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# Are conventional energy megaprojects competitive? Suboptimal decisions related to cost overruns in Brazil

Alexandre C. Köberle[a,b,*], Rafael Garaffa[a], Bruno S.L. Cunha[a], Pedro Rochedo[a], André F.P. Lucena[a], Alexandre Szklo[a], Roberto Schaeffer[a]

[a] *Energy Planning Program, Graduate School of Engineering, Universidade Federal do Rio de Janeiro, Centro de Tecnologia, Bloco C, Sala 211, Cidade Universitária, Ilha do Fundão, 21941-972 Rio de Janeiro, RJ, Brazil*

[b] *Grantham Institute, Imperial College London, Exhibition Road, London SW7 2AZ, London, United Kingdom*

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ABSTRACT

Cost minimization is arguably the most important criterion governing decisions about energy sector infrastructure construction. Usually, a winning project is picked among similar alternatives based on lowest levelized cost of energy, because, ceteris paribus, economies of scale drive down the unit cost of energy delivered. As such, megaprojects – here defined as costing more than a benchmark US$ 1 billion – are perceived as more competitive than smaller-scale options. However, megaprojects are prone to construction cost overruns and delays that, if included *ex ante*, may change the optimality of decision for a given project. We hypothesize that optimistic assumptions on techno-economic performance of megaprojects favor their inclusion in the solution of integrated assessment models (IAMs), preventing higher shares of non-hydro renewables, energy efficiency and other low-carbon options. To test this hypothesis, we ran the COPPE-MSB energy system cost-optimization model for infrastructure expansion. We estimate a factor (named Z factor, for zillions) to determine cost differences both within Brazil and vis-à-vis international parity and adjust the model's parameters for CAPEX and construction times of projects qualifying as megaprojects. Results show decreased coal and increased wind power generation, and a reduction in the number of new refineries leading to higher imports of diesel and gasoline.

## 1. Introduction

Cost minimization is arguably the most important criterion governing decisions about energy sector infrastructure construction and is a common decision variable in computational models assessing energy sector expansion options, including integrated assessment models (IAMs). Although other criteria can also play a role, a winning project is usually picked among similar alternatives by providing the lowest cost per unit of energy delivered (Connolly et al., 2010). There is a general perception that bigger projects deliver cheaper energy by spreading costs over a larger amount of energy produced. The reasoning is that, all else being equal, economies of scale drive down the unit cost of energy delivered. As such, megaprojects – here defined as projects that face a benchmark investment of US$ 1 billion or more (Baccarini, 1996; Flyvbjerg et al., 2003; Koppenjan, 2005; Merrow, 2011) – are perceived as more competitive than smaller-scale options. However, this ceteris paribus assumption may be untrue since the high visibility and high impacts of megaprojects often create public opposition, bureaucratic hurdles and unforeseen circumstances that increase the project's risk and may add significant costs and construction delays. This results in construction cost overruns (CCO) that, if included *ex ante*, may change the optimality of the decision for a given project. In cases where CCO are the rule, smaller-scale, modular options may indeed be the optimal solution to meet growing energy demand, not only in terms of avoiding CCO of the projects themselves, but also by avoiding back-stop options that must be implemented to fill the gap in supply caused by construction delays.

The underperformance of large infrastructure projects is a global phenomenon and happens in a number of infrastructure sectors. For example, Flyvbjerg et al. (2002) assessed 258 transportation infrastructure projects in 20 developed and developing countries in 5 continents and found that errors in cost estimation are not so much the cause of underperformance as the lack of critical strategic analyses. Regarding the energy sector, Sovacool et al. (2014) analyzed 401 electricity generation projects in 57 countries and found that hydropower and nuclear power plants have high CCO and suffer from longer and more frequent construction delays than solar and wind projects. Ansar et al. (2014) show that the cost-benefit ratio of hydropower

* Corresponding author.
*E-mail addresses:* akoberle@imperial.ac.uk, alexkoberle@gmail.com (A.C. Köberle).

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plants with large reservoirs is worsened by CCO in 75% of the projects, and that 96% of them end up costing more than originally planned. Furthermore, the authors point out that, especially in developing countries, smaller-scale projects should be the preferred choice due to the long construction periods required for megaprojects. In the oil & gas sector, megaprojects have become the norm with CCO affecting an estimated 69% of refining projects globally, with 79% facing construction delays (EY, 2014).

CCO also seem to be a more critical phenomenon in countries where infrastructure expansion is key to growth. For instance, Morris (1990) assessed 133 projects of 10 different sectors in India during the 1980s and estimated an average CCO of 82%. More recently, according to EY (2004), Latin American countries showed a 102% average budget cost overrun in oil and gas megaprojects – a number far above that of other regions, like Europe and Asia-Pacific, that faced a 57% average budget cost overrun.

In a broader sense, there are many reasons behind the underperformance of megaprojects: from poor management – including technical, economical, behavioral and political circumstances (Flyvbjerg, 2014) – to chaotic dynamics (Olaniran et al., 2015). Also, planners tend to be optimistic about the required construction time and the costs and benefits of megaprojects, especially in the financing phase of a project.

For energy conversion facilities in particular, economies of scale are usually associated with a geometric scale factor expressing the relationship between volume (output capacity) and area (capital cost) (Green and Maloney, 1997), so that the larger the capacity the lower the cost of unit energy delivered. For instance, this is clearly indicated in different databases on capital costs of power generation plants (Black and Veatch, 2012; EIA, 2014, 2013; Coelho and Szklo, 2015; IEA, 2014a; NEA/IEA, 2010; UNFCCC, 2015) and of oil refineries (Coelho and Szklo, 2015; Gary et al., 2007; Meyers, 2003; OandG, 2010). However, for different reasons, the observed reality is that CCO are much more present in megaprojects than in smaller-scale or modular enterprises (Sovacool et al., 2014). This leads us to venture the idea that energy megaprojects actually suffer from diseconomies of scale, meaning that, more often than not, large projects do not deliver the expected low-cost energy, and that this is particularly true in developing countries.

Brazilian infrastructure megaprojects are particularly prone to delays and CCO. Construction delays, and even complete stoppages in the worst cases, are often caused by environmental licensing inefficiency (many times stemming from misguided decisions based on a conceptual project). This increases the lead time before a project begins to bring in revenue. Moreover, inadequate and/or precarious infrastructure leads to losses in productivity, with some Brazilian regions more heavily impacted than others. For example, the relatively richer South and Southeast regions boast better infrastructure, such as roads and ports, than the other regions, where better infrastructure removes logistics bottlenecks thereby increasing productivity.

Among the many cases in point, the construction cost of the Belo Monte hydropower plant (11 GW) is a highly contentious issue. According to Norte Energia (2011), its initial cost in 2010 was US$ 11.3 billion, but currently, with over 50% of the construction complete, the amount approaches US$ 27 billion.[1] Also, the construction of the Angra 3 nuclear power plant[2] (1.4 GW) restarted in 2010 with a US$ 10 billion budget so far for the megaproject, which is much higher than originally budgeted. Construction delays are also rampant. Angra 3 was supposed to come online in 2015, but the expected operation start year is now 2018 (Eletronuclear, 2015). Two recent refinery complexes under construction in Brazil (RNEST and COMPERJ) are facing long delays and will have taken more than 10 years to build by the time they are finished. As a matter of fact, chances are that one of them, the COMPERJ complex, will never be completed, although a significant fraction of its initial CAPEX has been already expended.[3] In Brazil, a recent assessment of infrastructure projects revealed an average 49% CCO and 106% construction time increase, with energy projects generally faring worse (Frischtak, 2016).

We use existing data and literature to estimate regional cost differences in the investment costs and construction times of projects fitting our definition of megaprojects. We then use these to test whether taking them into consideration would change the optimality of the decision to build them, as projected by a technology-rich energy systems model for Brazil. We hypothesize that overly optimistic assumptions on the technical and economic performance of megaprojects favor their inclusion in the solution of not only this model, but of integrated assessment models (IAMs) in general, preventing a higher share of non-hydro[4] renewables, energy efficiency and other low-carbon options in the long-term energy planning. After all, it is impossible to say a priori whether changes in the input parameters of a cost-minimization model will change the solutions, since the solutions may be robust to the changes proposed. Thus, to test our hypothesis, we run the Brazilian version of the MESSAGE model (COPPE-MSB), adjusting the parameters for CAPEX and construction times of technologies that can be qualified as megaprojects. This is an additional contribution to the previously mentioned literature on megaprojects, emphasizing the CCO impacts on decision making supported by IAMs solutions. In addition, we propose a parametric methodology to estimate the sources of CCO in Brazil, including industrial productivity and location factor.

This study has two main objectives:

1. To understand and estimate the differences in cost and construction times of large-scale projects across the five Brazilian geographical regions by introducing a so-called Z factor, which adjusts costs for each region vis-à-vis international parity.
2. To assess whether these changes in regional costs affect the solution of a cost-optimization model for the expansion of energy infrastructure in Brazil (the COPPE-MSB model).

The next section describes the methods for model and scenario construction, including a detailed description of the Z factor used to determine cost differences of megaprojects both within Brazil and vis-à-vis international parity. Section 3 describes and discusses the results, while Section 4 offers a sensitivity analysis on wind power plant delays and on Z factor probability values. Section 5 brings conclusions and policy implications.

## 2. Methods: model and scenario construction

First, we need to define what we mean by a megaproject. As mentioned in the Introduction, megaprojects are defined as those that face a benchmark investment cost over $1 billion dollars, and this requires clarification. Infrastructure projects that exceed this benchmark are of such magnitude and complexity, they mobilize production factor inputs (capital and labor) that exceed what is available locally. The literature reveals that large-scale technically- and socially-complex energy projects can face higher risk of cost overruns and construction delays. Complexities here include the indivisibility and the technically radical

[1] According to Ansar et al. (2014), the mean overrun for major dam projects is 100% over original estimates, so that the Belo Monte complex could, indeed, end up costing US$27 billion; http://www.bloomberg.com/news/articles/2014-03-13/megadams-are-dismal-investments.

[2] According to Portugal-Pereira et al. (2018), there is a general increasing trend of overnight construction cost and lead time for nuclear power plants worldwide, suggesting a negative learning curve effect.

[3] Petrobras press release. 22 July 2016. Available at http://www.investidorpetrobras.com.br/en/press-releases/comperj-project.

[4] Small hydropower plants are not included here as they do not classify as megaprojects, and are included for the remainder of this study with wind and solar in the category of non-hydro renewables.