in other sectors.

Six key themes

THEME 1: An end-to-end approach, powered by digital, is required.

The development of a solar project needs to be tracked from the earliest conceptualization, when the LCOE estimates and financial case are developed, through to operational start-up. The end-to-end approach needs to look at both the commercial side of a project—tracking the LCOE of project/asset during the life cycle of the project/asset—and operational side, managing the flow of documents, materials, handovers, and tracking workforce productivity and interfaces across the different project stakeholders.

THEME 2: Front-end data and analytics are key to optimize LCOE.

Analytics are required across the origination, business development and conceptual design phases, all leveraging large data sets, i.e., site selection parameters, panel orientation, assessment of solar resource, future energy prices, power purchase agreement (PPA) terms, current and future technical specifications, cost and performance data on module and tracking systems, and O&M costs.

THEME 3: Collaboration on the cloud is paramount to commercial and operational management of partners.

Develop a collaborative digital environment for document management and version control of the contract and associated project documents during the project life cycle, including records of the design documents, permits and licenses, audit trails of communications related to variations, and purchase orders.

THEME 4: Invest in digital construction including robotics, supply chain and digital worker.

Invest in analytics to improve the construction process. This includes increasing visibility in the construction progress and the materials in the supply chain and to monitor schedule and contractor performance, robotics to do the drilling, pile driving, installation and even operation, mobility to support workers on the field, and automation of module assembly.

THEME 5: Enhance cybersecurity resilience while increasing readiness for regulatory compliance.

Strengthen cybersecurity investments and practices for renewables that support compliance with existing regulations, leading practices and increase resilience against and fast response to potential attacks.

THEME 6: Assess O&M impact on design and LCOE.

Assess the impact of O&M technology choices, maintenance approach, and confirm that learnings are passed to the next project.

Addressing these six themes is critical to the future success of players that want to grow their solar portfolios. Digital is a key enabler, and those investing in digital are better positioned to address the themes and capture the related opportunities. We have defined eight key digital capabilities that generators can use to create new value and performance.

INTRODUCTION

Study context

Overall, solar photovoltaic (PV) is the world's fastest-growing renewable technology, reaching approximately 400 GW of installed power in 2017 and representing 2 percent of installed electricity generation capacity. China, the European Union, the United States and Japan are the main drivers of this growth. The solar PV market ranges from an individual household rooftop solar installation to solar farms of hundreds of MW; in between there is community and larger C&I private solar generation. "Utility-scale" generally refers to grid-connected solar farms of 5 MW or greater (12,500 to 20,000 solar panels) up to solar parks with capability in the hundreds of MW (millions solar panels). The number of panels depends on productivity, technology and location. In 2017, the median installed cost of solar PV in the United States fell to \$2.0/W AC (alternating current) or \$1.6/W DC (direct current), with the lowest \$0.9/W AC.1 Utility-scale solar can be four times less expensive than rooftop solar.²

Our report focuses on grid-connected utility-scale solar PV development, such as large solar farms with tens of thousands to millions of panels. The value chain of solar development can include different parties and transactions between every step of development. Given the fragmented value chain and the scale of development in large utility-scale solar projects with a huge number of material movements and a large workforce, digital technologies can significantly improve the integration across parties and the conceptual design of the solar plant, as well as detailed plant engineering and construction. Indeed, some of the largest utility-scale solar projects are becoming so complex that they are starting to face the same historical challenges faced by oil and gas capital projects, resulting in difficulties in delivering on time, on budget and to a high standard.

These challenges are largely driven by the complex supply chains of new capital projects, which result in many experiencing cost or schedule overruns. This problem is compounded by the shortage of operational insight and lack of quality assurance and oversight over the process due to scattered data from various sources, legacy software systems and a lack of standardization. An all-inclusive platform allowing a detailed real-time view of the projects at every stage is becoming an increasingly attractive prospect for the renewable energy sector.

LIGHTING THE PATH

Use of DC/AC ratio in our study

Inverters are electronic devices or circuitry which convert DC—generated by a solar cell—AC to be injected into the transmission lines (or electricity grid). Hence, the selection of the inverter during the engineering and design phase plays an important role in the project design and performance. To that end, it is important to consider how much DC power the panel will supply and how much AC power the inverter can yield. This is also known as the inverter's power rating. The ratio of how much DC capacity is installed to the inverter's AC power rating is called the DC/AC ratio.

Traditionally, it was understood that the most desirable ratio was at 1 to 1.1. However, more recently-due to the decrease in solar panel costs-it has emerged that oversizing the DC capacity to get a higher ratio (e.g., 1.3) allows the plant to gather energy when the production is below the inverter's rating. The trade-off is the cost of the inverter clipping, or power limiting, which ensures the inverter is operating within its capabilities, resulting in lost energy production during peak production hours. However, studies have shown that the lost production generally only happens for 10 to 20 percent of the day.³ Our study both uses capacity numbers quoted in DC, and in DC/AC ratio given its increasing relevance and changing dynamics.



Figure 1. Inverter DC/AC ratio and power output.

Source: Bromberg, David. Aurora Solar blog, posted March 14, 2017, https://blog.aurorasolar.com.

Solar growth has been driven by the falling costs of solar panels but also by government incentives. As illustrated in Figure 2, in many markets utility-scale solar is now one of the lowest-cost energy sources, with a continuously falling LCOE.

There is an increasing expectation that solar will need to stand on its own without subsidies or other regulatory supports. Additionally, solar projects funded through PPAs are even more time-sensitive as the commercial terms are linked to the committed delivery timeline, so delays directly impact the LCOE. This means an already crowded market will become even more competitive. Investors will need to minimize the LCOE of solar projects. The LCOE estimates are composed of several factors, including estimates of yield/resource, electricity price, technology choice and component costs, construction costs, O&M cost, and asset life.

Figure 2. Comparison of LCOE by technology.



Levelized cost (\$/MWh)

Source: Lazard's Levelized Cost of Energy Analysis - Version 11.0," © Lazard, November 2017. https://www.lazard.com.

*Represents estimated implied midpoint of LCOE for offshore wind, assuming a capital cost range of \$2.36 to \$4.50 per watt.

Many factors in the different stages of solar project development influence the LCOE:

Business development, characterized by competitiveness, regulation and markets, and matching the PPA with the project. **Engineering,** where the biggest factors are knowledge consolidation, learning from previous projects and the competitiveness of the design.

Procurement and

contract management, which is getting more complex due to the number of suppliers and partners including the role of EPC contractors (vs. operators).

Construction,

driven by quality, health, safety, environment (QHSE), time monitoring and automation on field. This also includes the handover to O&M.

Although this report focuses on the development of grid-connected, utility-scale solar projects, O&M is important. The O&M approach impacts the design, planned investment and, as the lifetime of solar projects surpass initial estimates of 20 years potentially up to 40 years, O&M will become a larger share of the LCOE.

Study methodology

This study builds on primary and secondary research, including insights from leading solar developers and engineering, procurement and construction (EPC) companies to better understand the current project development approaches, challenges and opportunities for further improvement. The study's six interviewees have developed projects in the United States, Latin America, Europe, India, Australia and the Middle East. They represent more than 8.3 GW of solar capacity installed, 9.4 GW under development and more than 200 projects in the pipeline. The study also draws on lessons from other industries with similar repetitive small project and construction processes such as industrial manufacturing and unconventional resource development processes, to bring to life some of the opportunities captured by other sectors. Figure 3 outlines the four main steps taken to develop this study.

Figure 3. Study approach.

Utility-scale solar development, project experience and leading-practices research In-depth interviews with solar developers and EPCs to better understand differing approaches and identify opportunity areas Validation of key improvement themes with Accenture industry experts Drill-down into key areas of opportunity and lessons learned from other industries



Output: Questionnaire on utility-scale solar project development and construction



Output: Comparative assessment of approaches





Output: this report

THE CURRENT UTILITY-SCALE SOLAR PROJECT LANDSCAPE

The study concentrated on key activities in solar-at-scale development projects: origination and business development, engineering, project and contract management, and construction (see Figure 4) and the most significant opportunities to improve the project execution process. Although the list of activities and challenges in utility-scale solar projects are fairly standard, who executes these can vary dramatically. Multiple parties are involved with a mix of owner, developer, investor, EPC and other service providers.

Figure 4. Utility-scale solar development activities.



Archetypes

Solar PV development has relatively low entry barriers, so there are more diverse players and operating models than other technologies, such as wind. As illustrated in Figure 5, players can participate in any of the value chain activities and often participate in different combinations, depending on the market and project. Across the value chain, third parties are also often used in parts of the process, e.g., design contractors, expediting agencies and construction companies.

We interviewed players representing various combinations of developer, owner and EPC. We did not interview pure financial investors that are not involved in the development of the solar farm. As previously noted, the key challenges are often common—irrespective of who executes the activity—but what differs are the capabilities of the owner/developer to optimize the LCOE of the project and how investments are made. To facilitate the discussion on opportunities and capabilities, we use two archetypes that represent the extremes:

- Owner/developer with a traditional EPC project development model (with limited or no engineering capability), and the EPC contractor performing the activity for the owner/operator.
- Owner/developer with full in-house engineering, construction and operations.

Figure 5. Numerous and fluid operating models for solar development.

Commercial management of the project net present value (NPV)						
Origination	Engineering	Construction				
Business development	Engineering	Handover to 0&M				
Project and contract management of EPCs, component suppliers, and construction contractors						
- Developers that do concept design and sell \rightarrow 🔺						
Owners that do the origina	tion, BD and concept design and then us	e EPCs to engineer and construct; owner operates				
• Developers that do full engineering design and sell \longrightarrow						
• Developers that do full engineering design and construction and sell \longrightarrow						
Play	ers that own, and have in-house capabili	ty to design, construct and operate				
Exit/sell project						

Key challenges and the role of digital

The most pressing challenge for solar generators is managing the end-to-end development process to meet the target cost, timeline and LCOE given the different transitions and parties involved in the process. In origination and business development, the primary challenges are finding, financing and competing for the most appealing projects given the uncertainty of technology and markets. In engineering, it's designing the most commercially competitive solution, including the technology choices and delivery model. In project and contract management, it's commercial and operational management of the contracts, including schedule, cost and project control structures. In construction, it's the management of large numbers of people and materials on the field to confirm safe, efficient operations and an effective handover to O&M (see Figure 6).

Figure 6. Key challenges across project activities.

Origination and business development

- · Prospecting for PPAs
- Finding optimal sites—yield, land access, transmission capacity
- Solar competition and being costcompetitive in a market with low margins/low barriers to entry
 Estimating expected cost three to
- Estimating expected cost three to five years out
- Grid access and interconnection
 process
- Increasing requirement to feed into grid in a controlled way
- Entering new markets
- Regulation and evolving renewable regimes
- Assessing market risk in a merchant-based model
- Achieving minimum profitability rate

Engineering and procurement

- Designing commercially competitive solutions
- Module selection and sourcing
- Control system decisions
- Capital and yield estimating of technology
- Interconnection applicationsTechnology selection
- Qualified staff to manage EPCs and engineering/design companies
- Knowledge consolidation and management
- Civil—often rely on local suppliers
- Permits and licensing
- Environmental assessments
- Determining the optimal project structure; e.g., should split scope across multiple EPCs?
- HSE compliance worldwide
- Regulation development for components, impacting procurement

Project and contract management

- Managing complexity of the intersection of project requirements
- Implementing project requirements in contracts
- Technical negotiation of/in contracts
- Managing contracts, margin risk, management of change orders, disputes/claims
- Reconciliation of supplier activities on site vs. contract obligations
- Managing EPC contractors and workforce on site
- Preventing schedule slip
- Live management of NPV and project returns
- Lack of document management
 and workflow tools
- Lack of staff that can QA/QC EPC and other contractors
- Managing HSE and sustainability
- Managing to contract in different jurisdictions
- Speaking the language of lenders

Construction and handover to operations

Budget and schedule

- Supply chain
- Experienced QA/QC resource and tools to oversee EPC and construction activity; e.g., audit trail, visibility of field activity, data management for O&M
- Productivity and time monitoring
- Automation on field
- HSE—statistics, root-cause analysis, onboarding, local compliance
- Management of civil works, often with local contractors in new markets
- Electromechanical—optimizing balance of system
- Verifying the checklist of O&M requirements to confirm smooth handover
- Managing differences from original as-built plant design
- Finding reliable, long-lasting relationships with EPCs

Management and visibility of all the transitions and handovers.

Optimization (vs. duplication) of capabilities across partners and functions.

End-to-end



Maximization of the project NPV across the life cycle.

All our study participants and Accenture industry experts agree that digital technologies can play a key role in addressing many of these challenges, given the characteristics of solar projects (see Figure 7):

- Large numbers of panels and inverters wellsuited to the Internet of Things monitoring solutions.
- Often, a pipeline of projects where learnings on components or process efficiencies can be leveraged from one project to the next one.

- Multi-tier supply chain with a high number of movements.
- Repetitive tasks that can be automated or robotized.
- A significant number of workforce-related services with different parties that need to collaborate.

Figure 7. Digital technologies that could be applied to project development.



However, as illustrated in Figure 8, the participants have different approaches ranging from using digital as a transformational tool applied across the end-to-end process, to targeted and focused applications, to an enabler of process changes.

Overall, the companies closer to the archetype of owner/developer with full in-house engineering, construction and operations had a larger digital investment across more activities and technologies. By contrast, companies closer to the archetype of owner/developer with a traditional EPC project development model (with limited or no engineering capability), and the EPC contractor that performs the activity for the above owner/operator were narrower in their

approach to digital. Instead, companies closer to this second archetype focused investment on the activities in their scope-business development. They expected their EPC partners to make the digital investments in engineering, project and construction management, and construction—the parts of the process the companies outsourced. However, we found that EPCs' digital investment was not as extensive as those companies having in-house operations. For both archetypes, analytics and cloud were viewed as digital technologies that would have the greatest impact on the utility-scale solar development process—analytics to minimize the LCOE from conceptual design, and the cloud to improve collaboration and data management in geographically distributed environments.

Figure 8. Comparison of the impact digital can have on utility-scale solar project activities.

	Origination and business development	Engineering and procurement	Project and contract management	Construction and handover to operations	End-to-end optimization and maximization of NPV
ANALYTICS	$\bullet \bullet \bullet \bullet \bullet \bullet$	$\bullet \bullet \bullet \bullet \bullet \bullet$		$\bullet \bullet \bullet \bullet \bullet$	$\bullet \bullet \bullet \bullet \bullet$
SOCIAL		• • • •	• •	•	• • • •
ROBOTICS	• •	•		••••	
MOBILITY	•			•	
AUTOMATION	•	•	•	•••	
іт/от	•	• •		•	
CLOUD		• • • • •	$\bullet \bullet \bullet \bullet \bullet \bullet$	• • •	$\bullet \bullet \bullet \bullet \bullet \bullet$
SECURITY		•			
COMPANY 1	COMPANY 2	COMPANY 3	COMPANY 4	COMPANY 5	COMPANY 6
Big Opportunity	Big Opportunity	Big Opportunity	Big Opportunity	Big Opportunity	Big Opportunity
Med Opportunit	y 🚺 Med Opportunit	y 🚺 Med Opportunit	y 🚺 Med Opportunit	y 🚺 Med Opportunity	y Med Opportunity

KEY THEMES AND OPPORTUNITIES

An end-to-end approach, powered by digital, is required.

The end-to-end approach for utility-scale solar projects needs to look at both the commercial side of a project-tracking the LCOE of project/asset during its life cycle-and the operational side, managing the flow of documents and handovers and interfaces across the different project stakeholders. With the reduction of projects financed by incentives such as feed-in tariffs (FiTs), production tax credits (PTCs), investment tax credits (ITCs) and an increasing reliance on C&I PPAs, an increasing commercial challenge is the origination and subsequent matching of C&I PPA commercial terms to project financials and managing and executing a large portfolio of PPAs and projects. Adopting an end-to-end approach improves the control, cycle time and cost management-making transitions smoother, confirming all parties are speaking from the same data set, and that the appropriate people are given the proper information to contribute to key decision making.

The need for an end-to-end view becomes even more critical in the larger utility-scale solar programs or in programs composed of a solar project pipeline linked to a PPA or multiple PPAs. In these larger developments, the projects are so complex that end-to-end visibility and control are required to meet project timelines.

Most of the study participants take a cross-functional approach to development and design and involved O&M early in the project

and during construction to facilitate a smooth handover. All were implementing or planning to implement a cloud-based workflow and document management solution. They varied in their use of collaboration tools and how manual or digital their approach to obtaining an end-to-end project view, including:

- Implementing an agile, user-centric platform that makes data from all stages in the project process available to different users, with views tailored to each user's needs.
- Developed an in-house, end-to-end workflow and document management solution with tailored views for each user that has been used on more than 300 projects.
- Embarking on a Six Sigma project, focusing first on the process changes and then planning to digitalize this process.
- Manual approach (tight team integration) to achieving an end-to-end view, supplemented by collaboration tools and the Microsoft toolset.

In addition, some interviewees have aggressive plans to achieve an end-to-end approach including setting up an end-to-end project control tower, exploring the adoption of Building Information Modeling (BIM) methods and multidisciplinary plant digital twin views, as well as pushing toward automation and robotics for a digital-by-design solar farm.

Management and visibility of all the transitions and handovers.

End-to-end



Optimization (vs. duplication) of capabilities across partners and functions.



CASE IN POINT:

Digital platform for E&C processes integration

Accenture is implementing a digital platform at a major multinational renewable operator to support them in the adoption of a truly end-to-end project approach. The platform is tailored to the differing needs of the project phases, whether it be document management, tracking real-time data or identifying benchmarks or LCOE changes. This is achieved through a multi-layered architecture in which the user experience is organized by workplaces accessed by the multiple internal and external project roles—such as engineers, project controllers and field workers—and is integrated with back-end systems and relevant databases.

The platform is organized by the two main areas for project development and project execution. Project development focuses on document/data versioning and dependencies in the development phase, covering things like cost simulations, technical configuration scenarios and procurement strategy. Project execution contains up-to-date information of the project including time, costs and risks, engineering workflows, expediting and logistics information, and construction and commissioning progress. Where applicable, cross-project workplaces are also created for information such as permits and licensing, PPAs, and funding and partnership agreements. Additionally, the platform can contain a workplace for external access, which is shared with suppliers for seamless collaboration through exchange of requests for information (RFIs), design changes, change orders and more. These features allow platform users to easily access information relevant to their role, while also enabling the end-to-end approach.

Figure 9. Personas in utility-scale solar project development.

Project developer	Project manager	Project controller
 Manage and analyze opportunity Conduct project financial evaluation Identify risks Collect approval from all departments in development phase 	 End-to-end project responsibility Analyze project technical and economic structure with business development Coordinate project execution team Coordinate relationships with suppliers and contractors Manage reporting 	 Manage general project schedule and costs Analyze deviations Conduct pre-shipment inspection Supervise charge request Monitor progress in material requisition
Contractor/field workers Gather and manage documentation from site surveys Perform construction Conduct material check Execute plant final installation 	↓ ↓ ↓ ↓ ↓ ↓ ↓ ↓ ↓ ↓ ↓ ↓ ↓ ↓ ↓ ↓ ↓ ↓ ↓	 Project engineer/engineering contract Perform basic and detailed design Monitor engineering progress Evaluate bidders Manage documents in procurement Supervise construction Conduct "as-built" check
Site manager/commissioning manager	PERSONAS	Contract manager
 Conduct site survey Monitor physical construction Work supervision and accounting Monitor site inspections Monitor automated operations 		 Collaborate with management team during procurement phase Manage purchasing request Check contractual milestones Evaluate change orders
Site material manager	Logistics manager	Supplier
 Confirm goods receipt Conduct quality and quantity checks Verify completeness of supply documentation Assure organization of storage areas 	 Responsible for supply chain from requisitioning, through procurement and shipment Supervise all shipment activities Manage warehouses for strategic supplies 	 Propose bids to the operator Provide the required material Issue material-related documentation

Figure 10. Personas' role in the utility-scale solar project development workflow.

PROJECT Analysis	INVESTMENT PROPOSAL	HANDOVER TO E&C	PROJECT EXECUTIO	N START	DETAILED DESIGN	MATERIAL REQUISITION
 Opportunity management (PD) Financial evaluation Authorities evaluation (PE+SM) Basic engineering 	 Investment package (PD) Finalization Risk identification Review 	 Project documentation storage (PM) Collection of approval from all department heads (PD) 	 General descrip project Project criticali (PD+PC Final rel project plan (PI 	technical tion (PE) risk and cies) ation execution A)	 Detailed design documentation (PE) Basic document redacting Start of procurement (PM+PE) Scheduling (PC) 	 Material requisition (PE) Progress monitoring (PE+PC)
DELIVERY	EQUIPMENT MANUFACT	URING DESIGN SPI	ECIFICATIONS	BIDDERS' T	ECHNICAL EVALUATION	PURCHASE REQUEST
 Goods receipt: check quantity and quality on site (SM+MM) Detailed check after handover from SM (Contractor +LM) 	 Preshipment inspec (LM+PC) Inspection report to issued (Supplier) Check contractual milestones (CM) Plan for shipping (SM+LM+Supplier) 	tion • Track pro- enginee be activities • Approva deliveral	ogress of ring s (PE+PM) I of ENG oles	 Complia Evaluatic (CM) Definitive (CM+PM) 	nce assessment (PE) on of assessment e purchase request ()	 Technical specification (PE) Scope of work (scheduling and supervising) (PM) Purchasing request (CM)
CONSTRUCTION	PHYSICAL PROGRESS	WORK ACC	EPTANCE	HANDOVER	TO 0&M	
 Gather documentation to access site (SM+Contactor) Area plant handover Supervise charge request (PC) 	 Perform constructio (SM+ Contractor) Update on progress Supervise progress (PC+SM) 	n • End of construct (SM+Co • As-built of differe (PE+SM)	ation works ntractor) verification ences	• Plant sta (SM+PE)	rt-up	
		PD: proj PE: proj SM: site PM: proj PC: proj CM: con LM: logi MM: (sit	ect developer ect engineer manager ject manager ect controller atract manager stic manager e) material ma	nager	Business develo Project executio Project executio Project executio Project executio	opment on – engineering on – procurement on – contracts follow up on – construction

2 Front-end data and analytics are key to optimize LCOE.

The business development and conceptual design activities are the most commercially competitive and sensitive area of all project activities. Intense competition, future technology cost estimation and regulatory evolution were cited as some of the main challenges. Recently, LCOE has been further complicated with the end of auctions, feed-in-tariffs and tax credits for solar capacity in some markets, requiring a developer to find and match C&I PPA requirements with projects. As a result, although it's clear the LCOE is trending downward, there is a huge variation in estimated LCOE, as illustrated in Figure 11.

In our interviews, all interviewees highlighted analytics in the origination, business development and conceptual design as one of the highest opportunity areas. There is a large data set that can be used to inform decisions and optimize LCOE: site selection parameters, panel orientation, assessment of solar resource, future energy prices, PPA terms, current and future technical specifications, cost and performance data on module and tracking systems, and O&M costs—including whether technologies that will save O&M costs but increase CAPEX costs will be used.

Players differ in the approach, level of detail and software they use for business development and conceptual design. Some use estimates based on past engineering project costs, while others use estimates based on a planned future cost reduction. In most cases, energy yield prediction software packages are used, but there are still many assumptions needed related to design choices and future technology costs. In bidding for projects, players also differ in their level of experience and aggressiveness, and some interviewees have seen bids lower than they believe to be economically viable.



Figure 11. Utility-scale solar PV LCOE and PPA price.

Source: "Empirical Trends in Project Technology, Cost, Performance, and PPA Pricing in the United States – 2018 Edition," Lawrence Berkeley National Laboratory, 2018, https://emp.lbl.gov.

Solar project challenges to be addressed

Origination and business development challenges addressed

Engineering challenges addressed



Prospecting for PPAs



Finding optimal sites—yield, land access, transmission capacity

Solar competition and being cost competitive in a market with low margins and low barriers to entry



Increasing requirement to feed into grid in a controlled way



Entering new markets

Regulation and evolving renewable regimes (incentives, political climate)



Assessing market risk in a merchant-based model



Designing commercially competitive solutions



Capital and yield estimating of technology

3 Collaboration on the cloud is paramount to commercial and operational management of partners.

One interviewee called the complexity of the intersection of all project requirements "staggering," with significant repercussions, including project delays, for missed document-filing deadline. Document management and contract version control and associated project documents during the project life cycle are critical to managing the project schedule and dispute resolution and delivery of the overall business case. It includes records of the design documents, permits and licenses, audit trails of communications related to variations, and purchase orders.

In the engineering and design phase, collaboration with third-party design companies, the EPC and construction contractors is critical to develop an optimized LCOE solar plant design that can be built. The interface management to meet project timelines, cost targets and to manage HSE is even more important during plant construction and includes all contractors, the module and inverter suppliers, the landowner, planning authorities and the network operator.

What is critical and common across all players and projects is contract formation and management-whether the developer chooses a single turnkey EPC contract in which the EPC subcontracts parts of the project and manages these contracts, or the developer directly manages a portfolio of contracts. A critical success factor in effectively managing partners highlighted by the interviewees is the need for qualified staff, with the commercial and operational experience to manage EPCs and perform quality assurance and quality control activities. Another success factor of successfully managing suppliers is treating EPCs as partners. For example, one of our interviewees has worked with the same four EPCs for more than 100 projects.

The business case is structured through the contracts and executed through the project planning, cost control, contract management and risk management activities. The contract formation and management include project governance, requirements, technical negotiation, provisions for managing variations and risks disputes, pricing and incentives, construction schedule, project performance and progress tracking, and the requirements for handover to operations.

Document management and collaboration tools on the cloud were two of the highest opportunity areas identified through our interviews. Coupled with analytics, a key opportunity is an ability to get an automated "value-of-the-project" update or alerts when variations or schedule changes will impact project value.

Solar project challenges to be addressed

Euripeering shellowers	Project and contract	Construction and handover to	
Engineering challenges	management challenges	operations challenges	
 Designing commercially competitive solutions Qualified staff to manage EPCs and engineering/design companies Knowledge consolidation and management 	 Managing complexity of the intersection of project requirements Implementing project requirements in contracts Technical negotiation of/in contracts Managing contracts, margin risk, management of change orders, disputes/claims Managing large workforce on site Preventing schedule slip Live management of NPV and project returns Lack of document management and workflow tools Lack of staff that can QA/QC EPC and other contractors Managing HSE and sustainability 	 Budget and schedule Experienced QA/QC resource and tools to oversee EPC and construction activity, e.g., audit trail, visibility of field activity, data management for O&M Management of civil works, often with local contractors in new markets Verifying O&M requirements (checklist) are being met to confirm smooth handover 	
	End-to-end challenges		

Management and visibility of all the transitions and handovers.

Optimization (vs. duplication) of capabilities across partners and functions.

Maximization of the project NPV across the life cycle.

Collaboration on the cloud holds great potential at different points in the project workflow, particularly where there is an interaction between different departments/parties that involves an information exchange. Some examples:

6

Operators and contractors

During the engineering and construction phase, all engineering disciplines are involved in the concept of a design plan program, actively collaborating with suppliers/contractors to approve design documents, but also to collaborate on follow-on activities, e.g., material management. Users can also leverage the cloud to monitor activities' progress and check completeness.



Business development vs. engineering and construction project execution

During the business development phase, the development team actively collaborates with engineering and construction to carry out preliminary analyses. Document exchange on the cloud enhances the pace of collaboration, enabling the teams to develop project costs and performance indicators in parallel.

End-to-end quality and HSE monitoring

The quality and HSE auditing takes place across the entire project. The cloud makes logging and accessing the history of quality checks in a way that is easy to access when a new check is performed. This means if a previous quality check was run with a similar result, the earlier analysis is easily obtainable, increasing efficiency and allowing the creation of a "results library" that can be accessed at all times.



Handover to O&M

This process includes the handover of a huge number of quickly retrievable documents needed by the O&M team to operate both locally and/or remotely through SCADA, control rooms, etc., fulfilling local legislation in terms of safety, hygiene, establishing processes to comply with grid requirements, and confirming the solar plant is protected and monitorable. The cloud enables O&M teams to retrieve documentation and communicate with the engineering and construction partners, particularly in case of:

- Inventory of missing or incomplete deliverables.
- Construction and/or quality deficiencies.
- Improvements and optimizations.

As cloud platforms become more prevalent, we envision a future in which there is far less documentation exchange via email, with teams simultaneously accessing and working on materials via the cloud. Furthermore, artificial intelligence (AI) and blockchain technologies will reduce the amount of documentation required, by allowing intelligent, secure ways of working among stakeholders, and minimizing the need for contractual and other management documents.

Invest in digital construction including robotics, supply chain and digital worker.

One MW of solar capacity requires approximately 2,500 to 4,000 solar panels. Projects that are 50 MW or greater will involve more than 150,000 panels. The sheer number of movements in managing the flow of materials and in safe panel installation means there is significant potential in leveraging digital technologies such as robotics and automation, digital supply chain and digital worker.

Some of the companies we interviewed have an in-house construction capability. These companies typically have made analytics investments to primarily gain better visibility of construction progress and materials movement in the supply chain. Analytics have also been leveraged for monitoring contractor performance, supporting field worker mobility and automation of module assembly.

For example, one developer we interviewed had many digital construction initiatives:

- Material-tracking solution from material acceptance to onsite installation.
- Onsite quality control-mobile quality checklist.
- Autonomous vehicles for terrain excavation and movement (approximately 30 percent of time reduction), trench excavation and cables posing (approximately 30 percent of time reduction and 50 percent of cost optimization), and panel installation.
- Onsite monitoring and tracking to automatically track people and vehicles.
- Field worker safety: wearable and real-time location tracking technologies for field worker positioning and human/vehicle interference management.

- Augmented reality solution to provide remote support to field workers.
- Site cameras for remote site monitoring.
- Drones to support automated progress monitoring and execute inspection.
- Remote construction room: solution to integrate all project data and information on site construction progress in a single platform.
- Site connectivity: services for a connected plant, from construction to operations.

Other companies outsource contracting and management of construction companies to the EPCs. In these cases, the most significant digital opportunity is document management on the cloud, including managing the construction checklist during handover to O&M. Ideally, flags and alerts would highlight the activity completion status in the handover checklist. Typically, developers that outsource project management and construction to the EPCs expect the EPC to invest in digital to support the construction process. Yet, EPCs are not necessarily prioritizing this digital investment; among our interviewees, this is the largest gap in the use of digital to improve construction.

Surprisingly, our interviewees did not highlight collaboration tools in the construction process as a high-priority opportunity. In contrast, we believe this is a key opportunity due to the sheer number of interfaces, including contractors, the module and inverter suppliers, the landowner, planning authorities and the network operator.

Construction and handover to operations challenges addressed



Budget and schedule



Supply chain

Experienced QA/QC resource and tools to oversee EPC and construction activity, e.g., audit trail, visibility of field activity, data management for O&M



Productivity and time monitoring



Automation on field



HSE—statistics, root-cause analysis, onboarding, etc.



Management of civil works, often with local contractors in new markets



Electromechanical—optimizing balance of system



Verifying O&M requirements (checklist) are being met to confirm smooth handover





5 Enhance cybersecurity resilience while increasing readiness for regulatory compliance.

With the increase in solar capacity and as digital increases the connection between solar plants and the larger grid, there is a growing risk of cyber attacks to solar assets and, as a result, a greater risk to the entire grid. Such threats come with potential negative impacts to companies and society in terms of data and energy security, as well as cost for lost production, breach response and physical repair. Hence, companies and regulators are recognizing the importance of cybersecurity.

Our interviews indicate that while not everyone is currently focusing on cybersecurity, those that do see it as a critical area include seeing the need to add cybersecurity requirements into project specifications for external suppliers and contractors, avoiding remediations at later stage.

Regulators around the world are recognizing the need to protect renewables assets from cyber threats, being part of critical infrastructure and as demonstrated by recent regulations, including the EU NIS Directive on cybersecurity, the ICS standards and leading practices such as ISO27001, IEC 62443, NIST 800-82 and NERC-CIP.

However, driving cybersecurity investments for renewables should not only hinge on compliance with existing regulations, but also on looking into leading practices on cyber resilience, taking into account the different types of attacks known to date. For example:

• **Hijacking physical control:** the attacker takes control of the solar inverter with the intent of damaging, disabling or destroying it. While the operator still has control of the asset, so does the attacker.

- Man-in-the-middle: The attacker uses software to remove the operator from the control chain, taking control of all traffic between the operator and the assets. The danger with this type of attack is that the operator may not even realize it is happening. While a solar farm may appear to be functioning normally, it actually may be infected and experiencing an attack.
- **Ransom:** The attacker either infects the system with a cryptovirus or physically adds hardware into a solar inverter, thus gaining control over other assets on the farm. The attacker then disables remote control of the power plant and holds it for a ransom.
- Horus scenario: The attacker aims to take a large portion of solar generation offline all at once, disrupting the supply balance to an extent that cannot otherwise be managed. This disruption could lead to a complete breakdown of the electricity grid, threatening overall energy supply. In addition, a successful breach could become a staging point for further attacks on the network—IT and OT—from an internal network. This is how advanced persistent attacks gain full control of large segments of corporate networks and make it extremely hard to expel the attacker.

Building cyber resilience requires the following key activities from solar companies:

- **Strategy and risk:** Assess risks to protect the entire value chain.
- **Cyber defense:** Build resilience into the extended environment, including the cloud, mobile devices and the Internet of Things.
- **Digital identity:** Get a highly scalable identity and access management system that dramatically accelerates time to market.
- **Application security:** Accelerate release cycles while developing, running and maintaining applications with security built in.
- **Managed security:** Scale security and compliance operations with innovative technologies, as-a-service capabilities and expertise.

The first step is to conduct a resilience diagnostic exercise to identify the weak spots and attack flows that hackers are likely to follow, and then determine the appropriate defensive capabilities. These exercises range from basic penetration tests to simulating professional motivated attackers and criminal attacker groups. Capability assessments can also be undertaken to evaluate the actual cyber defense capability covering all its dimensions-organizational roles, governance, processes, operating model, KPIs and methodologies and tools for security risk assessments. The outcomes of a resilience diagnostic and capability assessment will produce a security roadmap with required steps for the solar operator to work toward achieving regulatory compliance, long-term attack-mitigation plans and required steps to create an organizational cybersecurity capability able to take on new threats in a continuously evolving regulatory landscape.



6 O&M impact on design and LCOE.

Historically, the solar farm O&M was viewed as simple—cleaning panels and replacing inverters regularly. Compared to the O&M for onshore wind (approximately \$15,000 to \$40,000/MW⁴), the annual O&M cost for utility-scale solar PV is smaller (approximately \$10,000 to 20,000/MW AC, so up to half the cost per MW DC). Although O&M costs are clearly declining as illustrated in Figure 12, O&M will become a larger share of LCOE given longer project lifetimes, the increasing dominance of tracking system, the higher DC/AC ratios running inverters, and analytics to support the analysis and actions to reduce production losses.

The companies we interviewed involved O&M and asset management during construction, managing O&M checklists to confirm smooth handovers. However, some companies involve O&M much earlier in the project process, in the design of solar farms. This is a practice becoming more important for a number of reasons:

• O&M technology choices such as self-cleaning panels need to be made at the design stage as it's a trade-off of more investment up front for O&M savings.

- The estimated asset life of solar farms is increasing, with some estimates of up 40 years.
- Slightly higher DC/AC ratios will increase wear on inverters and the increasing prevalence of tracking systems mean more moving parts that could fail.
- Monitoring technologies and platforms support enhanced, actionable productionloss analysis and maximize yield through targeting and optimizing O&M activities, e.g., predicting inverter failure, when panels need to be washed, trade-off analysis between the cost of O&M and the value of increased production.
- Companies with a pipeline of solar projects means learnings from component performance during monitoring can be quickly built into the next farm. One of our interviewees viewed the feedback loop between O&M and their monitoring systems to engineering as critical as they managed all component procurement in-house.



Figure 12. Cost of O&M for solar PV in the United States.



Source: "Empirical Trends in Project Technology, Cost, Performance, and PPA Pricing in the United States – 2018 Edition," Lawrence Berkeley National Laboratory, 2018, https://emp.lbl.gov.

CASE IN POINT:

Envision Digital's solution for production loss analysis and actions

O&M for solar was previously viewed as simple with minimal costs given the lack of moving parts. However, with the scale of solar growing, the increasing use of tracking systems and the increasing life span of solar plants, investment in tools such as Ensight[™] Solar that can decrease O&M cost (efficient O&M) and increase revenue generated per O&M dollars spent (smart O&M) are becoming increasingly important, especially during the LCOE optimization of the project.

Ensight Solar is an advanced analytics platform developed by Envision Digital for the ongoing performance assessment of solar PV power plants. The platform goes beyond monitoring, using real-time data from standard tags and can quantify production losses based on real operational plant performance. Using advanced data analytics, Ensight Solar provides corrective actions to improve production when economically viable.

Advanced analytics tools allow O&M operators to track tighter performance ratios, which can be incentivized by asset owners as part of the O&M contract. Future O&M costs can be calculated by entering the cost of equipment failures and maintenance activities such as inverter failures, sensor issues and washing frequency. Additionally, O&M providers can move away from the traditional scheduled maintenance approach by using the tool to decide when it makes economic sense to act. Specific examples of how Ensight Solar has optimized the cost of O&M for clients include:

- **Tracker monitoring:** Ensight Solar can detect if one tracker is shading another, identifying the amount of shade loss and automatically recommending an adjustment to the tracker schedule and whether this would be economically recoverable.
- Wash optimization: Instead of following a standard wash schedule as determined by the O&M contract, Ensight Solar uses data on the plant performance, weather, soiling and wash cost to determine optimal wash schedule and notifies the operator when the next wash is due.
- **DC input monitoring:** Ensight Solar conducts regular comparisons of DC inputs to the inverter or strings (if string monitoring is available) and identifies the outliers and those which are losing the most energy, eliminating the need for manual spot checks.

In addition to minimizing the cost of production loss, Ensight Solar's ability to conduct ongoing performance assessments of multiple plants, reduces labor-intensive work previously carried out in error-prone Microsoft Excel spreadsheets or other one-off scripts. This enables the dramatic scaling of MW under management without having to increase team size, improving the LCOE and further highlighting the importance of investment in analytics tools early in the project.



Figure 13. Select Ensight Solar dashboard outputs.





Source: Envision Digital.

DIGITAL CAPABILITIES FOR SOLAR PROJECT DEVELOPMENT

In an industry with such a fragmented value chain, all players recognize the advantage of an end-to-end approach, cross-functional involvement early in the process and collaboration with partners. Players also recognize the value of data and analytics in the front end to optimize the LCOE and already use software packages that attempt to optimize the design to maximize solar resource yield. Some players have even developed in-house applications to manage the commercial and operational paperwork during the solar project life cycle. As regulatory supports are reduced, competition and cost pressure will become more intense. A key challenge now is the origination and subsequent matching of C&I PPA to project and managing and executing a large portfolio of PPAs and projects.

Addressing the six themes identified in this report are critical to the future success of players that want to grow their solar portfolios. Digital is a key enabler, and those investing in digital are better positioned to address the themes. We have defined eight key digital capabilities to help solar players exploit the six themes: opportunity and portfolio management; LCOE optimization; engineering and contract management; supply chain management; execution of field-level activities; cybersecurity; health, safety and environment and end-to-end portfolio/project control (see Figure 13).



While most players are basic in their digital capability, many are investing in workflow, collaboration, document management, and project life-cycle management and tracking tools. The largest disparity in investment is in construction, the execution of field-level activities, supply chain and materials management. This is largely due to lack of clarity around who should invest in the tools for this part of the process, given the prevalent use of third-party contractors. However, as project pipelines grow, with some companies developing hundreds of projects and project sizes growing to hundreds of MW, managing field movements will become more critical. The repetitive nature of laying thousands of panels, dependent on delivery and installation of components according to a project schedule, is like any manufacturing environment. We expect that the impact digital has had on manufacturing supply chains will be similar for utility-scale, grid-connected solar.

Figure 14. Comparison of digital capabilities for solar project development.

		BASIC	ADVANCED	VISIONARY
Origination and development	Q Opportunity and portfolio management	Electronic tracking of opportunities, projects and PPAs. Origination largely based on tender response.	Benchmarking tools, optimization and scenarios of opportunities and potential PPAs with overall portfolio value, individual PPA and project values and market-specific opportunities and risks.	Advanced analytics for project identification, evaluation and multidisciplinary decision-making portfolio on changes/forecasting.
	LCOE Optimization	Spreadsheets integrate data from packaged systems estimating resource yield, component costs and O&M estimates.	Conceptual design, layout and optimization tools, enabling variations/scenarios in design/components.	Advanced analytics that incorporate design optimization, yield and cost calculators, and regulatory, market and technology uncertainty.
Optimize design and execution	Engineering and contract management	Shared drives, basic tools to manage documents and contracts. Primarily procedure- based cross-functional integration. Manual performance management.	Cloud-based project life cycle. Document management and ENG authoring tools for 3D civil, electrical, mechanical and instrumentation and control, supplemented with collaboration tools.	Design collaboration powered by BIM methods and multi-disciplinary digital twin views. Blockchain smart contracts, event/milestones automatically trigger actions. Proactive performance management. Real-time LCOE impact.
	Execution of field-level activities	In-place site connectivity and limited use of workforce tools. Some automation of specific panel installation. High reliance on field oversight.	Workforce effectiveness tools, quality control planning and performance construction book. Virtual assistant for field workers. Automation of repetitive and critical tasks.	Full site connectivity and accessibility through mobile devices and remote commissioning system. Maximize use of robots and drones. Feedback loop to reduce cost, cycle time and improve quality.
	Health, safety and environment	Manual approach to HSE, together with limited data management for verification of lessons learned. Vetting of local suppliers/contractors to confirm policy compliance.	Digital tracking tools for HSE team (paperwork, permits, compliance, status and issues, records incidents/ideas, and supplier HSE performance monitoring).	Full holistic approach to HSE. Advanced analytics and predictive modeling to identify risks. Cloud-based integrated control of connected workers and real-time virtual safety assistant via IoT, mobile and extended reality.
Optimize supply chain and handovers	C Supply chain management	Leverage manufacturers' supply chain, manual tracking, basic use of warehouse systems' supply chain.	End-to-end material management. Tracking and tracing system/service, integrated with project plans. Optimization of lead times and inventories.	Multi-tier supply chain control tower. End-to-end visibility from component manufacturer to installation and smart warehousing. Automated "value-of-project" update via alerts/notifications.
	Cybersecurity	Risk assessment in the plants, planning and deployment of basic remediations.	Compliance to regulations and ICS standards/leading practices. Diagnostic based on simulated penetration tests and comprehensive capability assessments; application of security roadmap.	End-to-end security framework. Advanced diagnostic and capabilities' assessments. Adoption of comprehensive ICS network security blueprint. "White hats" for verification of possible breaches during plant operations.
	End-to-end portfolio/project control	Basic toolset for end-to-end tracking of project progress and asset value/LCOE. Manual management of transitions and handovers.	Integrated data platform providing tailored views to different stakeholders. Single source of truth of project status, value/LCOE impacts, and version, handovers.	Smart user data platform that alerts all relevant stakeholders about any events or data points impacting their role, persona, or objective. Ability to run and share scenarios and impact on LCOE.

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