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Cost overruns and delays in energy megaprojects: How big is big enough?

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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 expected. The purpose of this paper is to estimate the probability distribution function of cost overruns and delays in the construction of power generation projects, with a particular focus on mega hydroelectric dams recently built in Brazil. Results show that construction costs were, on average, 97.53% above the initial estimates. The distribution that best fits the hydroelectric power plants costs overruns 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 fits the hydroelectric plants delays is the lognormal distribution. The essential statistical message obtained in this paper is that megaprojects fail to deliver the economies of scale embedded in large projects because the exposure to risk is disproportionate to the financial economies they can generate. Decision makers should carefully evaluate whether "bigger is better".

1. Introduction

The term mega in projects is related to large amounts of investments, long construction periods and high levels of technical complexity. Megaprojects have also been defined as projects involving more than one billion dollars in investments (Baccarini, 1996; Flyvbjerg et al., 2003; Merrow, 2011). They are generally described as high risk, complex, with a high degree of uncertainty and intense in social and environmental impacts, while involving many stakeholders (Clegg et al., 2002).

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 (Sovacool et al., 2014).

In microeconomics, economies of scale refer to the costs reduction resulting from the increase in the size and use rate by an enterprise. Moreover, in theory, economies of scale in projects also contribute to the reduction of transition costs (Sheffrin, 2003). Formally, an increase in production volumes may imply in an increase in production costs to a greater or lesser extent. The economies of scale concept reflects the relationship between increased production and the corresponding increase in costs (Silva, 2015).

Economy of scale is the impetus behind critical mass production innovations, such as Henry Ford's production lines, which allowed the reduction of car prices to levels at which middle-class families could acquire (Sovacool and Cooper, 2013). Economies of scale are not limited to transportation. This conventional wisdom is also applied in the energy industry aiming at efficiency gains, through the implementation of large centralized production units.

Historically, the energy system success has become associated with some assumptions. Planners believed that energy systems should be composed of a few, but large, units of supply and distribution, and that these units should be composed of large monolithic devices rather than small redundant models (Hirsh, 1989).

However, as more and more larger infrastructure projects are being proposed and built around the world, it is becoming clear that many of these projects have weak economic, environmental, social performances and a corruption high probability (Christoffersen et al., 1992; Ansar et al., 2014; Magnusen and Samset, 2005; Reuters, 2014; Locatelli et al., 2017).

Excessive cost overruns often put project viability at risk. In the case of mega hydropower projects, cost overruns are almost a rule as are showed by the existing literature. Ansar et al. (2014) found that nine out of ten dams suffered cost overruns in the past. Other previous studies confirmed the same trend in power projects (Merrow et al., 1900; Ansar et al., 2014; Sovacool et al., 2014; Awojobi and Jenkins, 2015; Awojobi and Jenkins, 2016). Different databases reveal the same result. According to Ansar et al. (2014), initially promoted as effective vehicles for economic growth, energy megaprojects can become an

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obstacle to it. Awojobi and Jenkins (2016) found that "greater complexity in terms of the size of the plant installed and the physical height of the dam are some of the origins of optimism bias and strategic parameters used to underestimate the cost of the projects". For Taleb et al. (2012), the reason is intrinsic to the conception of megaprojects. 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 cost overruns and delays in the projects.

The mega hydropowers newly constructed in the Brazilian Amazon rainforest are emblematic. Brazil faces significant energy supply challenges. Electricity demand is, for example, estimated to nearly triple between 2014 and 2050, requiring an overall increase in electricity generation from the current 513 TWh to 1624 TW h by that year (EPE, 2014). The Brazilian government's Economic Growth Program (PAC) aimed to expand electricity supply through low-carbon sources (PAC, 2017). However, as the Amazon mega hydropower projects are unlikely to achieve their predicted financial returns, consumers may have to pay higher prices to keep their lights on and are hostage of a centralized energy system that heavily relies on rainfall.

Addressing this issues, the purpose of this paper is to assess the cost overruns and delays of energy megaprojects, focusing specially on mega hydropower projects recently built in Brazil, using a probabilistic approach. It also aims to discuss the policy implications of mega projects cost analysis in the energy system planning. In order to do this, we used an international database developed by Sovacool et al. (2014) and a forecasting method called "Reference Class Forecasting" fully implemented for infrastructure projects by Flyvberg (2004).

The innovative characteristic of this paper and its contribution to the literature are various. First we develop probabilistic distribution functions of cost overruns and delays for different energy projects using the broad database developed by Sovacool et al. (2014). Then we apply these probabilistic distribution functions to adjust the risk level of Brazilian mega hydropower projects, which are very emblematic. And finally we discuss how to deal with megaprojects´ risks already in their design and execution, showing evidences borrowed from complex theory that the economies of scale associated with the largest energy projects are not always as high as expected. As such, this study can help as an input to further works that intend to incorporate the risk of energy megaprojects into integrated scenarios for decision making.

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

This paper is structured as follows. Section 2 presents the methodological approach to reach the paper's aims. Section 3 analyses the power plant construction performance through probability distribution functions of costs overruns and delays of different technologies. Section 4 explores past Brazilian hydroelectric megaprojects construction performances. The class reference method is applied to determine the risk adjusted level of each project analyzed. In this section, the best approaches to minimize cost overruns and delays in energy megaprojects are discussed. Section 5 sums up the main conclusions of the paper, highlighting the need to elaborate a cost overrun and delay reference class to get more reliable estimates in energy sector in Brazil.

2. Methodological procedure

2.1. Database

The database used to conduct the probabilistic analysis was taken from Sovacool et al. (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 longer than 10 km. The sample contains 6 project types: thermal power plants fueled with 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, when available, the project construction estimated and actual time. All values were adjusted according to cumulative inflation for the period 2012–2016.

It is important to highlight that 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 (Sovacool et al., 2014). 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) apud (Sovacool et al., 2014). 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) apud (Sovacool et al., 2014).

The database contains costs overruns and delays incurred in the construction of 401 power plant 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 8495 km transmission lines. The database can be found in Appendix A.

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:

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

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 are 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, these statistics 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.