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Power Plants as Megaprojects: Using Empirics to Shape Policy, Planning and Construction Management

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Abstract

Megaprojects are historically associated with poor delivery, both in terms of schedule and cost performance. Empirical research is required to determine which characteristics of megaprojects affect schedule and cost performance. Capital-intensive power plants can be understood as megaprojects and time delays and cost escalation during the construction phase can undermine their overall economic viability. This paper presents a systematic, empirically based methodology that employs the Fisher Exact test to identify the characteristics of power plant megaprojects (PPMs) that correlate with schedule and cost performance. We present the results of applying this methodology to a dataset of 12 PPMs using nuclear, coal, and renewable resources as case studies. The results highlight the importance of modular technologies, project governance, and external stakeholder involvement. Key findings both support and contradict the literature. The paper provides two major original contributions. First, we present and apply a systematic, empirical and statistical approach to understanding PPMs planning and construction. Second, we show how this approach can be used to inform public policy and project management with regard to PPMs.

Keywords: Megaprojects; power plant economics; capital intensive; project management; construction management; budget; schedule.

1 Introduction

Over the next twenty years, an unprecedented level of investment in energy infrastructure is predicted. The capital investment required to keep pace with the world's energy needs to the year 2035 has been estimated by IEA (2014) as $48 trillion: $40 trillion of this sum will relate directly to investments in new and replacement energy infrastructure. IEA (2014) predicts that Europe alone will invest more than $3 trillion in the energy sector over this period and the vast majority of this (69%) will be in new power plants. Increasing energy demand fosters the development of energy infrastructures (power plants, electrical grid, pipelines, energy storage etc.). Part of this energy demand will be satisfied by "small-scale projects" (e.g. gas turbine or rooftop photovoltaic plants) but some will be satisfied by large-scale and complex "megaprojects" due to their capital nature; these include long pipelines, nuclear power plants, large wind farms and large dams. Of the new power plants, indications are that three-quarters of the spending will be on plants using nuclear power and renewable resources, with the remainder of the investments taking place in fossil-fuel power plants (IEA 2014). A description of the risks and challenges in building large infrastructure projects is available from Van de Graaf and Sovacool (2014) and Sovacool and Cooper (2013).

Decisions related to energy investment, even in the so-called "de-regulated markets", are generally guided by government policy rather than market signals (de la Hoz et al. 2014; Locatelli et al. 2015a). Interventions related to investments in new power plants, therefore, represent a highly significant and influential tool of any government's energy policy and, in many cases, a substantive level of public expenditure (see for instance the detailed case of France from Maïzi and Assoumou (2014)). Power Plant Megaprojects (PPMs) are often seen as too late, too costly, and fail to provide for society the promised benefits. The essential nature but poor performance of energy infrastructure megaprojects in general suggests room for improvement. Effective energy policy is thus also predicated upon improvement in megaproject design and delivery.

We present the results of a rigorous and systematic investigation to identify megaproject characteristics that contribute to the effective design and delivery of new PPMs and thus provide guidance for policy-making and decision-making about future projects.

2 Literature review

2.1 What is a Megaproject

Gellert and Lynch (2003, p.16) show that *"Mega-projects can be divided analytically into four types: (i) infrastructure (e.g., ports, railroads, urban water and sewer systems); (ii) extraction (e.g. minerals, oil, and gas); (iii) production (e.g. industrial tree plantations, export processing zones, and manufacturing parks); and (iv) consumption (e.g. massive tourist installations, malls, theme parks, and real estate developments)"*. There is not a single accepted definition of megaproject in the literature and different criteria can be adopted toward this end. For instance, from the investment point of view, megaprojects have budgets above $1 billion with an high level of innovation and complexity (Flyvbjerg et al. 2003; Locatelli et al. 2014a; Merrow 2011; Van Wee 2007). Looking at the operations phase, megaprojects are projects having long-term and far-reaching effects on their environment (Orueta and Fainstein 2008; Ren and Weinstein 2013, Warrack 1993)

With respect to the economical dimension, Warrack (1985) argues that $1 billion is not a constraint in defining megaprojects, as sometimes a relative approach is needed because in some contexts, a much smaller project (such as one with a $100 million budget), could constitute a megaproject. Warrack (1993, p.13) also presents ten main features of megaprojects: "*joint sponsors, public policy, uniqueness, indivisibility, time lags, remoteness, social environmental impact, market impact, risk, and financing difficulty*". Van Marrewijk et al. (2008, p.591) define megaproject as *"multibillion-dollar mega-infrastructure projects, usually commissioned by governments and delivered by private enterprise; and characterised as uncertain, complex, politically-sensitive and involving a large number of partners".* This latter definition emphasizes the organizational complexity that comes with the presence of multiple private firms in connection to the political stakeholders (namely, the government).

Therefore, megaprojects are temporary endeavours (i.e. projects) characterised by: large investment commitment, vast complexity (especially in organisational terms), and long-lasting impact on the economy, the environment, and society. Large energy infrastructures are typically delivered through megaprojects. The working definition of an energy megaproject adopted in the current research is: *"an energy infrastructure with an a budget of at least $1 billion with an high level of innovation and complexity with, in operation, a long-term and far reaching effects on their environment"*.

2.2 Megaproject performance

Merrow (2011), analysing a dataset of 318 industrial megaprojects from several sectors, shows that as many as 65% of them can be considered a failure. The oil and gas production sector is the worst, as 78 % of megaprojects in this industrial sector are classified as failures. Therefore, there is a huge scope for the study and application of a risk framework specific to megaprojects, as presented in Kardes et al. (2013).

Focusing on the electricity sector, infrastructure PPMs are no exception to this pattern. Ansar et al. (2014) analysing a sample of 245 large dams (including 26 major dams) built between 1934 and 2007 found that actual costs were on average 96% higher than estimated costs and actual implementation schedule was on average 44% (or 2.3 years) higher than the estimate. Koch (2012) shows that budget overruns range from 0% to 65% and lead-time overruns range from 9% to 100% for offshore wind farms. Sovacool et al. (2014a) shows that three-quarters of megaprojects are over budget with an average overrun of 66%.

PPMs suffer from large differentials of cost to budget both in absolute and relative terms. Hydroelectric and nuclear power plants are the worst performers. Sovacool et al. (2014b) test six hypotheses about construction cost overruns related to (1) diseconomies of scale, (2) project delays, (3) technological learning, (4) regulation and markets, (5) decentralization and modularity, and (6) normalization of results to scale worldwide. They discover that different technologies generally exhibit different behaviour (with again nuclear as worst performer), but smaller, decentralized, modular, scalable systems have less cost overruns in terms of both frequency and magnitude and both in absolute and relative terms. Kessides (2010 and 2012) provides an extremely critical analysis of nuclear power plants. He discusses risks, cost escalations, delays, and safety issues of this technology. He shows that, with current project management performance and system issues (such as grid and fuel cycle), large nuclear power plants are not suitable for most countries. Locatelli and Mancini (2012) focus on two nuclear projects in particular (Olkiluoto 3 and Flamanville 3), discussing how budget costs have been underestimated despite historical evidences. All nuclear and most gas and coal power plants can be considered megaprojects. In Europe, 58 nuclear reactors are currently planned or proposed (WNA 2014). Even investments in renewable energy power plants (such as large-scale offshore wind farms and solar plants) frequently take the form of megaprojects. In the UK alone, 13 wind-farm megaprojects are under consideration (Pierrot 2014).

Given the prominent role that megaprojects will play in the provision of new power plants, it is concerning that they are renowned for their poor delivery record in terms of timeliness and budget (Flyvbjerg 2006; Merrow 2011; Sovacool et al. 2014b). Furthermore, their planning and construction plays a fundamental part in securing their effective operation and intended life-cycle benefits. Too often, megaprojects are seen as providing a solution that is too late, too costly, and fails to provide promised benefits to society. In sum, more effective design and delivery of infrastructure megaprojects is becoming increasingly important to effective energy policy as a whole.

3 Methodology

3.1 Cross-case analysis

The research methodology used here is an inductive cross-case analysis, a technique that takes similarly constructed cases and uses a structured process to review the cases to arrive at "cross-case" patterns. These "patterns" are the used to generate theoretical propositions. The approach adopted is based on the seminal work of Kathleen Eisenhardt (1989), who derived a process where theoretical generalizations could be generated from reviewing a set of cases of a particular phenomenon. Eisenhardt (1989, p.545) also discusses "reaching closure," i.e., *"when to stop adding cases, and when to stop iterating between theory and data"*. She advises researchers to stop adding cases upon reaching theoretical saturation and/or when the incremental improvement to quality is minimal. Four to ten cases usually work well because too few cases will be insufficient for empirical grounding and generalization and too many cases will be overly complex in terms of data management. In our effort to generate statistical evidence across several variables, we reached 12 cases. It was extremely difficult to increase this number of cases because of the lack of availability of primary and secondary data. Regarding the geographic constraint (Europe), we note that the research is enclosed within a broader research stream initiated and supported by the Megaproject COST Action[1]. The main objective of this Action is to understand how megaprojects can be designed and delivered to ensure their effective commissioning within Europe.

Statistical analyses can be used to reveal relationship between PPMs characteristics (independent variables) and PPMs performance (dependent variables). However, there are inherent problems in trying to understand these relationships. First, the absolute number of PPMs is small for statistical purposes. For example, even though the new nuclear power plants in Europe has a value of several billions, this represents less than 60 projects and most likely only a percentage will be built. Most statistical techniques associated with establishing relationships require a far greater sample size (Stuart and Ord 1994). Furthermore, it is not possible to test parametric distributions. i.e. distributions assuming that data has come from a certain probability distribution and hence infers about its parameters (Leach 1979). Second, data associated with PPMs characteristics is rich and qualitative and hence needs to be converted into a quantitative form to enable statistical analysis. This process is notoriously difficult (Easterby-Smith et al. 2012). Third, the evaluation of "performance" for projects in general and PPMs in particular can be controversial (Ika 2009). Traditionally the project management literature focuses on the iron triangle, namely cost, schedule and quality while, more recently, a growing importance is given to the cost/benefit analysis for the project stakeholders.

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[1] The Megaproject COST Action is funded by COST Programme. (COST is an intergovernmental framework aimed at facilitating the collaboration and networking of scientists and researchers at European level.) The Megaproject COST Action focuses on improving the design and delivery of megaprojects across sectors in Europe.

3.2 Fisher Exact test

In order to overcome the research challenges previously presented, we adopt the Fisher Exact test (see appendix B for a detailed explanation). The main advantage of this test relates to the ability to identify correlations within small data sets (Leach 1979). However, the Fisher test has two main limitations. First, it limits the typology of variables (both independent ad dependent) to be considered; these must be binary/Boolean variables (i.e. Yes/No, On/Off, True/False). Hence the test is less informative than other approaches because it only considers black and white and not the grey spectrum between these two extremes. Whilst binary data are commensurate with the use of the Fisher Exact test, it can only detect a relationship between an independent and dependent variable and cannot describe the nature of the relationship. Second, the test only considers the correlations between one independent and one dependent variables (i.e. one vs. one). Therefore, the test does not consider the mutual (or compound) correlations between variables. Finally, the investigators only chose to evaluate the PPMs performance in terms of its planning and construction (both lead-time and cost). This enabled an unambiguous characterization of performance but had the drawback that the trade-off between construction costs and lead-time and operational efficacy cannot be investigated.

We chose to adopt a higher significance level than that traditionally associated with this type of research (i.e. p-value<0.15 rather than a more typical value of p-value<0.05). This means that statistically significant findings must be dealt in a circumspect fashion with regard to suggested causation.

3.3 Dependent variables

In order to investigate relationships, a purposive sample of 12 PPMs was selected from the wider portfolio that had been created by the Megaproject COST Action. These PPMs were selected to represent a wide range of technologies (coal, nuclear, wind and solar) and a geographic spread throughout Europe. These PPMs are delineated in Table 1.

Project Name	**Moorburg**	**Lunen**	**Datteln**	**Andasol**	**Olkiluoto 3**	**Flamanville 3**	**Hinkley point**	**Oskarshamn Modernisation**	**Torrevaldaliga Nord**	**Mochovce**	**Greater Gabbard**	**Anholt Offshore**
Type	CPP	CPP	CPP	SPP	NPP	NPP	NPP	NPP	CPP	NPP	OWF	OWF
Country	Germany	Germany	Germany	Spain	Finland	France	U.K.	Sweden	Italy	Slovak Rep	U.K.	Denmark
Size (budget)	€ 1.8bn	€ 1.4bn	€ 1.2bn	≈ € 1 bn	€ 3bn	€ 3.3bn	£ 20bn	€ 3.3bn	€ 1.5bn	€ 1.8bn	€ 4bn	€ 1.3bn
Client/ Plant owner	Vattenfall Europe Generation AG	Trianel Kohlekraftwerk Lünen GmbH and Co. KG	E-On	Solar Millennium	Teollisuuden Voima (TVO)	EDF (Électricité de France)	Nuclear New Build Holding Company Limited (NNBHC)	Oskarshamnsverkets Kraftgrupp OKG	ENEL	Slovenské elektrárne, a.s.	Greater Gabbard Offshore Winds Ltd (GGOWL)	Anholt Offshore Wind Farm

Table 1 PPMs considered in the analysis (NPP = Nuclear Power Plant; OWF = Offshore Wind Farm; CPP = Coal Power Plant; SPP = Solar Power Plant)

The qualitative cases describing the PPMs are coded according to the presence (or absence) of 32 binary characteristics (detailed in Appendix A). The theoretical provenance for these characteristics is given in the next section. Each PPM was "coded" according to performance. The following performance (dependent) variables were considered: delayed during the planning phase; delayed during the construction phase, and costs over budget.

Precise definitions are given in Table 2. Once the PPM had been coded, the dataset was used to identify which of the 96 potential relationships (c.f. 32 binary independent characteristics and 3 binary dependent performance items) demonstrated statistical significance using the Fisher Exact test.

Dependent Variable Construct	**Operationalization**
The project was delayed in the planning phase	The project was judged to be delayed in the planning if the actual commencement of physical construction was more than 12 months later than the planned date for the commencement of construction. The planned date for the commencement of construction was taken to be a publically available figure obtained either through direct interview with the project client or through public review at the time as close as possible to the point at which the first formal activity (such as the first stage in the acquisition of any land rights required for the project) was entered into. The actual date for the commencement of construction was taken at the point at which any physical construction activity related directly to key functionality of the project was undertaken as reported through direct interview with the project client or through public review
The project was delayed in the construction phase	The project was judged to be delayed in the construction phase if it exceeded the planned date for entry into service by 12 months set at the point of entry into construction. The planned date for the entry into service was taken to be a publically available figure obtained either through direct interview with the project client or through public review at the time as close as possible to the commencement of construction work. The actual date for the entry into service was taken at the point at which output from the project was first provided to its intended beneficiaries as reported through direct interview with the project client or through public review
The project was over-budget	The project was judged to be over budget if the final cost of the project was greater than the 110% of the original estimate (adjusted for the inflation). The estimated cost was taken to be a publically available figure obtained either through direct interview with the project client or through public review at the time as close as possible to the point at which the first formal activity (such as the first stage in the acquisition of any land rights required for the project) was entered into. The final cost was taken to be a publically available figure obtained either through direct interview with the project client or through public review at the point at which the project entered operation. The final cost and initial estimate were assumed to have been made on the same basis.

Table 2 Project Management performance definitions

3.4 Independent variables

Despite substantial research effort to understand the precursors of megaproject performance, a unified and cohesive view on what these might be is yet to emerge. Furthermore, most of the empirical work has been carried out in the context of the transport sector, and not the energy sector, and different methodological approaches appear to identify different factors (De Jong et al. 2013). Individual case studies have highlighted a number of diverse explanations illustrated in Table 3.

Source	**Megaproject Studied**	**Characteristics affecting Performance**
(Giezen 2012)	Metro Extension, Netherlands	Complexity in governance
(Marrewijk and Clegg 2008)	Environ project, Netherlands, Tunnelling Project, Australia	Project culture
(Davies et al. 2009)	Airport Terminal.UK	Modularisation
(Han et al. 2009)	High Speed Rail, Korea	Degree of Change, Inappropriate scheduling tools, lack of client ability

Table 3 Precursors of Megaproject Performance Identified by Case-Study Investigations

The few large-scale statistical analyses of megaproject performance that have been undertaken (Flyvbjerg 2006; Merrow 2011) highlight different issues. Following an analysis of a database of 252 transportation projects, Flyvbjerg (2008) proposed that the reasons why megaprojects performed poorly were optimism bias or strategic misrepresentation. Merrow's (2011) work was based on "industrial" megaprojects that included a large number of energy megaprojects (318), but only 8 power plants. His work indicated that the main root causes of project failure were a failure to undertake sufficient planning and engineering at the start of the projects as well as misaligned incentives throughout the project. Other works try to explain project performance by looking just at particular dimensions, such as public-private partnerships (Cabrera et al. 2015) or the role of private equity (Gemson et al. 2012). Empirical studies by Sovacool et al. (2014a; 2014b) rely on extensive database composed by 401 electricity infrastructure projects. Certain technologies (hydroelectric and nuclear power) and project size (the larger the worst) are the variables with the strongest correlation with budgetary cost overruns.

Given the lack of cohesiveness among existing theoretical explanations for megaproject performance, and their empirical focus mainly in the transport sector, we chose to combine the existing theoretical understanding of megaproject performance with a portfolio of practical findings from the Megaproject COST Action (Brookes 2013). This led to the formulation of five categories of PPMs characteristics that were reviewed with respect to their impact on performance. These categories were:

- Megaproject External Stakeholder Characteristics
- Megaproject Governance Characteristics
- Megaproject Environment Characteristics
- Characteristics of Technology within the Megaproject
- Characteristics of the Megaproject's Formal Project Management Approach

Appendix A gives decomposition of the broad categories into individual megaproject characteristics and the operationalization of these characteristics into binary representations.

4 Results

The first result is that only a few of the PPMs characteristics demonstrate a statistically significant relationship with performance. Of the 96 potential relationships, only seven proved to be statistically significant; these are indicated in Table 4 and key insights are highlighted below.

Category	Independent Variables	Correlating with	P-value
Modularity	Project is modular – dependent modules	On budget	3%
	Project is modular – independent modules	Delay in planning	7%
Project Type	The project is about a nuclear reactor	Over budget	11%
	The project is about a renewable plant	On time construction	12%
External Stakeholder Interactions	Already existing environmental group (such as Greenpeace) have objected to the project	Delay in construction	5%
	There was public acceptability at local level (no protest)	Over budget	8%
Governance	The project uses an SPE structure	On Budget	12%

Table 4 Results from the statistical analysis

4.1 Modularization

In recent years, modularization has been advocated as a way to improve performance of large infrastructure projects. In the power sector, this has been particularly advocated for nuclear power plants (Matzie 2008; Kog and Loh 2012; Locatelli et al. 2014b). According to GIF/EMWG (2007) it is necessary to distinguish two types of modularization:

- Modularization (a single plant with dependent modules): this is the process of converting the design and construction of a monolithic or stick-built plant to facilitate factory fabrication of modules for shipment and installation in the field as complete assemblies (e.g. a modern large nuclear power plant like the AP1000 (Matzie 2008))
- Modular unit (many plant with independent modules): this involves a group of units assembled onsite from factory produced modules that can work independently (e.g. the units in a wind farm or a Small Modular Reactor like Nuscale (Locatelli et al. 2015b))

The results of this investigation partially corroborate the use of modularization because stand-alone PPMs built by assembling dependents modules can be delivered on budget. However, PPMs that are built as independent modules (e.g. wind farms) face delays in planning. Therefore, it is very important to distinguish between the two approaches towards modularisation: a stand-alone functional unit made by dependent modules as compared to a series of independent modules deployed in the same site.

4.2 Project Type

This category investigates the effect of the power plant typology. There are three macro categories of PPMs in the database: nuclear reactors, large renewable plants (solar and wind farms), and coal plants. Combined Cycle Gas

Turbine (CCGT) plants are not included because they are rarely classified as megaprojects. Not surprisingly, as shown by Sovacool et al. (2014a and 2014b) the results show that the delivery (or repowering) of a nuclear reactor is correlated with budget overrun. In fact, all the nuclear projects in the database are over budget. Conversely, renewable projects are correlated with on-time delivery.

4.3 External Stakeholder Interactions

The dominant paradigm in the existing literature is that improving external stakeholders' acceptance of a project will increase the chance of the project being successful (Aaltonen et al. 2008; Loch et al. 2006; Olander and Landin 2005). The empirical evidence provided by this investigation suggests that this may not be the case. A lack of protest at the local level was associated with PPMs cost overrun, while the objections of environmental groups (such as Greenpeace) are associated with delays in construction. Two factors may be influencing these seemingly counter-intuitive findings. Firstly, this characteristic was operationalized as no protest being evident. This is not the same as the project being seen as acceptable at a local level; thus a better operationalization of this construct may be required. Secondly, because we were not able to employ multivariate statistical analysis (due to sample constraints), our investigation may have failed to detect the influence of certain mediating variables. It is also plausible that sometimes protests are well founded, i.e. that protested projects are not expected to be beneficial for a large number of stakeholders.

4.4 Governance

The literature considers that "project governance" is one of the key aspects in the delivery of megaprojects (Locatelli et al. 2014a; Müller 2009; Ruuska et al. 2011) This investigation found a statistically significant relationship between the presence of a Special Purpose Entity (SPE) and project performance. According to Sainati et al. (2015) the SPE is a fenced organization having limited pre-defined purposes and a legal personality. SPEs are typically involved as organisational support in Public Private Partnerships (PPP) and Project Financing (PF). The use of SPE may have different impacts on PPMs, in particular on the following areas:

- Cost and availability of external funding (Finnerty 2013);
- Alignment of project stakeholders during the project delivery and/or across the lifecycle phases of the PPMs (Clifton and Duffield 2006; Nisar 2013);
- Risk and responsibility sharing between project stakeholders (Grimsey and Lewis 2002);
- Taxation (BCBS 2009); and
- Project management flexibility (Medda et al. 2013).

Since SPEs are tailored to the specific PPMs context, it is difficult to generalise about the motivations leading to SPE formation. Apart from the fiscal and financial areas of impact, once SPEs are in place, they play a central role in the governance of PPMs. This investigation suggests that there is mutual unfamiliarity combined with the need to forge a shared modus operandi for the new SPE; once these new relationships have been successfully established, they reap rewards in terms of a more timely construction phase.

4.5 First-of-a-Kind Technologies

It is worth noting the PPMs characteristics that did not appear to have a statistically significant relationship with performance. FOAK (First-of-a-kind) technologies have frequently been associated with poor performances in planning and constructing power plants (Finon and Roques 2008; Levitt et al. 2011). For example, the UK Royal Academy of Engineering report makes a very strong case for only using mature designs and technologies for nuclear power (ROA 2010).

Our investigation suggests that this link may not be that strong. This may be because new technologies comprise only a minimal component in the overall novelty of a PPM. The high levels of novelty in every PPM (in terms of a new environmental context, new stakeholders, new clients, new contractors, new supply chains) outweigh any reductions in risk made possible by the use of known technologies. It is possible that the literature overemphasizes the negative relationship between FOAK projects and performance, in terms of both time and cost. However, the Fisher Exact test did not confirm this widely discussed hypothesis (i.e. the finding is not statistically significant). Thus it is not possible to confirm nor reject the hypothesis discussed in literature (i.e. that FOAK projects suffer poor performance). Enlarging the sample of cases would be helpful in this regard.

5 Discussion and Conclusions

This investigation sought to frame and understand the relationships between PPMs characteristics and performance during their planning and construction. The goal is to use this greater understanding to more successfully introduce new PPMs and hence to improve the effectiveness of energy policies.

This investigation has a number of limitations. Firstly, our dataset is relatively small and geographically constrained. The European context of the PPMs studied means that, whilst it may be possible to extend our findings to comparable environments (such as the USA), it would be more speculative to assume these findings would apply in the BRIC economies (Brazil, Russia, India and China). Secondly, the statistical analysis technique employed, which is appropriate for smaller sample sizes, demands that dependent and independent variables are expressed in a binary “categorical nature” that limits what can be ascertained about relationships. Thirdly, by concentrating only on planning and construction, whole life-cycle performance is not captured. Despite these limitations, tentative but useful conclusions can be drawn from this investigation.

The first point to note is that this investigation has identified very few characteristics that have a statistically significant relationship with PPMs performance. This means that policy-makers should be extremely circumspect in commissioning PPMs as they have very little evidence to guide them. The relationships uncovered by this investigation both support and contradict some of the existing understanding of the factors that influence PPMs performance. This investigation has also discovered relationships between characteristics and performance that had not been previously identified in the literature (see Table 5).

	PPMs Characteristics
Relationship partially **supported** by this investigation	Modularization improves performance Nuclear projects are over budget
Relationship **not supported** by this investigation	Increasing acceptability to local external stakeholders improves performance First-of-a-kind technologies decrease performance
Potential new relationship with performance supported by this investigation	Presence of special-purpose entities is related to performance

Table 5 Relationships assessment

These findings suggest that those who seek to deploy energy policies through the commissioning of PPMs should be less concerned with the novelty of technologies in these projects and more concerned with reconciling policy intentions with stakeholder concerns. Our findings also suggest that commissioners of PPMs should consider plant modularization.

Furthermore PPMs characteristics that do appear to be related to PPMs performance seem to affect different elements of project performance in different ways. A trade-off in performance appears to exist. For example, modularization in new PPMs may lead to a longer planning period but this is counter-balanced by a greater probability of delivering the project on time during the execution phase. The same performance profile is evident in the use of SPE for project governance. These findings intimate that those responsible for the commissioning, design, and delivery of PPMs may need to be more sophisticated in their understanding of the impact of certain factors on performance. In particular, they need to develop criteria for assessing the trade-offs between planning performance and delivery performance.

This investigation was predicated on the juxtaposition of two issues: firstly, PPMs play a vital role in implementing energy policy and secondly, PPMs performance is generally poor. This investigation provided a novel and systematic approach to understanding the characteristics associated with good and poor PPMs performance. Though somewhat tentative and limited, the findings provide guidance for policy-makers and project managers to ensure that PPMs perform as intended and consistent with policy goals. Further research in this area, particularly in terms of multivariate analyses, will yield an even better understanding of how the billions of dollars needed for energy infrastructure can be invested in the most effective manner.

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Appendix A – Independent Variables

Independent Variable Characteristic	Operationalization	
	NO (0)	YES (1)
International environmental activists have been raised concern against the project	No evidence of actions from environmental groups	The project has been openly censured by international environmental groups such as Greenpeace
The project has national public acceptability	There are relevant protests or referendums against the project at national level.	The population living in that nation was supportive (or not objected) about the project
The project has local public acceptability	There are relevant protests or referendums against the project at local level	The local population was supportive (or not objected) about the project
Environmental activists and regulators have been engaged ex-ante, not ex post	External stakeholders have been involved after the construction started	External stakeholders have been involved before the construction started, particularly in the planning process
Local residents were involved in the project	The local resident were excluded from the project planning	There are formal established procedures (like the "débat public" in France) to involve residents in the decision makers

Table A.1 Megaproject external stakeholder characteristics

Independent Variable Characteristic	Operationalization	
	NO (0)	YES (1)
Project has a foreign EPC company	The EPC has is main headquarter in the county hosting the project	The EPC has is main headquarter in a foreign country
The project is mono cultural (weak definition)	Client and EPC have different nationality (main headquarters in different countries)	Client and EPC have the same nationality (main headquarters in the same country)
The project is mono cultural (strong definition)	Client, EPC and all the important first tier contractors have different nationality (main headquarters in different countries)	Client and EPC and all the important first tier contractors have different nationality (main headquarters in the same country)
More than 50% share of the client is under government control	The national state own directly or indirectly less than 50% of the share in the project	The national state own directly or indirectly more than 50% of the share in the project
The project has an SPE	No SPE are involved in the delivery of the project	One or more SPE are involved in the delivery of the project as Client and/or EPC
EPC and Client are different	The EPC is delivering the power plant for a certain customer	The EPC will own the power plant

Table A.2 Megaproject governance characteristics

Independent variable		Operationalization	
		NO (0)	YES (1)
The project has a strong regulation system as evidenced by:	a) The safety authority stopped the project or very similar projects in the same country	The definitions don't applies to the project	The definitions applies to the project
	b) The authority give fine to the EPC or one of the internal stakeholders in the project		
	c) Action from the authority postponed the final completion of the project		
The project fit in the long term plan of the country's government		There are no evidences to support how the project fit in the long term plan of the country's government	There is at least an official document presenting how this project fits in the long term strategy of the country
There is planned a long term stability in usage and value		There is no evidence of long term value/stability planned	There is evidence of instruments like a price floor for electricity to support the long term stability of the project
The project enjoys political support as evidence by:	Support of the national government (first definition)	There are not official documents or incentives or subsides from the national government to support the project	There are official documents or incentives or subsides from the national government to support the project
	Support of the national government (second definition)	The national government has not supported the plant trough includes direct financial subsidies, loan guarantee and tax exception.	The national government has supported the plant. This includes direct financial subsidies, loan guarantee and tax exception.
	Support of the local government	There are not official documents or incentives or subsides from the local government to support the project	There are official documents or incentives or subsides from the local government to support the project
Financial Support from the European Union (EU)		The plant has not been partially financed by the EU	The plant has been partially financed by the EU

Table A.3 Megaproject environment characteristics

Independent variable		Operationalization	
		NO (0)	YES (1)
The project is nuclear reactor		The project is not about a nuclear reactor	The project is the construction or major refurbishment of a nuclear reactor
The project is a coal power plant		The project is not about a coal plant	The project is the construction or major refurbishment of a coal power plant
The project is a renewable power plant		The project is not about a renewable plant	The project is the construction or major refurbishment of a renewable power plant
The plant is modular	The project is modular - dependent modules	It is a stick built power plant	The plant is the results of the assembly for several different dependent modules (as in modular large nuclear power plant)
	The project is modular - independent modules	It is a stand-alone power plant	The plant is the result of several independent, equal module (like in a wind farm)
The plant is a FOAK (First Of A Kind)	FOAK strong – global level	At least a similar project was delivered somewhere in the world	The plant is the absolutely the first in the world or the design has radical modification respect to existing ones
	FOAK weak – country lev	At least a similar project was delivered somewhere in the country	The plant is the absolutely the first in the country or the design has radical modification respect to existing ones

Table A.4 Characteristics of technology within the megaproject

Independent variable	Operationalization	
	NO (0)	YES (1)
Project uses planning by milestones	There is no evidence that the project Manager (PM) used a "Planning by milestone" approach	There is evidence that the PM used a "Planning by milestone" approach
Project uses of Formal project management tool and technique	There is no evidence that the PM heavily used formal project management tool and techniques. At least: Gantt chart, PERT (or simulation), Risk analysis, Earned Value, Cost schedule control System.	There is evidence that the PM heavily used formal project management tool and techniques. At least: Gantt chart, PERT (or simulation), Risk analysis, Earned Value, Cost schedule control System.
Usage of performance metrics	There is no evidence that the PM used performance metrics	There is evidence that the PM used performance metrics
Project has a high quality feasibility study	The feasibility study has been made internally and not assessed by independent organisations.	To avoid biased hypothesis there is evidence that the Feasibility study has been made by a company not involved before and after in the project.
Project has a well-developed FEED (Front End Engineering Design)	Frequent design amendments and elaborations	There are not change of the FEED during the construction and The FEED was finished before the construction started

Table A.5 Characteristics of the megaproject’s formal project management approach

APPENDIX B – Using the Fisher Exact test

There are a bewildering variety of statistical techniques that can be employed to spot relationships between independent and dependent variables. The Fisher Exact test's purpose is to ascertain whether or not an independent variable is associate with the presence (or absence) of a dependent variable. The key features of the Fisher Exact test are as follows.

Firstly, it makes no assumption about distributions. The Fisher Exact test is a non-parametrical statistical significance test. Parametric tests assume that the data have come from a particular type of probability distribution (e.g. a normal distribution) and makes inferences about the parameters of the distribution (in case of normal distribution mean and variance). Making these assumptions about the shape of a distribution can make its use unreliable. With a non-parametrical test (like the Fisher Exact test), it is not necessary to make "a priori" assumptions on the data distribution and therefore this type of test can have a wide application.

Secondly, it uses categorical data in the form of a contingency table. The test is used for categorical binary data. In statistics, a categorical variable is a variable that can take on one of a limited, and usually fixed, number of possible values: in the case of binary categorical data, there are only two possible values. The Fisher Exact test is used to examine the significance of the correlation between the two binary categorical variables. The Fisher test requires a 2 x 2 contingency table for its input data. A contingency table looks like in that shown in Table B1.

			INDEPENDENT VARIABLE	
			The project involves an SPE	
			YES	NO
DEPENDENT VARIABLE	The project is over budget	YES	Number of projects that have an SPE and are over budget	Number of projects that do not have an SPE and are over budget
		NO	Number of projects that have an SPE and are on budget	Number of projects that do not have an SPE and are on budget

Table B1 – Example of contingency table

Thirdly, it is an exact test. The probability of a relationship existing between the variables can be calculated exactly and not estimated as in other statistical techniques. A wide number of freely available excel macros are available to download and calculate the probability value. The p-value can be calculated as follow. Table B2 represents the cells by the letters a, b, c and d, call the totals across rows and columns marginal totals, and represent the grand total by n.

		Independent variable		
		Yes	No	Row Total
Dependent variable	Yes	A	b	a + b
	No	C	d	c + d
	Column Total	a + c	b + d	a + b + c + d (=n)

Table B2: Contingency table code

Fisher showed that the probability of obtaining any such set of values was given by the hypergeometric distribution:

$$p\ value = \frac{\binom{a+b}{a}\binom{c+d}{c}}{\binom{n}{a+c}}$$

The significance probability (p-value) represents how likely it is that the result detected by a statistical analysis could have resulted from chance rather than due to a real relationship between the variables in question. In this respect the smaller the "p-value" the better. In academic research, the p-value usually needs to be less 0.01 to be accepted (i.e. there is less than a one percent chance that the result came about through pure chance.) However, there is no clear rationale why such a small p-value is necessary. A p-value would need to be much smaller than 0.01 when examining safety critical relationships. However, in the context of understanding megaproject delivery performance, much bigger p-values can still yield useful results. Of course, a critical scrutiny of the results, to understand if there is a causation for the correlation, is always necessary.

The main limitation of the Fisher Exact test is that it tests every variable by itself. In other words, maybe variable A and B, examined alone, are not correlated with a certain project outcome, while the contemporary examination of A and B could show a correlation. Statistical techniques, like machine learning, are available to perform these tests, but they require more cases. Therefore, again, the Fisher Exact test is a good tool for a first scrutiny.

Another limitation of the Fisher Exact test is that, like all tests of its kind, is subject to type I error and type II error. In statistical hypothesis testing, a "type I error" is the incorrect rejection of a true null hypothesis (a "false positive"), while a type II error is the failure to reject a false null hypothesis (a "false negative"). More simply stated, a type I error is detecting an effect that is not present, while a type II error is failing to detect an effect that is present. With a relatively small sample, the type II error is more likely. For example tossing a coin 10 time and get 6 head and 4 tail is not statistically significate. Tossing a coin 10.000 time and get 6.000 head and 4.000 tail is statistically significate. Further information about this test can be found in (Leach 1979; Sheskin 2011).