



WHITE PAPER

Unleashing the potential of Digital & AI technologies in energy large capital projects

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Positioning for future success in the rapidly transforming energy sector demands massive capital investment from companies throughout the ecosystem. Digital & AI technologies are critical to realizing the anticipated return on such investments. This paper describes the large capex projects characterizing today's energy industry, and the role of Digital & AI Technologies. It then presents findings from BCG's comprehensive survey and strategic assessment of energy companies, first owners then contractors and vendors, identifying the critical ways energy players can leverage Digital & AI to realize unprecedented value and increase ROI.

Large capital investments are transforming the energy industry

The energy industry is changing rapidly, demanding massive capital investments from companies throughout the ecosystem. The capital expenditure (capex) on major projects in the sector is forecast¹ to reach \$5 trillion in 2023, up 55% from 2022 (Figure 1).

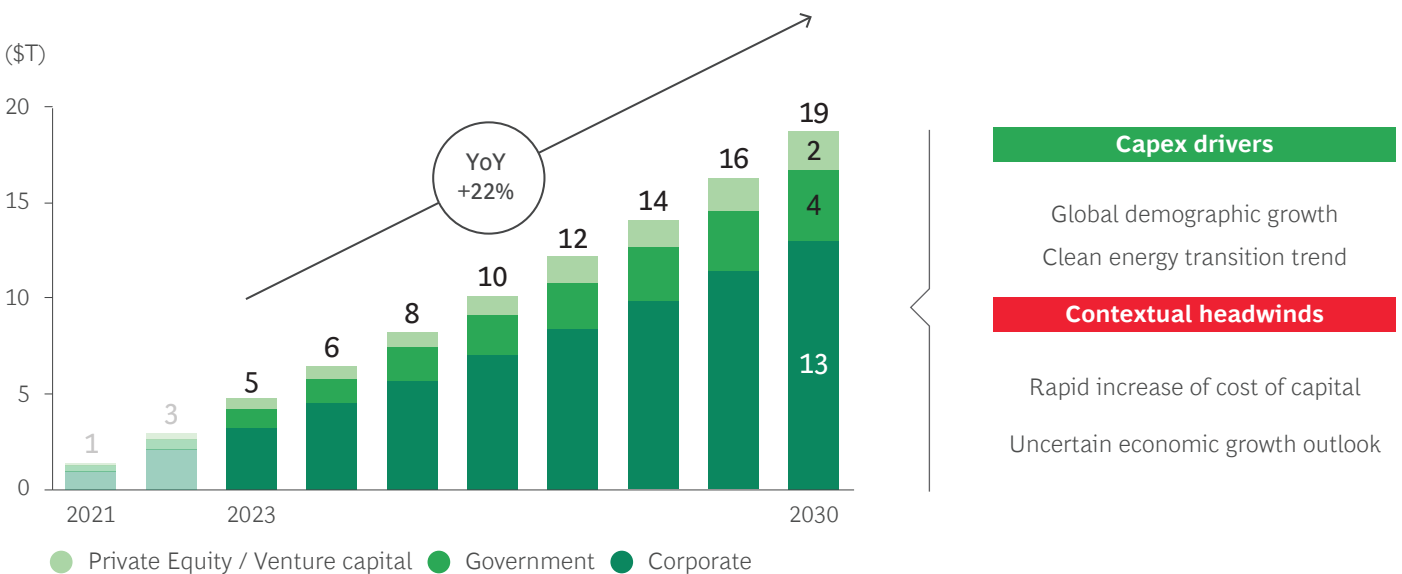
Two factors are fueling this surge. The first is demographic growth. As global populations continue to expand, particularly in emerging markets, the demand for infrastructure and power production is intensifying, requiring further investments. The second is the clean energy transition. Guided by International Energy Agency (IEA) targets, governments and companies are investing in renewable energy plants and electrification to mitigate climate change and reduce carbon emissions.

However, temporary headwinds are on the horizon that will require companies to carefully consider and optimize such major expenditures. These are caused by the increased cost of capital, as central banks raise interest rates to fight inflation, and uncertain economic growth outlook, particularly in the Asia-Pacific region.

Most regions show a substantive increase in owners' large capital project investment (Figure 2), as record revenues during the global energy crisis have driven large companies' spending. We are also seeing strong investor activity in the Middle East boosting demand, project investment, and overall momentum. APAC is an exception to this trend, presenting a flat scenario on average due to the headwinds mentioned above, driven by a slower-than-expected post-pandemic economic recovery.

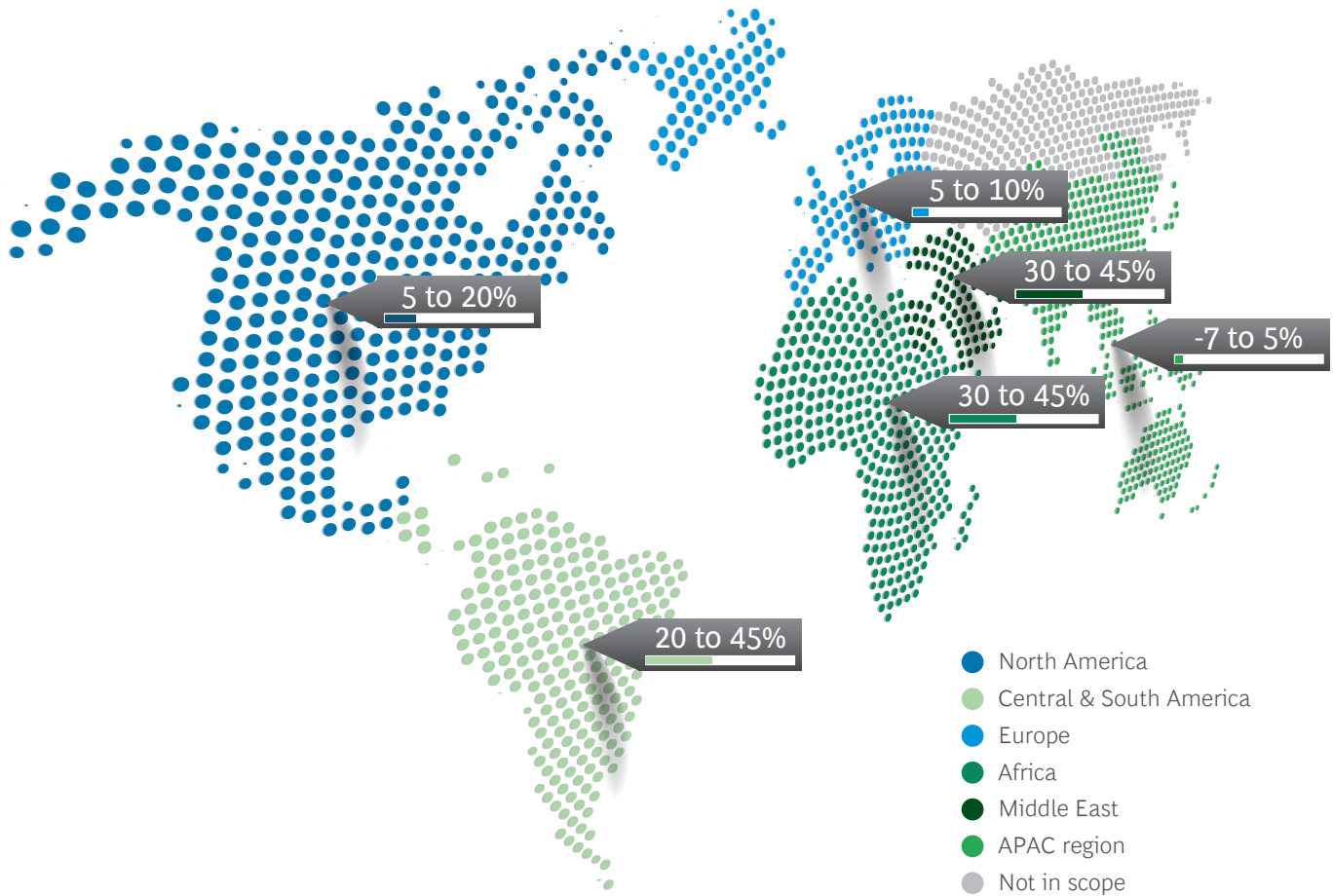
1. IEA Net Zero Energy Scenario; Company-stated targets; Modeled assumptions; BCG CEI analysis

Figure 1 | Forecasted cumulative global energy capex growth through 2030



Note: CapEx = Capital Expenditure; YoY = Year on year; IEA = International Energy Agency; CAGR = Compounded Average Growth Rate
Source: IEA analysis; BCG analysis; S&P Market Intelligence

Figure 2 | Worldwide significant increase of energy capex



Note: capitalization weighted average of top 10 companies per region; for geographical regions, the location of the company's HQ is considered
Source: IAE World Energy Investment 2023; Public company annual reports and earnings presentation; BCG analysis

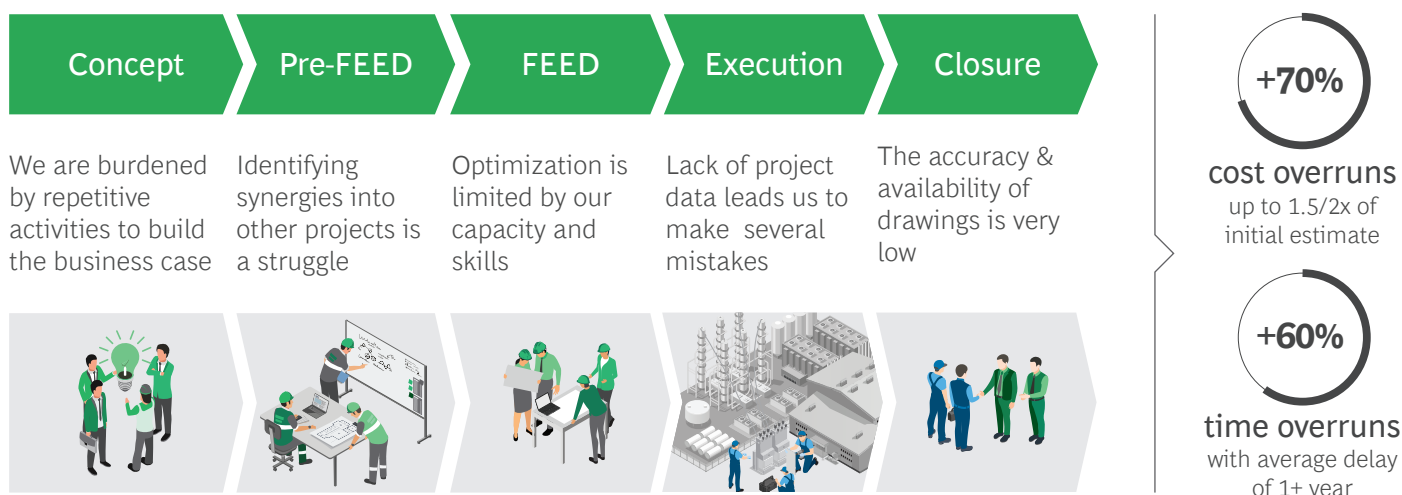
However their scale, complexity, and timelines make investment in these projects inherently risky (Figure 3). Seventy percent of large capex projects incur cost overruns, with final expenditures up to 175% of initial estimates. Sixty percent of such projects take longer than planned, with delays averaging a year beyond the initial timeline.

BCG has identified 35 key pain points along the typical project lifecycle, which can be grouped into three main clusters:

- **Sub-optimal and time-consuming activities** - e.g., review of contractors' submitted engineering drawings, generation and evaluation of alternative expenditure scenarios
- **Lack of visibility and information for decision making** - e.g., missed opportunities for cross-project material optimization, misaligned plans
- **Rework and critical error detection** - e.g., re-engineering due to late detection of errors, inconsistent verification of materials and quality certification

But companies are increasingly embracing digital technology as a crucial enabler to reduce costs and time, minimize internal costs (opex), shrink carbon footprints, and increase safety.

Figure 3 | Most capital projects incur in significant cost and time overruns



Note: FEED = Front End Engineering Design Source: BCG analysis (sample size = 555 O&G capital projects executed between 2010 and 2020)

Digital investment is growing, shaped by seven major trends

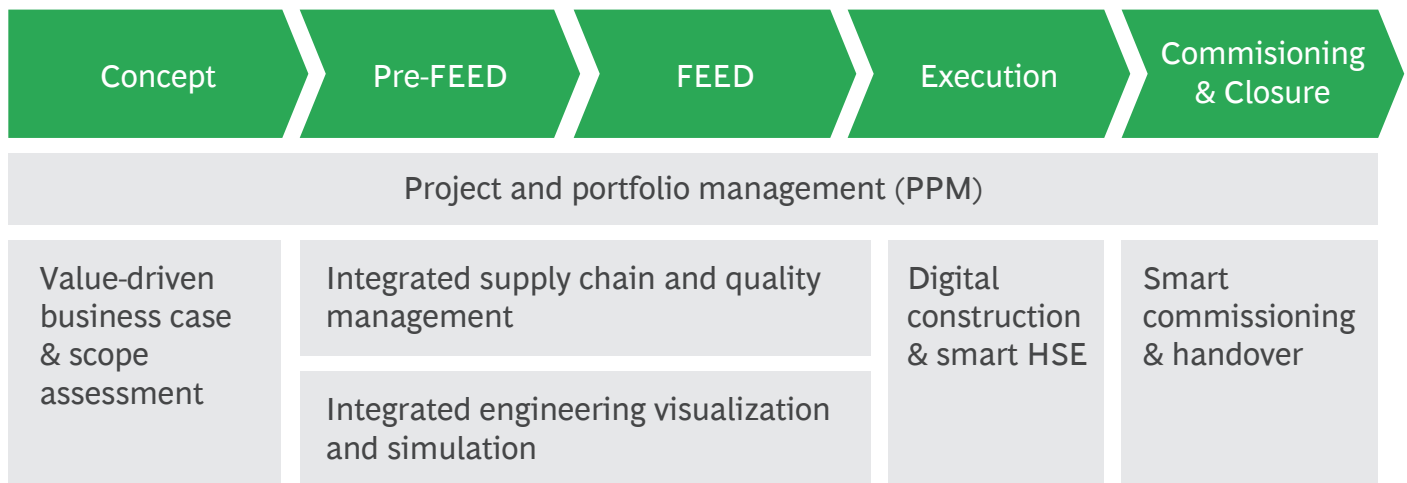
Energy companies today allocate 1-2% of revenue for digital investments. This number is growing consistently at about 10% annually, and is projected to reach 1.5-3% of total revenue by 2026. The increase shows the industry pursuing digital transformation to enhance efficiency, unlock new opportunities, and optimize the entire large capex project lifecycle. Seven trends are leading digital investments and ensuring the ROI of large capital projects

1. **AI and generative AI** - e.g., future trend detection, optimal design selection, documentation creation and extraction
2. **AR and VR** - e.g., ATEX inspection, training, remote collaboration
3. **Blockchain** - e.g., smart contracts, data encryption
4. **Cloud and quantum computing** - e.g., scalable infrastructure, global accessibility, quantum computational power and cryptography
5. **Robotics and automation** - e.g., manufacturing automation, collaborative robots, UAV
6. **IoT and 5G connectivity** - e.g., predictive maintenance, process optimization, connected and managed assets
7. **Digital twin and BIM** - e.g., asset lifecycle management, clash detection, virtual validation

BCG framework identifies high-value digital use cases in large capex projects

Before discussing the BCG framework identifying high-value digital use cases for large capex projects, it is useful to review the project lifecycle. Capital projects typically progress through five key phases: Concept; pre-FEED; FEED; Execution; and Closure. The Concept phase identifies the business opportunity by highlighting net benefits and assessing high-level risks and related impacts. Pre-FEED defines the design basis and project parameters, including scope, cost and schedule estimation, alternative technologies selection, and economic sensitivities check. FEED finalizes the engineering proposal, develops a detailed execution plan, prepares the bid, and contracts with contractors and suppliers. Execution involves delivery of detailed engineering drawings and specifications, procurement and delivery of material and services, construction of facilities per design and schedule, and performance of inspections and checks. Closure includes a review of start-up readiness for commissioning, the commissioning itself, and then subsequent handover to operations of assets and documentation.

Figure 4 - BCG framework shows how digital can support large capex project success



Note: FEED = Front End Engineering Design; HSE = Health, Safety, Environment
Source: BCG Analysis

The BCG framework first identifies six broad ways that digital technologies can support the energy industry's large capex projects, mapped to the project lifecycle (Figure 4). It then defines 45 specific digital use cases, also categorized by type of support and life cycle stage.

- A. **Project and portfolio management (PPM)** - optimize large projects' management and effective planning through smart digital tools for analytics, forecasting, and automation
- B. **Value-driven business case and scope assessment** - facilitate project scope and feasibility assessment, business value identification, and opportunity prioritization
- C. **Integrated supply chain and quality management** - enhance material tracking along entire supply chain, automate contractor qualification and anomaly detection
- D. **Integrated engineering visualization and simulation** - improve project design and collaborative decision-making, enhancing drawing accuracy and availability
- E. **Digital construction and smart HSE** - ensure plant and workforce safety, automate construction progress tracking, and proactively minimize site risks
- F. **Smart commissioning and handover** - streamline processes of commissioning and handover, ensuring smooth transition from construction to operations

Given the long list of ways that digital solutions can support large capital projects, where should companies focus? Most of the benefits in terms of overall project cost and end-to-end time reduction are concentrated in the early stages of the project, reflecting the tremendous importance of inherent decisional capability. **BCG estimates that up to 5% of overall project cost savings can come from two actions. The first is identifying potential design flaws, limitations, or constraints during the Concept phase, which helps avoid costly modifications later. The second is addressing major project uncertainties during pre-FEED and FEED, which streamlines cost estimation and risk mitigation. Similarly, two key actions can reduce the end-to-end project timeline by up to 25%.** First, automating and streamlining key activities during Concept and pre-FEED saves time anticipating commissioning and handover to Operations. And second, early-stage accurate project definition ensures smoother execution, minimizing delays and rework. Ensuring full project alignment with business needs and optimal design during the Concept phase minimize risks and costs of changes, errors and delays.

Study respondents describe digital priorities and experience

BCG has conducted a comprehensive global survey and strategic assessment of 50+ companies, identifying the critical ways they leverage digital technologies to realize value and increase ROI in their large capex energy projects. Table 1 summarizes key types of stakeholders surveyed, their roles, and specific market topics investigated.

Table 1. Survey stakeholders and market topics

Stakeholders and their roles in large capex energy projects	Market topics investigated
<ul style="list-style-type: none"> • Owners own and operate the plants, evaluate and bear the financial risks, allocate the budget, initiate and manage the project (includes Integrated energy companies, Multi-utilities, and Network operators) • Contractors design and execute the project including engineering, procurement, construction and installation activities (includes EPC, OEM, oilfield services**) • Vendors provide technologies (e.g., SaaS, Cloud infrastructure), and solution implementation and configuration services <p>** EPC = Engineering, Procurement and Construction; OEM = Original Equipment Manufacturer</p>	<ul style="list-style-type: none"> • Market and capex overview: the current investment plan, portion of investments related to digital, and trend in coming years • Value for future investments: the most valuable project phases for implementing digital solutions and key use cases, assessing market maturity level and obstacles for implementation • Generative AI adoption: current level of adoption and maturity, first movers' implemented use cases

Owner Overview

Fifty-eight percent of owners surveyed are already investing in new solutions. They are on average in the process of scaling targeted digital use cases, including completing some Proof of Concepts (PoCs).

To implement new use cases and scale priority solutions, 3 out of 4 owners plan to further increase digital spending on managing large capex projects (by on average 15%) in the next three years, reaffirming the importance and value of such initiatives.

However, most owners risk missing the opportunity to digitally reduce costs and maximize value because they are not sufficiently focused on the most critical phases of a project's success (i.e., Concept and pre-FEED). Instead, they are concentrating their investments more on PPM (selected by 70%) and Execution (selected by 75%). However, it is in the early, critical, and costly phases that disruptive technologies like Generative AI can help make complex processes more efficient or generate and compare alternative scenarios.

Although the majority (70%) recognizes the importance of Generative AI and has begun to explore its potential through experimentation with some use cases, the remaining 30% may miss the transformative opportunity by not seeing its value.

In addressing the challenges of transformation and the implementation of innovative technologies, 70% of owners name acquiring external skills and resources for support as the key enabler for success. This is followed by the challenge (relevant for 35% of the respondents) of costs exceeding the allocated budget.

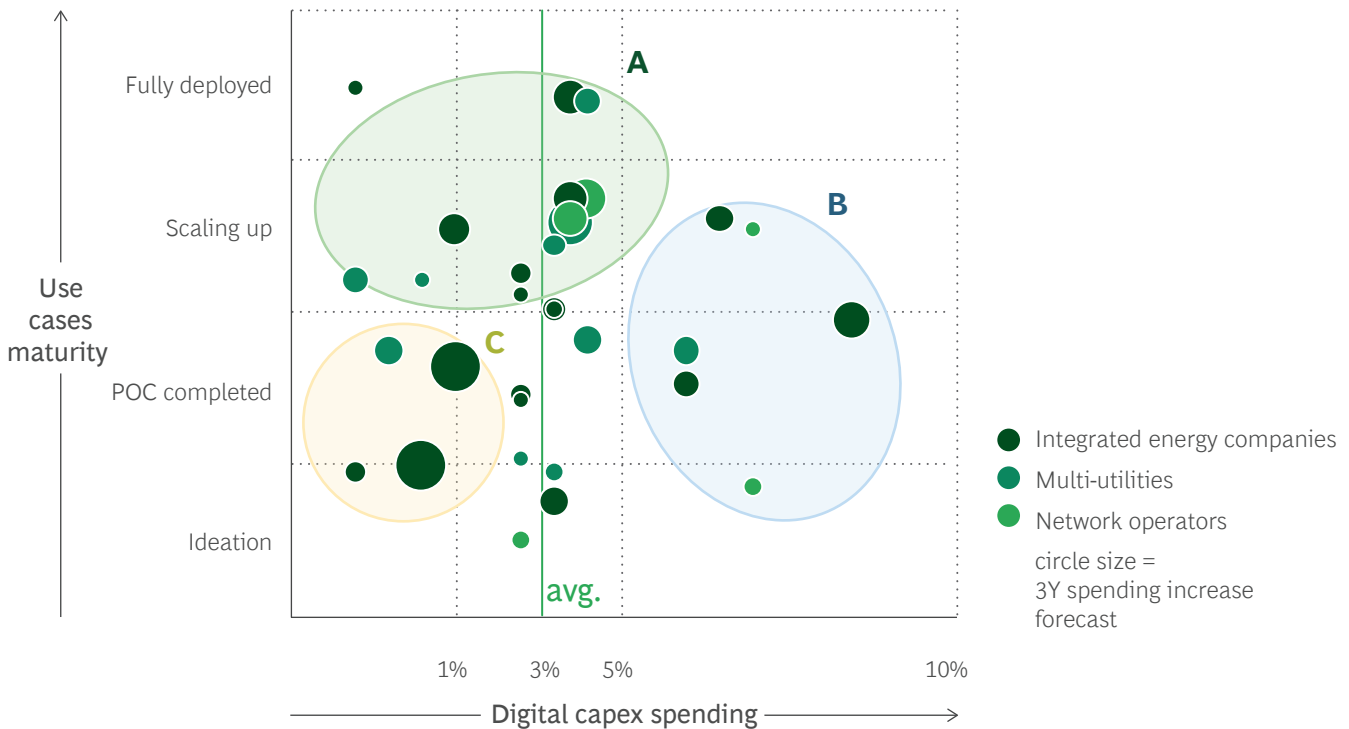
Digital investment and maturity in large capex projects

All stakeholders reported some degree of digital investment in support of their large capital projects. Respondent companies allocate on average 3% of their capex for enhancing the management of these projects.

In terms of maturity level, most of the energy owners surveyed have completed use case proof-of-concepts and are scaling up, confirming the adoption of digital technologies. BCG's analysis reveals three distinct maturity / investment patterns (Figure 5):

- Companies that are scaling up successfully witnessed positive ROI, and plan to further increase digital spending in the next 3 years to fully deploy use cases
- Companies with a significant portion of capex reserved for digital, but a higher implementation risk due to limited internal capabilities and know-how
- Companies that recently started on the transformation path, and are planning to further increase capex spending to scale up faster

Figure 5 - Owners overview: use cases maturity correlates with capex investment in digital



Note: FEED = Front End Engineering Design; HSE = Health, Safety, Environment
Source: BCG Analysis

Leveraging digital tools

Increasingly, owners are defining and enforcing the application of their own internal digital tools e.g., design tools, DMS²) in major projects. They are encouraging contractors to collaborate through use of the digital tools provided, improving management of the project overall.

This may mean higher financial and informational costs to contractors as they migrate to owners' digital requirements. However, contractors continue to recommend specialized tools to be used in specific projects and phases (e.g., execution). While 40% of owners surveyed enforced the use of their own digital tools, 55% are currently following a more hybrid case-by-case approach based on contractors' inputs, and 5% are themselves adapting to contractors' digital tools.

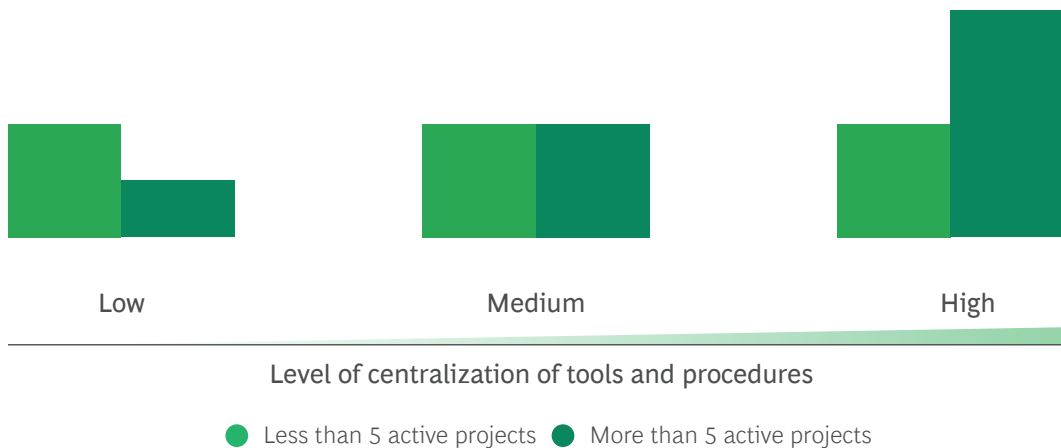
The second trend we are seeing is toward the centralization of digital tools. Such centralization across facilities and geographies is essential for the management of multiple projects (Figure 6). Seventy-nine percent of companies with five or more active large capex projects report a high level of centralization in their digital tools, compared to only 25% of companies with fewer than five active projects. Meanwhile, smaller players with plans to scale up major project activity say that they will pursue greater centralization.

Emphasis on specific project phases

Owners and contractors emphasized similar phases of a project (Figure 7). Both groups view Execution as the most important phase. And both tend to underestimate the impact of Concept and Pre-FEED phases, despite this being where the greatest benefit lies in using digital technologies to reduce costs and time. But for owners, Project and Portfolio Management (PPM) activities and supporting digital solutions are prioritized as fundamental to streamlining and controlling the entire large capex project lifecycle. Contractors, meanwhile, are much more focused on the Closure phase's project commissioning and handover activities, to reduce delays and related costs and contractual disputes.

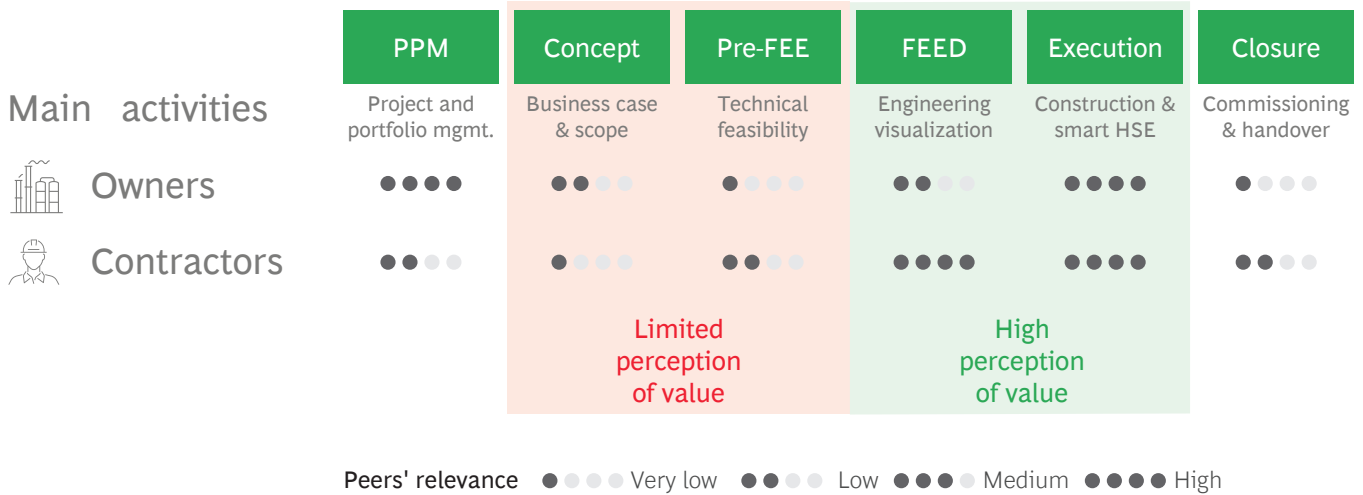
2. DMS = Document Management System

Figure 6 | Centralization is essential for managing multiple major projects



Source: BCG interviews of energy companies; BCG Analysis

Figure 7 | Comparing Owner and contractor perceptions of project phases



PPM = Project and Portfolio Management; FEED = Front End Engineering Design
 Source: BCG Analysis

Figure 8 | Key energy players perception of use cases relevance and maturity



Source: BCG Analysis

The value that owners and contractors assign to the project phases is reflected in the maturity level of their respective use-cases per phase.

Within the domain of energy capital projects, a comprehensive evaluation of insights from industry stakeholders resulted in the identification of specific use-cases, considered most relevant from the majority of interviewed energy players.

Projects portfolio summary and analytics: enable overall project portfolio overview, capture historical data on operating assets, capital projects and potential future investments to create a forecast of future financial performance. In addition, leverage analytics to understand intra and cross project progress including job orders status and completion milestones

Concept generation powered by Gen AI: streamline and automate the process of generating diverse project concepts leveraging generative AI, exploring a wide array of alternative project ideas to uncover different solutions

Centralized supply chain control tower: real-time material trading and demand optimization across portfolio projects to minimize schedule overruns and budget overspend, based on material and tags data (e.g., master data, stock quantities) and construction needs defined in the project design phase (e.g., generation of optimized material take-off list)

Real-time collaborative platform: real-time collaboration platform (for contractors and engineers) to enable simultaneous collaboration on drawings and 3D models, including AI detection of errors and generation of warnings (based on engineering standards and digitize checklists) to enable expedited reviews with improved accuracy

Advanced work-package planning: track work progress in real-time on augmented, color-coded 3D models of construction sites; simulates and optimizes the construction activity sequences based on construction timing, construction sequence constraints and delivery dates. Verify in real-time work package feasibility (e.g., availability of materials, resources)

Virtual commissioning and trainings powered by VR: leveraging VR and digital twin technologies, simulate or even virtually execute commissioning activities and training steps minimizing the commissioning time, costs and enhancing the startup experience

Contractors demonstrate a narrower portfolio of implemented use cases, the result of increasingly vertical solutions and the desire to propose specific use cases to operators. However, there is considerable overlap between those identified as relevant for operators and contractors.

Obstacles and enablers

Respondents – including companies' c-level executives and senior managers with exposure to digital investments in large capex projects – reported different obstacles to the implementation of digital tools. Owners considered the biggest challenges to be the **limited in-house capacity** and experience with the latest technologies, **high implementation costs** compared to initially allocated budgets, and the **lack of partners and suppliers** who can support them in grounding digital use cases from start to finish. Contractors, on the other hand, said the main obstacle is having project sponsors recognize the value of their digital solutions.

Furthermore, most respondents highlighted resistance to change as a relevant obstacle. This may stem from the uncertainty around adopting disruptive solutions, or **lack of awareness** and support from key stakeholders about potential benefits. Forty percent of respondents are trying to overcome **resistance to change**.

Conversely, 85% of the surveyed companies identified data management or software as the most crucial enabler for implementation. More than 45% ranked data management as highly relevant: accurate data in a unified platform is critical for ensuring the reliable insights and informed decision-making that underpin successful digital initiatives. They considered software of medium relevance, with cutting-edge solutions seen as fundamental for streamlining / optimizing workflows and processes to ensure operational efficiency. They viewed hardware as less relevant, but recognized the need for a robust backbone that facilitates seamless data transmission and scalable infrastructure for optimizing operations, and the role of field hardware for data creation and sharing.

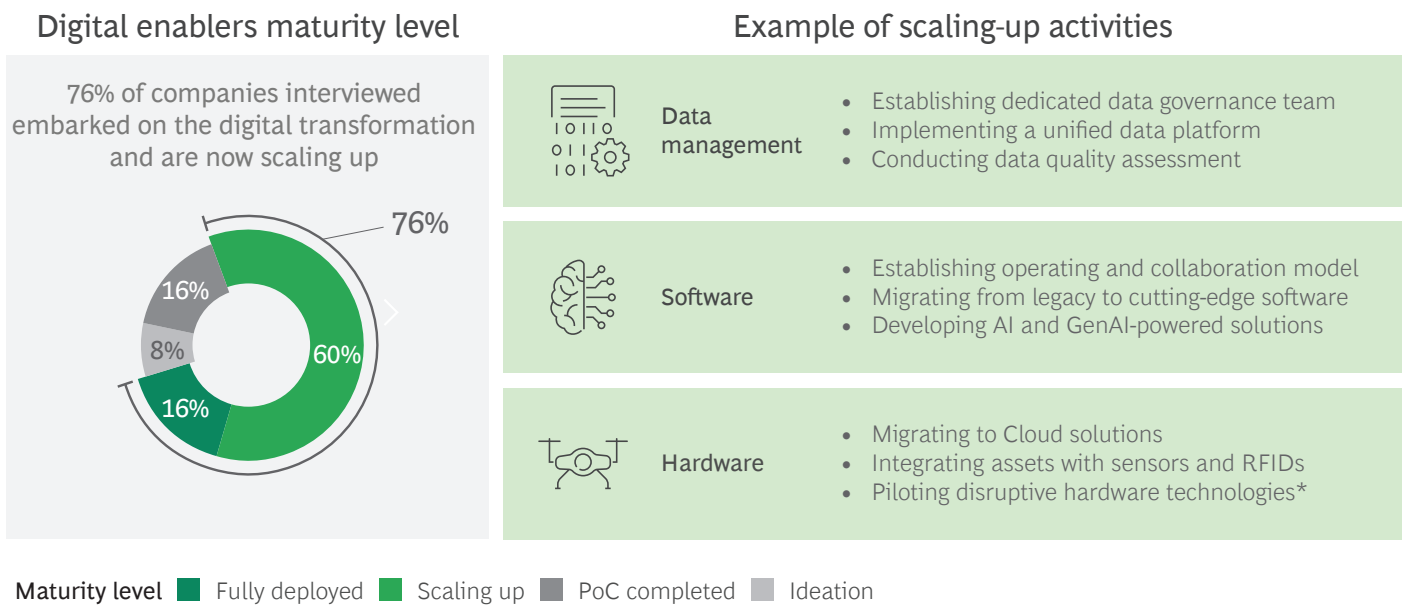
Progress on the digital journey

Seventy-six percent of the energy players surveyed have embarked on some form of digital transformation, and 60% of these are already scaling up solutions (Figure 9). Examples of scaling up activities include:

- Data management: establishing a dedicated data governance team; implementing a unified data platform; conducting a data quality assessment
- Software: establishing an operating and collaboration model; migrating from legacy to cutting-edge software; developing AI and Gen AI-powered solutions
- Hardware: migrating to cloud; integrating assets with sensors and RFIDs; piloting disruptive hardware technologies (e.g., UAV³, laser scanners)

3. UAV = Unmanned Aerial Vehicle

Figure 9 | Progress on digital enabler maturity and examples of scaling up activities



*. e.g., drones

Source: BCG interviews of energy companies; BCG Analysis

Meanwhile, 70% of first movers are exploring Generative AI and launching proof-of-concept initiatives. These early use cases include generation of: optimized structural designs for material minimization; extraction documentation and summaries; alternative layouts and scenarios for analysis; and models for data interpretation and synthesis. But use of Gen AI is still in its early days; no owners or contractors reported using it frequently, and 30% of respondents did not expect to use it at all.

Software vendors offer a different perspective. They highlighted three challenges in generating value for customers with their innovative and disruptive solutions:

- **Positioning the solution in customers' IT landscape.** As non-traditional players enter the market with vertical solutions targeting specific parts of larger processes, it is increasingly crucial for vendors to fit into the customer-specific IT landscape. Some vendors are teaming up with best-of-breed solution providers to better integrate their offerings.
- **Ecosystem participants moving at different speeds.** Software vendors deal with differing innovation speeds throughout their ecosystems. Their perceived agility might outpace partners and integrators, leading to disparities in progress. One way they are addressing this disconnect is using flanking system integrators with their own professional services.
- **Building client project sponsorship.** In the complex corporate landscape, the challenge lies in finding a committed project sponsor who values the solution and is determined to implement it. Software vendors often find themselves in an 'evangelical' role to align stakeholders on the importance of taking action.

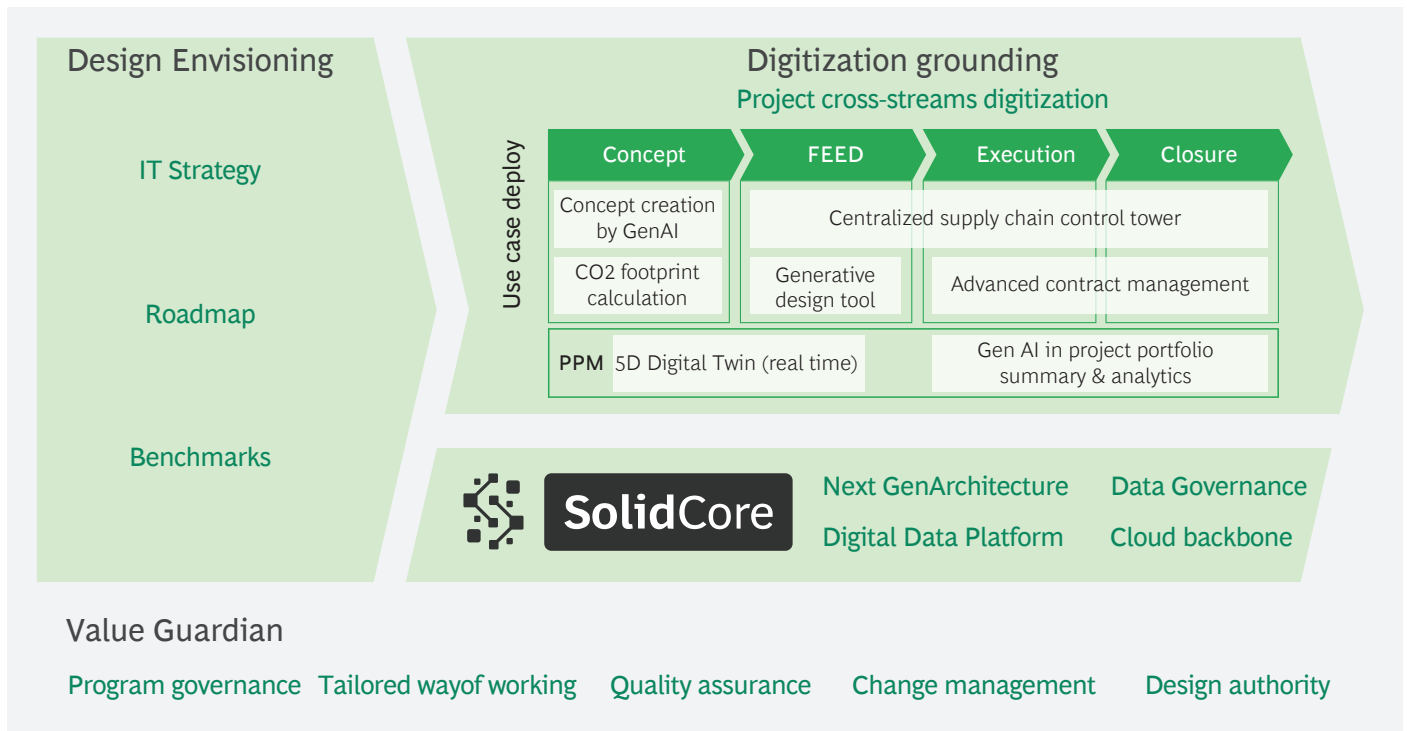
Advancing digital contribution to large capex energy projects

In conclusion, energy companies are ramping up their digital investments to optimize capital projects. Success in this endeavor varies based on the stage of their digital transformation journey and the effective prioritization of value-added use cases, across a diverse range of maturity levels within the industry.

However, many are struggling to fully leverage the immense potential of digital technologies during critical project phases where its significance and value are most evident. As investment in digital capital expenditures continues to rise, so does the risk inherent in its implementation, coupled with a heightened variability in the return on investment (ROI). This intricate and interconnected dynamic poses both opportunities and challenges for energy companies navigating the evolving landscape of digitalization in their capital projects.

Harnessing digital technologies is now imperative in mitigating risk and realizing expected returns of high capex energy projects. The pivotal question no longer concerns the decision to adopt these technologies, but rather the strategic allocation of investments to maximize their impact.

Figure 10 | Area of focus to boost digitization in capital projects



Source: BCG bullet-proof approach for large capital projects management

Energy companies in early stages of digital transformation should focus on mapping and establishing the context for the optimal path forward. However, most of the interviewed energy companies already envisioned the strategy and are focusing on:

- **Solid Core:** designing and setting up the optimal application and infrastructure architecture that enable the rapid implementation of innovative digital use cases
- **ValueGuardian:** establishing and executing the ‘control tower’ based on project governance, tailored ways of working, design authority, quality assurance, and change management
- **Use Case grounding:** With these foundational steps completed, companies can then prioritize the execution of targeted digital use cases either for a specific project or to drive wider cross-stream digitization. Depending on the circumstances, these could range from integrated carbon footprint calculation to project portfolio analytics to advanced contract management. For organizations with more mature digital capabilities, we see many unexploited opportunities to leverage Generative AI. These include rapid prototyping, CAD design optimization, documentation generation and summarization, and data synthesis and interpretation.

Energy companies face an overabundance of digital opportunities, and tremendous pressure to realize the expected benefits from their major projects. Focusing on the project phases, tools, and deployment approach that deliver the greatest impact will be key.

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