

# **COST OVERRUNS AND DELAYS ON ENERGY MEGAPROJECTS: WHEN BIGGER IS WORSE**

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## **ABSTRACT**

Power generation megaprojects are central in energy planning and policy. However, many megaprojects fail to deliver the scale and efficiency aspirations initially established. The purpose of this paper is to estimate the costs overruns and delays probability distribution function for electric power generation technologies, with emphasis on the mega hydroelectric dams recently constructed in Brazil. The results show that the construction costs were, on average, 97.53% above the initial estimate. The distribution that best fit the hydroelectric plants costs overrun is the gamma distribution. For the delays, the construction completion time had an average increase of 74.28%, or 3.5 years. The distribution that best fit the hydroelectric plants delay is the log-normal distribution. The essential statistical message of the results obtained in this work is that megaprojects fail to deliver the economics of scale embedded in large projects because exposure to risk that is disproportionate to the financial economies they can generate. Decision makers should carefully evaluate when "bigger is better".

**Keywords:** Costs overrun; Delays; Energy Megaproject; Forecasting.

## **1. INTRODUCTION**

Power generation megaprojects are central in energy planning and policy. This can be noted over the last decades, in which big infrastructure projects have risen sharply in magnitude and frequency, financed by national governments and private capital development banks. One reason for companies to invest in megaprojects is the perception that large projects will produce economies of scale (SOVACOOOL, GILBERT and NUGENT, 2014).

However, many megaprojects fail to deliver the scale and efficiency aspirations initially established. Taleb *et al.* (2012) argue that the economies of scale embedded in large projects face exposure to risk that is disproportionate to the financial economies they can generate, which leads to costs overruns and delays in the project.

The objective of this paper is to estimate the costs overruns and delays probability distribution function for electric power generation technologies; and analyses the mega hydroelectric dams recently constructed in Brazil. To do so, it uses an international database developed by Sovacool Gilbert and Nugent (2014).

In developing this type of analysis it is hoped to create a diligence method to estimate construction's cost and time of new energy enterprises in the country. By improving the sector's estimates through the use of *ex-post* analysis, the entire energy system benefits, as more realistic estimates avoid financial expenditure, allow a better evaluation of the investment alternatives and project delivery times.

## **2. RESEARCH METHODOLOGY**

### **2.1 DATABASE**

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The database used to conduct the probabilistic analyzes was taken from Sovacool, Gilbert and Nugent (2014). The authors collected reliable data on construction cost and time for all types of generation plants larger than 1 MW of installed capacity and transmission line designs larger than 10 km. The sample contains 6 projects types: thermoelectric plants, generation plants that depend on fuels such as coal, oil, natural gas and biomass; nuclear reactors; hydroelectric power plants; wind farms; solar photovoltaic (PV) and heliothermic solar parks; And, high-voltage transmission lines. The projects in the database have data related to: the year the project was put into service; geographic location; project name; installed capacity (MW); estimated construction cost; actual construction cost; and if available, the project construction estimated and actual time. All values were adjusted according to cumulative inflation for the period 2012 to 2016; the rate was taken from the US Inflation Calculator website, accessed September 2016 (US INFLATION CALCULATOR, 2016).

The project start and end time definition is not clear, since some studies usually measure them in terms of the first concrete spill, others use the mobilization time and others use the pre-construction time, including the licensing and ordering process. It was simply accepted the beginning and end stated in the documentation (RAMANA, 2009). Regarding the construction cost definition, it was treated as "the installation components assembling process, the realization of civil works and the components installation before starting commercial operation" (BENOIT and NOEL, 2011). This definition, although concise, may not always lead to accurate figures, since detailed cost information is often a property, which creates a potential discrepancy between public and private reports (CARTER, 2010).

The database contains costs overruns and delays incurred in the construction of 401 electricity projects developed between 1936 and 2014 in 57 countries. In sum, these projects required US\$ 858 billion in investment and totaled 325,515 MW of installed capacity, in addition to 8,495 km transmission lines.

## 2.2 FITTING DISTRIBUTION

Before adjusting one or more distributions to a data set it is usually necessary to choose good candidates from a pre-selected set of distributions. This choice can be guided by stochastic processes knowledge, which governs the modeled variable or, in the absence of knowledge about the underlying process, by observing its empirical distribution (MULLER and DUTANG, 2015).

In addition to the empirical graphs, descriptive statistics can help choose candidates to describe a distribution among a set of parametric distributions. Especially asymmetry and kurtosis are useful for this purpose. A non-zero asymmetry reveals a lack of empirical distribution symmetry, while the kurtosis value quantifies the weight of the tails compared to the normal distribution, whose kurtosis value is equal to 3 (MULLER and DUTANG, 2015).

Three parametric distributions were selected to best fit the data set, Normal distribution, Lognormal distribution and Gamma distribution. The empirical distribution parameters were estimated by maximizing the likelihood function, defined as:

$$L(\theta) = \prod_{i=1}^n f(x_i|\theta)$$

Where  $x_i$  represents the  $n$  observations of the variable  $X$  and  $f(.|\theta)$  is the parametric distribution density function (MULLER and DUTANG, 2015).

The goodness of fit test measures the distance between the parametric distribution reference values and the empirical distribution. There are three classic goodness of fit tests in the literature that it was used in this study: Cramer-von Mises, Kolmogorov-Smirnov and Anderson-Darling (D'AGOSTINO and STEPHENS, 1986).

The Anderson-Darling statistic is especially interesting when it is important to emphasize the tail, as well as to characterize the distribution main body (CULLEN and FREY, 1999). For this reason, this statistic is often used to select the best distribution in risk assessments. In this study, it was used as the decision criteria to define the best fit distribution to the dataset.

### 2.3 CLASS REFERENCE FORECASTING

Cost-benefit analyzes and socio-environmental impact assessments are typically core documentation for decision-making in large infrastructure projects. Such analyzes are based on activities estimates, materials, labor, machinery, time and cost. However, the estimates fail often (FLYVBJERG, 2009).

For Flyvbjerg (2009), this does not show the cost-benefit analyzes are uselessness. But if the purpose of these documents is to aggregate information for decisions, then the conventional *ex ante* cost-benefit analysis should be supplemented with an *ex post* empirical risk analysis, including the uncertainties related to the estimates documented. For infrastructure megaprojects, this would be a kind of empirical cost-benefit diligence, something that is rarely done today.

If project managers really consider important to obtain correct cost, benefit and risk estimates, it is recommended to use a promising method called "class reference forecasting" to reduce the estimates imprecision and bias. This method was originally developed to compensate the cognitive bias of human predictions, found by psychologist Daniel Kahneman in his work - Nobel Prize's winner in economics in 2002 (FLYVBJERG, 2009).

The following will only present a method overview, based mainly on Lovallo and Kahneman (2003) and Flyvbjerg (2006). The prediction based on the reference class requires the following three steps:

- I – identify a relevant past projects reference class. The class should be broad enough to be statistically significant but narrow enough to be truly comparable to the specific design;
- II - establish a probability distribution for the selected reference class. This requires access to credible and empirical data for a sufficient number of projects within the reference class to draw statistically significant conclusions; and
- III - compare the specific project with the reference class distribution, in order to establish the most probable result for the specific project.

It is observed in Figure 1 what prediction by reference classes represents in statisticians' language. First, the reference class means prediction is greater than the average estimate of the conventional forecast - the promoters' predictor, indicated by the darker curve - in relation to the reference class - indicated by the clearer curve. Second, the reference class prediction expands the estimate of the conventional forecast interval (FLYVBJERG, 2009).

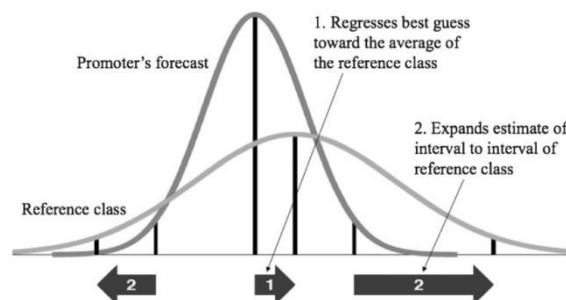


Figure 1: What reference class forecasting does, in statisticians' language.  
Source: Flyvbjerg (2009).

Planners should compare their estimates with the reference class distribution. This would make it clear to planners that unless they have reason to believe that they are substantially better predictors and planners than their colleagues who have made the forecasts and planning the

projects in the reference class, they are likely to underestimate the construction costs. Finally, planners would use this knowledge to adjust their predictions, making them more realistic. This article investigated the question of the mega hydroelectric dams construction through the "outside view" or the application of the reference class method - known in the literature of decision making under uncertainty. Imprecision between planned and obtained results can be a useful proxy for the underlying risk factors that lead to estimation errors (ANSAR et al., 2013). For example, cost overruns reduce the investment attractiveness, and may even make it questionable at very high levels. Bacon and Besant-Jones (1998, p.317) apud Ansar (2013) offer a summary:

The economic impact of a construction cost overrun is the possible loss of the economic justification for the project. A cost overrun can also be critical to policies for pricing electricity on the basis of economic costs, because such overruns would lead to under pricing. The financial impact of a cost overrun is the strain on the power utility and on national financing capacity in terms of foreign borrowings and domestic credit.

### 3. DISTRIBUTION FITTING RESULTS

Figure 2 shows the costs overruns frequency analysis for each power generation source. It is interesting to note the costs overruns different frequency distribution between the different sources; there are two groups: the first composed by nuclear and hydro technology, and the second composed by renewable and thermal sources.

Positive learning curves were expected from all sources: once managers, builders, and operators gain experience, it would expect construction times and real costs to decrease, and improvements in technology should further reduce costs. However, significant reductions in final project costs have been attributed to rapid "learning", especially, in solar and wind power plants, as can be observed below.

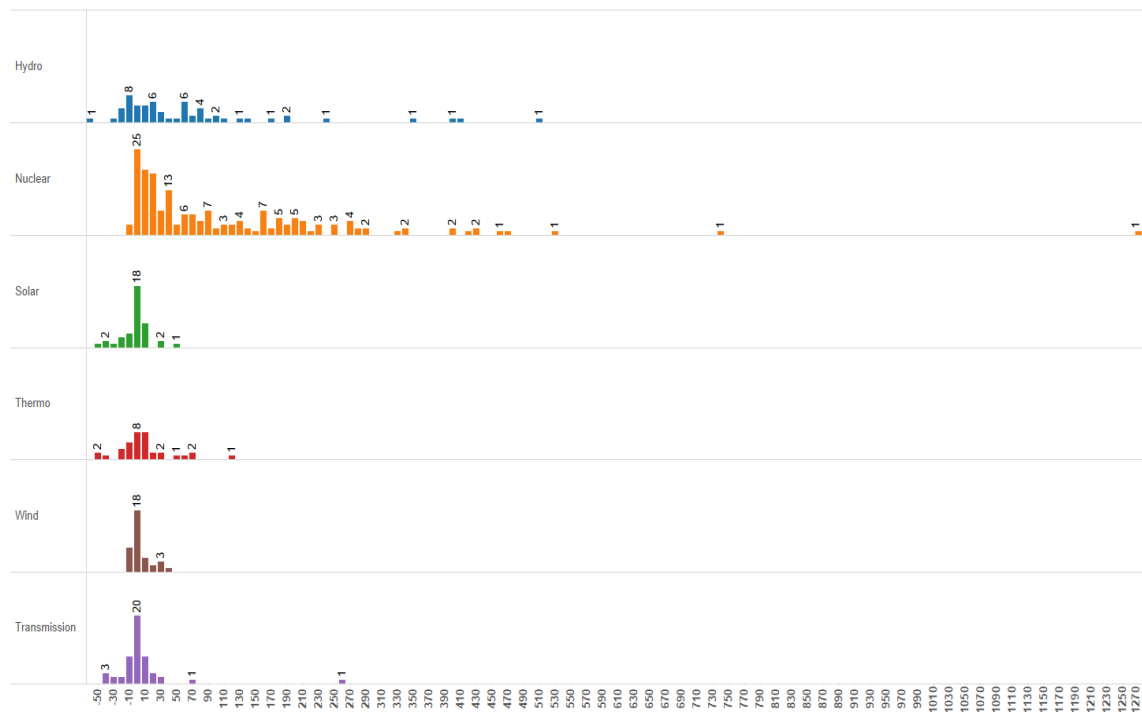


Figure 2: Costs overruns frequency analysis (%) by source.  
Source: Author, 2016.

Table 1 shows the statistical summary of costs overruns (%) for each source. The statistical approach described above was used to fit a parametric distribution to the dataset. The result is shown below.

Table 1: Statistical summary of costs overruns (%) by source.

Variable	Hydro	Nuclear	Thermo	Wind	Solar	Transmission
Number of projects	61	180	36	35	39	50
number of projects with costs overrun	47	175	24	20	16	20
Costs overrun (%)						
Mean	70.6	117.3	12.6	7.7	1.3	8
Min	0.9	1.3	1.2	0.4	2	2.3
Max	512.7	1279.7	120	44.4	50	260
Median	65.6	67	14.3	8.6	12.85	15.4
Standard deviation	116.5	152.8	29.9	13.6	12.9	56.1
skewness	2.12	3.41	1.78	0.94	1.65	3.98
Kurtosis	7.28	22.61	5.84	2.55	5.43	19.74
Distribution	gamma	gamma	triangular	triangular	triangular	triangular
parameters	$\kappa = 0.876$ e $\theta = 125$	$\kappa = 0.769$ e $\theta = 166$	1.2; 14.3; 120	0.4; 8.6; 44.4	2; 4.8; 50	2.3; 15.4; 260

Source: Author, 2016.

Figure 3 shows the frequency analysis by source and Table 2 the statistical summary of delays by reference class. The reduced number of observations hinders statistical inference. However, it can be observed that solar and wind sources, due to the rapid learning curve, present a delivery time lower than initially estimated.

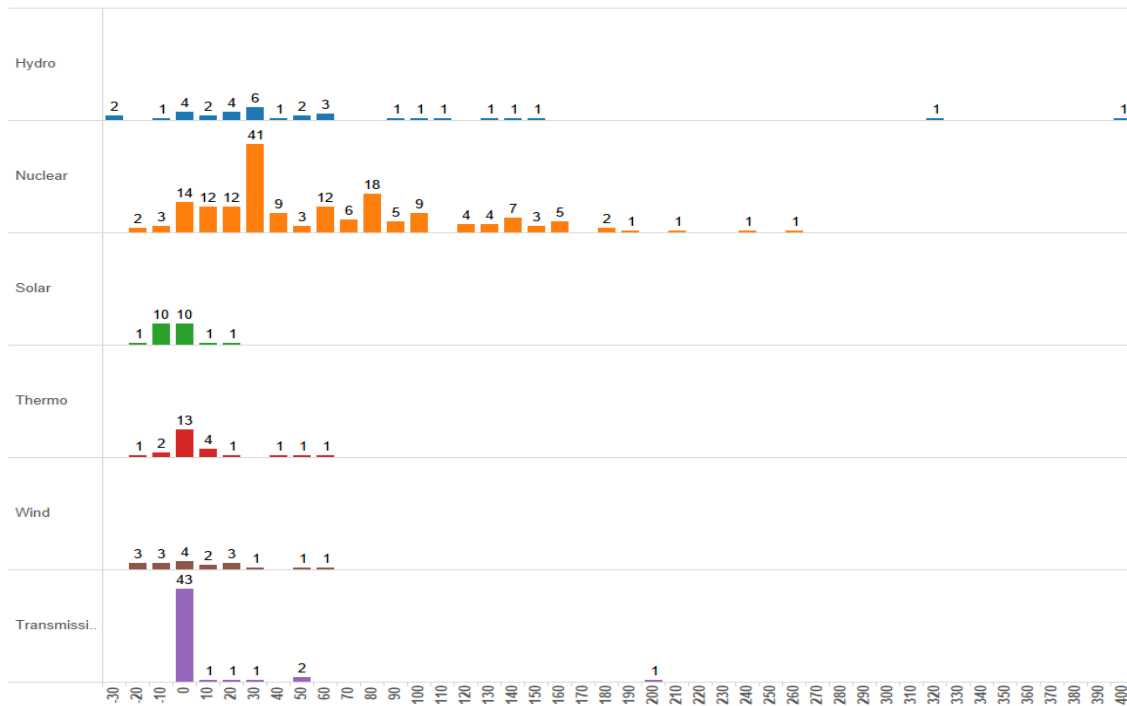


Figure 3: Delay frequency analysis (%) by source.

Source: Author, 2016.

Table 2: Statistical summary of delays (%) by source.

Variable	Hydro	Nuclear	Thermo	Wind	Solar	Transmission	
Number of projects	61	180	36	35	39	50	
number of projects with delay	29	165	11	8	5	6	
Delay (%)	Mean	63.7	64	10.4	9.5	-0.2	7.5
	Min	2.9	1.7	4.3	10	2.5	10.4
	Max	401.7	261.9	66.7	60	25	202.5
	Median	38	56.7	16.7	26.8	8.3	41.6
	Standard deviat	90.8	51.3	20.2	17.1	9.3	71
	skewness	2.53	1.15	1.21	0.79	0.91	2.17
	Kustosis	9.82	4.17	3.29	2.7	2.66	7.99
Distribution	lognormal	gamma	triangular	triangular	triangular	triangular	
parameters	$\kappa = 3.74$ e $\theta = 1.10$	$\kappa = 1.70$ e $\theta = 50$	4.3; 66.7; 16.7	10; 26.8; 60	2.5; 8.3; 25	10.4; 41.6; 202.5	

Source: Author, 2016.

Despite the limitations imposed by the sample size, it is clear that costs overrun and delays are common for electricity generation technologies, with some generation sources showing more severe deviations and, therefore, must undergo more detailed risk analysis.

#### 4. HYDRAULIC POWER MEGAPROJECTS

Brazil faces significant energy supply challenges. The electricity demand is, for example, estimated to nearly triple between 2014 and 2050, requiring an overall increase in electricity from the current 513 TWh to 1,624 TWh (EPE, 2014). Currently, the strategic response to meet this challenge is "big problems, big solutions", such as the large hydropower plants construction - mainly in the north of the country.

Inspired by the prosperity promise, there is a flood of mega dams being developed after a decade or two (ANSAR et al., 2013). The Belo Monte hydroelectric plant, in Pará, Santo Antônio and Jirau, in Rondônia, Teles Pires, in Mato Grosso, are some of these examples.

Mega dams are, however, controversial because they exert considerable financial costs (WORLD BANK, 1996); (WDC, 2000). In addition to the financial calculation, large hydropower plants have a profound environmental impact (SCUDDER, 2005); (STONY *et al.*, 2005) and social (DUFLO and PANDE, 2007); (SOVACOOOL and BULAN, 2011).

The reference class used to carry out the comparative statistics comes from the database developed by Sovacool, Gilbert and Nugent (2014), as shown above.

We chose to work only with cost negative values, which in this case are represented by values greater than zero in the sample. The objective of this cut is to skew the costs overruns sample, making it more conservative in relation to the costs overruns risks. The parametric distribution that best fit the costs overruns data was the gamma distribution,  $X \sim (\kappa = 0.876, \theta = 125)$ , Figure 4.

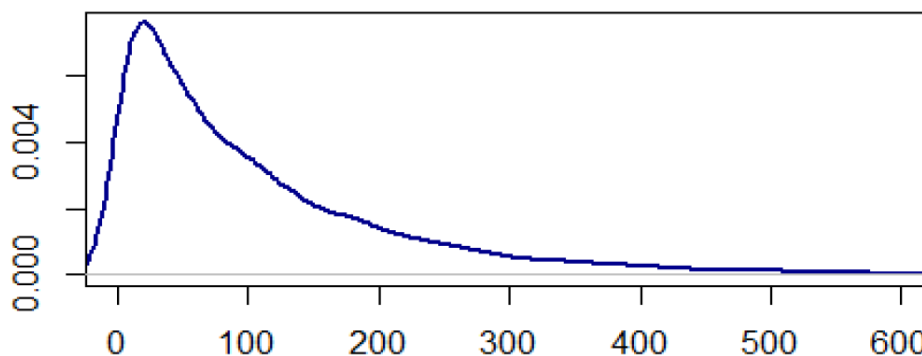


Figure 4: Costs overruns distribution function probability for mega hydroelectric plants construction. Source: Author, 2016.

In relation to the costs overrun, the following observations are made:

- i. 8 out of 10 projects suffered additional costs in constant local currency terms. The costs overrun frequency and magnitude is greater than the underestimated cost errors, the slope is for adverse outcomes;
- ii. The costs were, on average, 97.53% above initial estimate, based on the sample projects that suffered additional costs. The costs overrun median value was 64.65%, with IQR of 77.52%;
- iii. The oversize graph shows the long tail on the right. The actual cost more than doubles to 1 in 10 projects;
- iv. The MW average cost increased by 63%. The costs sunk in the construction phase are passed on to the civilian population - who ends up paying for the accumulated errors.

When the Jirau hydroelectric plant (3 300 MW) in Rondônia was auctioned in 2008, the planned investment for the project construction was R\$ 8.7 billion (ANEEL, 2008). The real cost in 2016 was 16.6 billion (CBIC, 2016). In percentage terms, the overrun was 91%. The Santo Antônio (3 568 MW), also located on the Madeira River, Rondônia, designed to cost entrepreneurs R\$ 12.2 billion, completed the works in the amount of R\$ 20.0 billion (CBIC, 2016) - 64% more than the initial budget. The Belo Monte dam with an installed capacity of 11,181 MW, the largest installed power in the country in recent years for a single project, was initially estimated at R\$ 19 billion. In 2016 the plant estimated costs was R\$ 32.9 billion (CBIC, 2016), which represents an additional cost of 70% - until the moment of this article.

The reference class application to compare the results distribution and establish the most likely outcome can be useful to control the estimates systematic errors. For example, based on this technique, the suggestion is that policy makers should increase their budgets by around 75% of the initial budget to get 50% certainty that their final costs will be within budget. If decision-makers are more risk tolerant, they should apply a 30% increase in the initial budget; however, they will have a 75% chance of obtaining a final cost that exceeds this value. The more conservative (risk averse) should raise their costs initially estimated at 180% to be 80% sure that they did not exceed their budget.

Table 3 shows the costs overrun probabilities and the additional increases in costs for the projects mentioned above, according to the forecasting method. The P50 would, in these cases, be the most indicated risk level to be taken.

Table 3: Project costs according to reference method.

Project	Estimated cost (billions R\$)	Neutral P50	Risk tolerant P25	Risk averse P80	Actual cost (billions R\$)
Jirau	8.7	15.23	11.31	24.36	16.6
Santo Antônio	12.2	21.35	15.86	34.16	20.0
Belo Monte	19	28.5	24.7	53.2	32.9

Source: Author, 2016.

Besides large dams are costly with severe budget reviews, it also takes time to be construed, on average, take 9.8 years to complete. The parametric distribution that best fits the data is a lognormal distribution,  $X \sim (\kappa = 3.74; \theta = 1.10)$ , Figure 5.

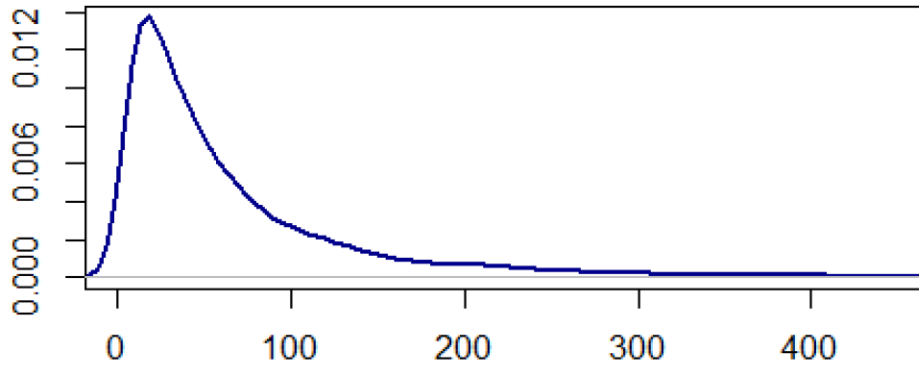


Figure 5: Delays distribution function probability for mega hydroelectric plants construction.  
Source: Author, 2016.

Regarding to delays, the following observations are made:

- i. Nine out of 10 projects suffered delays in the initial schedule;
- ii. The construction completion time had an average increase of 74.28%, or 3.5 years, with a median value of 38% or 1.5 years. As the costs overrun, the delays also show evidence of being systematically underestimated.
- iii. The delay parametric distribution graph also reveals a long tail, not as fat as the costs overrun tail. Costs overrun have greater risk of getting out of control than schedules.

The mega hydroelectric projects planned in the country northern region also did not escape the systematic delays. The Jirau dam, which started work in 2008, was planned to start operating in July 2015 (CBIC, 2016). It had the deadline extended to September 2016, followed by further extension, October 2016 (CBIC, 2016). The first turbines went into operation 16 months after the initial planning, suffering a 27% initial schedule variation. The Santo Antônio hydroelectric plant, also beginning in 2008, expected to be completed in December 2015, ended the works only in November 2016 (CBIC, 2016). This plant has a low delay rate, 1 year or 14.28%, and is promoted as an example in the sector. The delayed highlight goes to the Jatobá dam, which was planned to finalize the works in May 2012, the new completion estimate is December 2019 (CBIC, 2016), 91 months' difference from the initial term or 7 years and a half. The iconic Belo Monte was also delayed. It begun in 2011 with completion expected in February 2015, it extended the deadline to start operating in June 2019 (CBIC, 2016) - an 80% variation in the initial schedule, approximately.

The delay probabilities and the additional increments in the project delivery time, according to the reference class method, are shown in Table 5.2 below. The P25 would be the most appropriate for the Jirau and Santo Antônio projects. For the Belo Monte hydroelectric plant, the delays chance to be accepted is greater, between P50 (neutral) and P80 (risk averse).

Table 4: Project delays according to reference method.

Project	Estimated time (month)	Neutral P50	Risk tolerant P25	Risk averse P80	Actual time (month)
Jirau	90	126	108	189	106
Santo Antônio	96	134	115	202	107
Belo Monte	62	87	74	130	102

Source: Author, 2016.

Finally, the greater installed capacity, the longer it will take to complete the works. In countries such as Brazil, which suffer from significant variations in inflation and exchange rates, the greater the project prolongation the greater the exposure to macroeconomic risks (ANSAR *et*



*al.*, 2013) - a key factor in the investment evaluation. In the short term these indicators are more stable and, therefore, the estimates are more reliable.

There is no doubt that harnessing and managing water power is critical to economies, however the theoretical propositions and empirical evidence from hydroelectric megaprojects suggest that megaprojects fail to deliver aspirations of scale and efficiency established initially.

The survey shows that major investment decisions in the energy sector routinely fail in the real world. However, the "theories of big" have maintained a lasting position in business and government practices: megaprojects are more and larger than ever, justified by theories of scale and scope (FLYVBJERG, 2014).

What the "theories of big" fail to incorporate into their logic is that oversizing a system increases its complexity disproportionately because the greater number of interactions and permutations now possible among more subcomponents, and this leads to fragility. Small errors in one or few interactions amplify in the larger system. All this has a financial impact: propensity for construction costs overrun; large invoices unexpectedly fixing new vulnerabilities as they become apparent as the system ages; and enormous decommissioning costs if the system has to be deactivated or collapses (ANSAR et al., 2013). Despite its Goliath appearance large investments break easily. A greater propensity for fragility is intrinsic to megaprojects.

## 5. FINAL REMARKS

The purpose of this article was to investigate the costs overrun and delays in the construction of mega projects in the energy sector, emphasizing the mega hydroelectric plants recently built in Brazil.

The essential statistical results message obtained in this work is that larger projects involve uncontrollable risks that cannot be anticipated and adequately mitigated. The economies of scale embedded in large projects face exposure to risk that is disproportionate to the financial savings they can generate, which leads to costs overrun and delays in the project.

Decision makers should carefully evaluate when "bigger is better" instead of assuming that this is a rule. They should also look for deviations from completion time estimates, costs and benefits, requiring more extreme stress tests, reflecting the phenomena complete variance, to determine the vulnerability threshold to which the investment they are about to undertake is subject.

More numerous small energy solutions could be more prudent from the perspective of risk management and net present value maximization, even if these projects increase the power cost unit. For now, it is considered that before undertaking a megaproject, decision-makers should rigorously consider other alternatives.

It is recommended for future studies the elaboration of a Brazilian projects database, with more observations and details. This database could be used to draw up a reference class for Brazilian energy sector projects, including the fuel industry. By improving the level of information on megaproject construction performance, decision-making processes are more likely to succeed.

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