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Abstract: Lovering et al. (2016) present data on the overnight costs of more than half of nuclear reactors built worldwide since the beginning of the nuclear age. The authors claim that this consolidated data set offers more accurate insights than previous country-level assessments. Unfortunately, the authors make analytical choices that mask nuclear power's real construction costs, cherry pick data, and include misleading data on early experimental and demonstration reactors. For those reasons, serious students of such issues should look elsewhere for guidance about understanding the true costs of nuclear power plants.

HIGHLIGHTS FROM A REPLY TO "HISTORICAL CONSTRUCTION COSTS OF GLOBAL NUCLEAR POWER REACTORS"

- Lovering et al. (2016) claim to accurately assess nuclear plant costs over time.
- The authors err by relying on overnight costs, which exclude interest.
- The authors cherry pick data (e.g, ignoring problems with French nuclear data).
- The article's cherry picked data don't even support the article's own conclusions.
- Lovering et al. is not a reliable source for costs of nuclear power.

A REPLY TO "HISTORICAL CONSTRUCTION COSTS OF GLOBAL NUCLEAR POWER REACTORS"

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ABSTRACT

Lovering et al. (2016) present data on the overnight costs of more than half of nuclear reactors built worldwide since the beginning of the nuclear age. The authors claim that this consolidated data set offers more accurate insights than previous country-level assessments. Unfortunately, the authors make analytical choices that mask nuclear power's real construction costs, cherry pick data, and include misleading data on early experimental and demonstration reactors. For those reasons, serious students of such issues should look elsewhere for guidance about understanding the true costs of nuclear power.

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INTRODUCTION

In the April 2016 issue of *Energy Policy*, Lovering et al. (2016) present data on the overnight costs of 58% of the nuclear reactors built worldwide. In that article, the authors purport to show that using this larger data set yields different and more accurate results than analyses that focus on individual countries, explicitly citing Koomey and Hultman (2007) for the United States and Grubler (2010) for France as examples of country-level treatments.

Underlying the Lovering et al. analysis is the assumption that including data from additional countries must yield a more accurate picture of cost trends for nuclear power. Ceteris paribus, that assumption holds, but in this case, all other things are not equal.

OVERNIGHT COSTS ARE INCOMPLETE AND MISLEADING

A key problem is Lovering et al.'s use of so-called "overnight construction costs", which exclude interest costs that accrue during construction. Overnight costs have been used in the utility industry for decades (EPRI 1993, Rothwell 2015), and they attempt to show a cost that is "meant to isolate the cost invariant to construction duration and interest rate, in order to capture the cost intrinsic to the reactor technology", as Lovering et al. put it.

While overnight costs do have a long history, there is simply no economic basis for comparing the costs of reactors without including the cost of capital and the construction duration. A key aspect of nuclear reactors that makes them such high-risk investments are that they are large scale, complex, and predominantly site-built. Hence construction takes years (even in the best case) and can extend over a decade or more.

Almost all modern reactor programs analyzed in detail to date have experienced significantly lengthened construction times (Sovacool et al. 2014a), which is ignored in the use of overnight construction costs by Lovering et al. Given that financing constitutes a significant part of nuclear costs in the real world, and that the very nature of nuclear power as a large scale, capital-intensive technology makes it particularly sensitive to financial risks, a study that ignores return on capital cannot give a true picture of the costs of nuclear power.

THE DATA PRESENTED REMAIN UNDISCLOSED, ARE CHERRY PICKED, AND DON'T SUPPORT THE AUTHORS' CONCLUSIONS

Lovering et al.'s conclusions are not reproducible, because the authors have not made their data set publicly available. We are unable to verify, for example, whether the data from South Korea and India are of the same quality as those for the United States, France, and other countries that have been more carefully studied, and won't be able to do so until Lovering et al release their data.

Lovering et al quote Cour des Comptes (2012) as their data source for French reactor-specific costs. That study is fraught with data manipulation and arbitrary accounting conventions that artificially reduce French nuclear construction costs and their significant cost escalation (for a critique see Grubler (2014).

Instead of reactor-specific cost data, the Cour des Comptes (CdC) study only presents pairwise aggregates of reactor construction costs that mask cost heterogeneity. In addition, €10 billion of construction-related engineering and labour costs and pre-operating charges have been arbitrarily excluded in the CdC cost numbers, artificially lowering total construction costs by 14 percent and making the French data inconsistent with other "overnight" construction cost estimates. In addition, interest during construction reported by the French national utility EdF of some €23 billion were arbitrarily reduced to €13 billion by CdC. The numbers presented by Lovering et al are based on the original CdC study, thus underestimating overnight construction costs by €10 billion (€73 billion versus €83 billion) and total construction costs by more than 30 percent, or €33 billion Euro (€73 billion versus €106 billion).

In addition, Lovering et al.'s presentation of nuclear costs relative to renewable costs omits unfavorable data from their nuclear dataset and favorable data on renewables that would indicate more dramatic renewable cost declines (see their Figure 13). That graph does not include nuclear cost data from all the countries they studied (leaving out West Germany, Canada, and India, which all show cost increases for nuclear power in the modern era) and includes only limited data for solar PVs. The graph omits the earlier substantial solar PV cost declines from the 1970s, 1980s, and 1990s (for modules that are similar to those now being produced), but also omits the past few years of PV cost declines. The cited source for PV costs, Seel et al. (2014), only covers the years 2000 to 2012, and PV costs have declined substantially since then (Barbose and Darghouth 2015, Bolinger and Seel 2015). The graph also omits wind power, which has shown substantial cost declines for many years (Wiser and Bolinger 2015).

Finally, the overnight costs as presented do not even support the article's conclusions. The abstract states "Our new findings suggest that there is no inherent cost escalation trend associated with nuclear technology". The article presents graphs for nuclear construction costs in the US, France, Canada, West Germany, Japan, India, and South Korea, but the only country where overnight costs appear to decline over time in the modern era is South Korea. In that case the data do not come from an independent source but from the country's nuclear utility, have not been independently audited, and are not disclosed (and of course do not include interest during construction, as discussed above). As a result, they do not meet the critical scientific criteria of reproducibility and thus utmost caution is advisable in drawing strong conclusions from those numbers.

Lovering et al.'s results suggest one example of overnight costs decreasing in the modern era, but the most sensible interpretation of their data is that almost all countries showed cost escalation from the 1970s onwards. This effect would be even more dramatic if the authors had included the costs of financing for a full accounting of nuclear construction costs and their historical evolution.

COST DATA FROM THE EARLIEST US REACTORS ARE NOT RELEVANT TO MODERN REACTORS

Lovering et al. include cost data for US demonstration reactors in the 1950s and early 1960s and for the so-called "turnkey reactors" in the US started 1964 to 1967. In both cohorts, overnight costs show a decline.

The authors argue that adding these early stage technologies (which were not included in the Koomey and Hultman analysis for the US) gives a fuller picture of cost trajectories. And indeed, these early examples do appear to show higher overnight costs in the US, which would result in a more downward-sloping cost trajectory for US reactors. However, the early demonstration reactors are so different in size and technology from later reactors that declines in costs shown in some countries during that period are at best only peripherally relevant to analysts trying to understand more recent or contemporary cost trends. Even the turnkey plants have attributes unique to that cohort, so it's hard to know without further study what lessons the cost declines for those reactors hold for plants constructed in the modern era.

Overnight costs for nuclear plants appear to have declined in the 1950s and early 1960s for demonstration reactors that were tens of MW or at most a couple of hundred MW in size (http://www.nucleartourist.com/basics/early.htm). Overnight costs also appear to have declined for a 600-800 MW reactors purchased under turnkey contracts from 1964 to 1967. What do those data tell us about the true costs for building 1000 MW reactors after 1970? Not much, as the utilities in the 1960s and later found out to their chagrin.

THE AUTHORS AGGREGATE COST DATA IN A MISLEADING WAY

In addition, the authors have used and applied their dataset in a misleading way. For example, they present a figure that aggregates nuclear costs across all countries in their Figure 12 and some countries in their Figure 13. This approach is misleading because there is not one cost trend (or learning rate) for all nuclear reactors–at best there is a trend in each country based on its unique institutional, social, legal, and technological context. The global "experience" with nuclear power is not as relevant as it is for mass-manufactured energy technologies like solar photovoltaic (PV) panels and wind turbines.

Lovering et al. make a similar point in their "Conclusions and Policy Recommendations" section, but ignore the importance of that point when creating those aggregated graphs:

> These results show that there is no single or intrinsic learning rate that we should expect for nuclear power technology, nor an expected cost trend. How costs evolve over time appears to be dependent on different regional, historical, and institutional factors at play. The large variance we see in cost trends over time and across different countries–even with similar nuclear reactor technologies–suggests that cost drivers other than learning-by-doing have dominated the cost experience of nuclear power construction. Factors such as utility structure, reactor size, regulatory regime, and international collaboration may play a larger effect (sic). Therefore, drawing any strong conclusions about future nuclear power costs based on one country's experience –particularly the US experience in the 1970s and 1980s–would be ill advised.

The fact that cost trends for nuclear power are so dependent on these other factors drives the differences in country-level experiences. Understanding the drivers for cost trends in different countries separately is the only way to glean meaning from these data. Lumping the data from different countries together without adjusting for those factors–as Lovering et al. do–just muddies the waters and prevents sensible analysis.

The fundamental difference between site-built and mass-produced technologies is why country-specific studies of cost trends still have meaning and resonance for nuclear power cost analyses, and why (in part) the costs of mass produced technologies continue to fall rapidly around the globe. Koomey and Hultman (2007) discussed the distinction (first raised by Nemet (2007)) of returns to *unit scale* (as in nuclear reactors) versus returns to *manufacturing scale* (as in solar PV and wind power). It has become clear in recent years that, at least for the current state of nuclear and renewable technologies, the second effect is far more powerful than the first.

THE ARTICLE MISCHARACTERIZES THE EFFECT OF THREE MILE ISLAND ON REACTOR COSTS

A final issue concerns the Three Mile Island (TMI) accident. Lovering et al. state

> Hultman and Koomey (2013) disputed the economic impact of the Three Mile Island accident on the US nuclear industry, but failed to observe its distinctive effects on overnight construction costs. These results suggest that the Three Mile Island accident in 1979 did uniquely affect the nuclear industry in terms of overnight construction cost.

These two sentences are a complete mischaracterization of what Hultman and Koomey wrote. The 2013 article was very clear that TMI was an important event for the industry. Its thesis was that *the factors that led to the demise of nuclear construction in the United States were present and growing before TMI*:

> "There can be little doubt that Three Mile Island affected the US nuclear industry, public opinion, and regulatory regime. It was, after all, the worst nuclear accident in the history of the United States, and even 34 years later remains the third worst nuclear accident globally. As such it very well ought to have affected, at a minimum, the domestic energy debate in the United States. Nevertheless, laying the entire blame for the decline of US nuclear power on the incident is not justified. The argument for doing so is superficially plausible, but it is incomplete

> and, if taken as the basis for future policies, dangerously misleading. The nation's nuclear industry was in fact facing substantial structural obstacles and economic challenges even before the accident, obstacles that reflect the challenging nature of nuclear technology in a world of fast-changing competition and fickle demand growth."

In addition, Koomey and Hultman's earlier analysis (2007) looked explicitly at costs as a function of construction start date, and discussed the effect of TMI.

We fully agree with Lovering et al. that TMI had impacts on costs, not least via increased regulatory requirements, as Koomey and Hultman noted in their original articles. We would further add that the accident also affected costs through longer construction duration and therefore more costly financing–an aspect that Lovering et al. ignore. But we would caution now, as Hultman and Koomey did then, about over-emphasizing the effect of TMI, because many other existing headwinds were already changing minds about what energy technologies best fit societal electricity needs. As Hultman and Koomey noted in 2013, *fully 40 percent of nuclear project cancellations in the United States happened before the accident at TMI*.

CONCLUSIONS

Analyzing the costs of electricity generation technologies is an exercise fraught with pitfalls. Unfortunately, Lovering et al.'s assessment of nuclear costs made several consequential errors. Their analysis incorrectly omits interest during construction, and thus substantially underestimates the effect of cost escalation over time. Their article also relies on cost data for early US demonstration reactors that are so different from existing reactors in size and technology that they are irrelevant to understanding cost trends of modern commercial reactors. In addition, the Lovering et al. data on reactor costs have not been released as supplemental material on the journal's web site. It is therefore impossible to evaluate the quality of these data or what the effect of correcting for interest during construction would be.

We note that the authors cherry pick data to suit their conclusions. Nevertheless, the presented data itself don't even support their stated conclusions, which is deeply puzzling. While Lovering et al claim that their data show a more nuanced picture, suggesting that cost escalation for nuclear reactors is not a real problem, their own data for the modern era show the contrary. With the exception of South Korea, whose data are not independently audited and therefore of unknown quality, all data paint a consistent picture: the investment risk of nuclear power is significant, costs almost always increased over time in the modern era, and cost overruns and lengthened construction times need to be considered carefully by investors and policy makers alike. Adding interest during construction, which Lovering et al. ignore, would only strengthen these conclusions.

Lovering et al. have also created a superficial and selective comparison with renewable technologies (omitting pre-2000 and recent cost declines of PV and omitting costs for wind altogether). A consistent picture emerging from most technology costing studies is that while trends are variable over time and between countries, mass-manufactured renewable technology costs have been decreasing rapidly in recent years, whereas individualized on-site-construction based nuclear costs increased in almost all cases in the modern era. Even among comparable large-scale on-site-constructed energy technologies, nuclear reactors stand out in terms of frequency and magnitude of cost overruns and escalation (Sovacool (2014a, 2014b); see also Gilbert et al.'s rejoinder to Lovering et al. in this Issue).

Better and more transparent data and methods are needed to illuminate critical technology investment decisions facing the world, including responding to the challenge of climate change. Lovering et al. use analytical methods that mask nuclear power's real construction costs, cherry pick data, and include misleading data on early experimental and demonstration reactors. For those reasons, serious students of such issues should look elsewhere for guidance about assessing the costs of nuclear power.

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