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Smart Grid implementation in China: A Cost-Benefit Analysis

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ABSTRACT

The Chinese government's net zero plan targets climate neutrality by 2060, emphasizing a shift in power generation from coal to variable renewable energy sources (VRES), reaching 29% in 2020. Integrating VRES necessitates a Smart Grid, managing energy flow bidirectionally and mitigating source variability. This study evaluates Smart Grid investment's economic gains in China via a cost-benefit analysis. Forecasting from 2020 to 2050, the analysis predicts a 6.1:1 Benefit-to-Cost ratio, akin to EPRI findings. However, data limitations warrant acknowledgment.

This paper seeks to explore the potential financial merits of deploying Smart Grids in China amidst transitioning to sustainable energy sources.

Keywords: Smart Grid, Cost-Benefit Analysis, Renewable Energy Resources, Automated Metering Infrastructure, Distribution Automation

NOMENCLATURE

Abbreviations

SG	Smart Grid
CBA	Cost Benefit Analysis
EPRI	Electric Power Research Institute
NETL	National Energy Technology Laboratory
VRES	Variable Renewable Energy Sources
RES	Renewable Energy Sources
B/C	Benefit-to-Cost
B USD	Billion US Dollars
BL	Baseline without SG
BLSG	Baseline with SG implementation
T&D	Transmission and Distribution
O&M	Operation and Maintenance

1. INTRODUCTION

This paper builds upon the preliminary study on the state-of-the-art of Smart Grid implementation in the contexts of China, US, and EU [1], as well as [2] in terms of approach to the Cost Benefit Analysis (CBA).

The ongoing global energy transition from fossil fuels to renewable energy sources (RES) in the effort to mitigate the effects of global warming necessitates an efficient grid capable of optimizing electricity management while actively engaging users. This advanced grid is commonly referred to as Smart Grid (SG).

The SG is a modernized electricity network that employs advanced technologies to enhance the efficiency, reliability, and sustainability of power generation, distribution, and consumption. It is a complex system that integrates a range of technologies, including advanced sensors, communication networks, and control systems to enable bidirectional communication and real-time monitoring. In contrast to the traditional grid, it accommodates several small power producers, incorporates many small-scale transmissions, and guarantees a decentralized market.[1]

However, a variety of factors have contributed to the relatively slow adoption of the SG in different countries. Some technical aspects include inadequacies in grid infrastructure (cybersecurity, energy storage capacity, energy and data management, communication issues, grid stability, interoperability, incompatibilities, and congestion relating to energy transfer capacity).

Additionally, the need for high capital investments and robust stakeholder engagement can pose social and economic challenges. Furthermore, due to the high level

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[1] https://www.smartgrid.gov/the_smart_grid/smart_grid.html

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of digitalization and data processing, users must be aware of privacy-related issues [3,4].

Despite of its great potential for renewable energy production, coal is the dominating source in China, followed by natural gas, hydropower, wind, solar, biofuels, oil and nuclear. Nevertheless, it is already one of the leading countries in the world in the adoption of a SG. It plans to modernise and expand its power grids with a total of USD 442 billion in investments over the period 2021-2025 in its 14th Five-Year Plan, contributed by the China's State Grid Corporation, China Southern Power Grid, and other regional companies [5,6].

In the United States, the Grid Resilience and Innovation Partnerships Program of the Grid Deployment Office promotes the robustness and adaptability of the grid by providing approximately USD 10 billion in incentives. Additionally, the Recovery Act's Smart Grid Investment Grant (SGIG) enabled financing of 99 projects through federal financial aid of up to 50 % of eligible costs.[2]

The implementation of a SG is very crucial for the development of a country because of the numerous benefits it offers. In the social aspect, it improves reliability, outage management and empowerment of consumers. Additionally, it leads to a reduction in electricity bills through the introduction of RES and improvements in public safety. The SG can contribute to the reduction of greenhouse gas emissions, improve energy efficiency and energy storage. In this regard, it's important to quantify the costs and benefits of implementation, serving as reference for governments to determine its practicality [7].

Here, we present a CBA for the implementation of a SG in China considering 9 aspects in which it can bring benefits. We computed the baselines before the Smart Grid implementation, after it, and the economic benefits it implies over a 30-years period from 2020 until 2050.

2. MATERIAL AND METHODS

It is crucial to quantify the costs and benefits that will result from the SG implementation in China, as it provides an objective perspective that guides future actions and decision-making processes. To achieve this goal, we based our calculations on the methodology proposed by the EPRI guide [8].

The analysis is divided in 3 parts. First, we considered the SG implementation costs, calculated using the EPRI guide for the USA with the difference that we computed the costs for 30 years instead of 20. Referring to the "Business as Usual" scenario adapted to the Chinese reality, which is composed by big generation facilities, among which there are intermittent renewables in the occidental region far away from the consumption centres located along the oriental and south oriental coast.

To compute the total implementation costs, we built a matrix of costs, according to the suggestions of [8] that divides the types of costs in general categories that we used such as capital investments, operation, and maintenance. Then, we included the involved devices for each type of cost. The data necessary to complete the matrix fall into three macro categories: data relative to infrastructure and consumers, penetration values and data relative to deployment costs.

For the total benefit after the SG implementation, we focused on 9 aspects for which we obtained the total baseline costs before (BL) and after the SG installation (BLSG). For each aspect, different assumptions were made when forecasting outcomes within the 30-year timeframe outlined in this study (2020-2050), as described in the next paragraphs.

3. RESULTS

The results obtained for the baseline without SG, with the SG, its implementation cost and the corresponding benefit are shown in Tables 1, 2, and 3.

BENEFIT CONSIDERED		BASELINE WITH NO SG - BL (B USD)	BASELINE WITH SG - BLSG (B USD)	SPECIFIC BENEFIT - BL-BLSG (B USD)
1	**GENERATION MIX**	19,219.76	16,603.24	2,616.52
2	**GENERATION CAPACITY INVESTMENT**	6,800.50	6,576.26	215.73
3	**T&D CAPACITY INVESTMENTS**	2,461.94	2,446.61	15.33
4	**T&D O&M COSTS**	590.01	531.01	59.00
5	**CONGESTION COSTS**	443.89	287.60	146.29
6	**AT&C LOSSES**	1,936.04	1,742.43	193.61
7	**METERING O&M COST**	35.42	24.43	10.99

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[2] https://www.energy.gov/gdo/grid-resilience-and-innovation-partnerships-grip-program

8	**EQUIPMENT FAILURE COST**	36.56	26.12	10.44
9	**OUTAGES**	75.00	34.87	40.13
TOTAL		**31,599.11**	**28,272.56**	**2,858.25**

Tab. 1: Total costs for the baselines of the 9 aspects considered before and after the SG implementation. We show the specific benefit for each aspect, as the difference between BL and BLSG.

	TOTAL (B USD)
IMPLEMENTATION COSTS	**468.29**

Tab. 2: Total SG implementation costs.

In Table 2, it is shown the total implementation costs employed within this study. However, it has not been assumed any specific temporal implementation model. The exploration of the potential influence of such a model on our findings holds interest, however, this will be better analysed in further studies.

	TOTAL (B USD)
TOTAL BENEFIT	**2,858.25**

Tab. 3: Total benefit obtained for the 9 aspects after the SG project implementation.

In Figure 1 we determined the percentage of the benefits in relation to the costs for each aspect before the SG deployment.

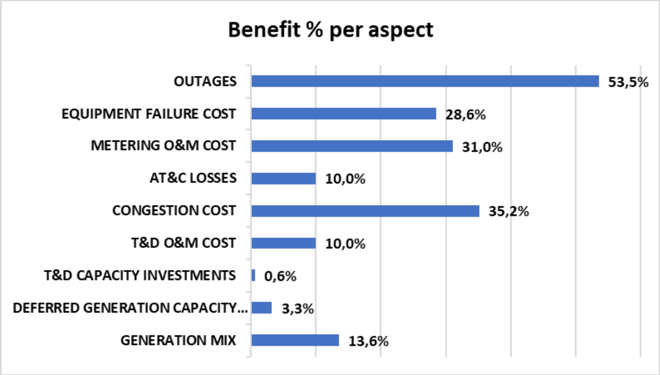

Fig. 1: Benefit ratio on each of the 9 aspects analysed, due to the implementation of SG.

In the case of the Congestion costs, with the SG implementation it would be possible to reach 0% curtailment by 2050, even if during this study we only considered the data for wind energy generation due to lack of data for other RES. Consequently, the benefit of uncurtailed energy would be bigger if other RES could have been considered. This can be better developed in future studies.

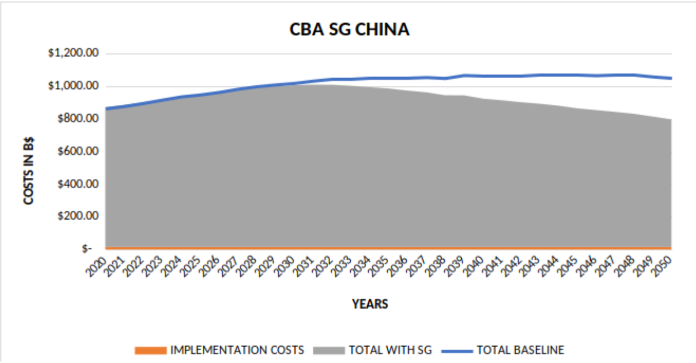

Fig. 2: Costs forecast associated to the SG implementation (orange), before the SG (blue) and with the SG (grey).

In Figure 2, the temporal evolution of the costs is presented. In orange, the costs for the SG implementation, in blue the total baseline without the SG and in grey is the baseline with the SG. It becomes evident that the benefits become significant over time, likely due to the decreasing prices of VRES.

Moreover, a B/C ratio equal to 6.1:1 was obtained, meaning that the SG will bring important benefits despite of its implementation costs.

4. DISCUSSION

In this sections, the nine aspect analysed are discussed.

4.1 Generation Mix

The implementation of a SG offers several benefits for the integration and optimization of Variable Renewable Energy Sources (VRES) because of its great adaptability. The baseline for the associated costs of generating electricity from the different sources for China (coal, gas, nuclear, hydropower, wind and solar) previous and after the SG was determined considering several sources [9]. The benefit comes from the fact that the prices of VRES tend to decrease while their implementation grows along time, considering the scenarios from [10]. It resulted as the most impactful benefit due to the adoption of SG.

4.2 Deferred Generation capacity investment

China is the responsible of 28% of the global investment in the energy sector [11], so this value was considered to calculate its investment baseline before the SG. For the benefit, we used the mean value from [8], given the similarities between the two countries in this regard. The SG has a potential role in lowering the need for immediate capacity investments.

4.3 Deferred Transmission and Distribution (T&D) capacity investment

Regarding the investment reduction, we conducted a linear fit to define the time evolution of the investments based on data of the investments made as a function of the energy consumption in the past. Then, applying the Energy consumption variation equation, the total BL was defined. For the benefit, the mean value given by [8] projected over 30 years was used. Due to the advancement and automation in energy flows the SG could defer T&D capacity investments.

4.4 Reduced T&D Operation and Maintenance (O&M) cost

We used a mean value of 6%, that represents the O&M of the T&D network. Besides, for the benefit, a 10% improvement was considered according to the NETL report [12]. This benefit is directly related to the previous one.

4.5 Reduced Congestion cost

It refers to the cost for producing Energy by carbon-fuelled power plants to compensate for the quantity of wind energy curtailed because of its unpredictability. For the benefit, implementing the SG it is possible to reach 0% curtailment by 2050 according to IEA scenarios [13]. Consequently, this cost will be reduced with the implementation of the SG, as it allow to increase the efficiency of VRES and help reduce curtailment.

4.6 Reduced energy (AT&C) losses

Mostly from transmission a mean value of 6.44% for losses was calculated from the historical data of Statista [14]. As a benefit, a 10% cost reduction was considered based on [15]. The SG can support energy management, allowing reductions in losses due to a constand control of the grid.

4.7 Reduced meters reading cost

The smart meters (SM) are a crucial component of the SG, so its O&M costs are included. The starting point was the Chinese SM market, evaluating the already installed number and the ones projected to be installed in the future. For the benefit, an average costs reduction is assumed as 45% [16]. Consequently, the BL is outlined as O&M costs increased by 45%. SG allow to reduce the O&M related to the meters reading, due to the implementation of the smart meters, a crucial equipment in the SG.

4.8 Reduced equipment failure

Since the SG allows a real-time control of the equipment, costs due to failure can be reduced. Based on [15,17], the failure rate was found due to overloading. The failure cost is calculated by taking as the unit cost the one of the equipment that must be replaced due to failure. Then, from [15] we assumed a 5% reduction thanks to the SG, which can detect and anticipate failures and malfunctions.

4.9 Reduced Outages

Having an interruption in the electricity supply represents big economical losses. From the paper [18] that analyses these costs in China, called Business Interruption Cost (BIC), they found that it reaches an amount of 1.44bn yuan per month. Converting it to USD and calculating the total loss per year, we obtained the BL without the SG implementation. In addition, for the BLSG, we assumed a mean value of 53.50% of outages that can be avoided thanks to the SG, values assumed from [19] and [20].

Finally, the total benefit for the SG project was derived by computing the difference between BL and BLSG (after adding the implementation costs). In addition, we computed the B/C ratio, which is a metric to assess the economic feasibility of the project. If B/C>1 the project is considered beneficial because its total benefit outweighs its total cost.

5. CONCLUSIONS

China is a major global investor in the energy sector and has significant potential for the RES introduction to its electricity grid. This would help the country to stop depending on coal for energy production. However, the implementation of a SG that facilitates the RES introduction has been slow. To quantify the viability of such a project, we performed a Cost Benefit analysis based on the methodology proposed by EPRI.

The result obtained was of 6.1:1 as B/C ratio, indicating that the project's total benefits outweigh its total costs. It's important to emphasize that the B/C ratio is a relevant and useful indicator of the project's feasibility. However, further studies and metrics will still be explored to have more accurate results in the future. Besides, it would be interesting to change some assumptions or find better models for the forecasts of the 9 aspects on which we focused during this study. This possibility will be better explored in future studies. Furthermore, we would like to apply this improved methodology to the case of a SG implementation in other countries.

In conclusion, the implementation of SG technology in China and the USA has the potential to yield significant benefits for the energy sector and society at large. These advantages include enhanced energy efficiency, cost reduction, improved grid reliability, and reduced carbon emissions. Despite the challenges associated with SG implementation, the potential benefits justify the pursuit of this goal as a contribution to a more sustainable and low-carbon future.

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DECLARATION OF INTEREST STATEMENT

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper. All authors read and approved the final manuscript.

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