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Assessing the role of electricity storage in China's high renewable energy penetration future

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Abstract

To cope with global climate change, the international community has reached a consensus that the dependence on fossil fuels should be irreversibly shifted and the transition to a high renewable energy penetration future is definitely feasible to realize the 2 degrees target by the end of this century. Key advantages of renewable energy, compared to fossil fuels, are free of carbon emissions and direct environmental pollution, thus can help further decarbonize the power sector. However, due to the intrinsic nature, renewables are more likely to present significant intermittency issue to power generation system operators than conventional resources. Among potential solutions, electricity storage is relatively attractive. Based on the linear optimization bottom-up technology China-MAPLE model, this paper conducts an in-depth assessment of electricity storage in achieving a high penetration future in China, by describing the volatility of electricity supply and demand as well as the intermittency characteristics of renewable energy at more detailed time-slices level other than the common annual level. Results show that electricity energy technologies can help stabilize the fluctuation of renewable power generation, and balance the supply and demand of electricity in each period. In order to support the rapid growth of renewable energy, the installed capacity of electricity storage should be 88GW in 2030, and gradually increases to 123GW in 2050.

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Keywords: climate change; renewable energy; intermittency; electricity storage; China-MAPLE model

1. Introduction

To address global climate change, the international community has reached a consensus that the dependence on fossil fuels should be irreversibly shifted and the transition to a high renewable energy penetration future is definitely feasible to achieve the 2 degrees target by the end of this century. In Paris

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Agreement, parties acknowledged the gap between current pledges and 2 degree goal and also agreed to pursue efforts towards 1.5 degree [1]. China as a pioneer in mitigating climate change will undoubtedly make further contribution and propose more ambitious reduction objective. In this respect, renewable energy as an attractive solution due to its key advantages of zero carbon emission and less environmental pollution, should play a more significant role in future. The share of renewable energy in power generation is only approximately 2.8% in 2015 throughout the world, but its strong growth gave a clear indication of accounting for all of the increase in global power generation [2].

As the world's largest coal fossil fuels consumer, China is confronted with much more urgent challenges and pressure to tackle with its carbon emissions issue during the transition towards low carbon economy. The China 2050 High Renewable Energy Penetration Scenario and Roadmap Study [3] reveals that a high renewable energy penetration scenario in 2050 with over 60% in China's total energy consumption and over 85% in total electricity consumption supported by renewables is both technically and economically feasible. However, there is still a long way to go, in consideration of the current level of 11.2% and 6.9% in 2014.

Due to the intrinsic nature, renewables are more likely to present significant intermittency and variability to power generation system than conventional resources [4]. Among all potential solutions, the deployment of electricity storage technologies seems to be relatively attractive. It can store electricity when the supply is adequate and the price is lower, whilst shift the stored energy during high priced electricity periods [5-7]. As the electricity market in China is still highly regulated, the electricity storage will act a role more of stabilizing the fluctuation of renewable power generation to balance power supply and demand relation than profit-seeking behaviors in the short term.

Based on the linear optimization bottom-up China-MAPLE model, this paper conducts an in-depth assessment of electricity storage in achieving a high renewable energy penetration future in China, by describing the volatility of power demand as well as representing the intermittent character of solar and wind power between more detailed time-slices instead of the commonly used annual level. Our research is essential and contributes to existing literatures in two aspects. Firstly, it presents more accurately the power generation and demand in disaggregated period and adds electricity storage technologies into energy technology model. Secondly, it also generates the incremental investment costs and provides optimal investment strategy to ensure a high renewable energy penetration future in China. The remainder of this paper is structured as follows. Section 2 describes the China-MAPLE model and methods to include electricity storage module. Section 3 presents modelling results and analyzes the role of electricity storage. Section 4 concludes our research and highlights some more on-going work needed to be done.

2. Methods

China-MAPLE is short for China-Multi-pollutant Abatement Planning and Long-term benefit Evaluation, aiming at analyzing energy consumption, CO_2 and normal pollutant emissions and considering the environmental co-benefits of reducing CO_2 emissions in China. Based on TIMES model [8], this bottom-up energy technology model contains modules such as resource supply, energy service demand, pollutant emissions and co-benefits evaluation. Meanwhile, it describes sectors such as power generation, end-use industry (over 20 sub-sectors like cement, steel and chemical manufacturing), transport and residential department. The design of scenarios in China-MAPLE model highlights the control over CO_2 emissions and normal pollutant emissions related to energy system, such as end-of-pipe control scenario, deep decarburization scenario and co-control scenario. To introduce new processes representing electricity storage technologies into the model, power generation and demand in disaggregated period should be presented more accurately by splitting time-slices at first. In power supply side, the intermittency of renewable energy among seasons and day/night have to be declared, while in demand side, volatility in the load curve of power system has to be depicted.

2.1. Splitting time-slices

In the China-MAPLE model, each year is divided into 12 time-slices to represent day, night and peak for four seasons. In this framework, the fraction of year for each period is determined by the actual physical length. As a consequence, the share for each season is approximately 25%, while 33.3% to 50% for day time, 41.7%-58.3% for night time and 8.3% for the peak period across various seasons.

2.2. Intermittent character of renewables

To present the intermittency of renewable energy, the availability factors at more disaggregated day/night or seasonal level rather than the annual level should be defined. The time-serial availability factors for wind resource are calculated based on the data of wind speed and air volume at 10-meter height during 1980-2009. It turns out that the relative share of national average density of wind resource among four seasons is 0.38, 0.21, 0.19 and 0.22 respectively. In addition, the daily volatility is primarily assumed constant. Given the time-serial availability factor for solar power, statistical data from 1957 to 2000 of 122 radiation stations obtained from National Meteorological Center is adopted. Results show that the fraction among seasons of average solar power is 0.30, 0.35, 0.27 and 0.19. In contrast to wind power, the volatility in day and night is quite different, with the availability down to zero at night.

2.3. Volatility in power load curve

In order to model the volatility in power load curve, the fraction of electricity consumed in each end-use sectors among various time-slices should clarified. However, due to the limitation of data availability in China, our research firstly turns to the monthly total electricity consumption data in 2010 to generate the overall seasonal share, which is estimated to be 24.6%, 27.2%, 24.7% and 23.5%. Then, the results of case study on the load curves of typical days for four seasons in 2007 are used to represent the daily volatility situation. Here, the introduction of electricity storage technologies is driven by the imbalance of power supply and demand caused by the concurrent intermittent renewable energy power output and volatile electricity consumption in reality. It should be noted that the JRC-EU-TIMES model just forces the additional solar and wind resources into storage facility through user constraints rather than unbalanced supply and demand of electricity [9].

2.4. List of storage technologies

Referring to ReEDS model [10] and JRC-EU-TIMES model [11], the electricity storage technologies considered in China-MAPLE model mainly focus on pumped hydro, compressed air energy storage (CAES) and batteries technologies, see Table 1. In comparison, thermal storage and hydrogen conversion technologies are much more expensive, and large scale of utilization can be realized unless substantial improvements are about to happen and significantly cut down the cost. Additionally, DC charging station makes full electric and plug in hybrid vehicles more acceptable and practicable [12-13]. However, due to the time-slices setting in current model, these measures are not taken into consideration.

Given pumped hydro and batteries, of which China has high technique level, the average costs are directly adopted, while for thermal storage and hydrogen conversion, costs are modified to be 20% higher than the average. Additionally, the costs in 2030 and 2050 are consistent with the trends given by JRC-EU-TIMES model.

Table 1. Details of electricity storage technologies

Technologies	Start year	Efficiency (%)	Lifetime (year)	Power cost USD/kW	Energy cost USD/GJ
Pumped hydro	2015	70-80	40-60	1499	33555
CAES	2015	50-70	30	567	15536
Lead-acid	2015	70-80	5-15	300-600	115257
Na-S	2015	75-90	10-15	1000-3000	57629
Li-ion	2015	90	5-15	1200-4000	345772

3. Results and analysis

In the reference scenario, the process of transition underway in energy demand can be starkly seen in China. The final energy consumption is still growing in future, but at a weaker rate of growth, reaching 4600Mtce in 2030 and slightly rising to 5110Mtce in 2050. From perspective of total energy consumption, it also gives a clear signal of increase at with sluggish growth rate, climbing from 3200Mtce in 2010 to 5960Mtce in 2030, and then increasing to 7290Mtce in the middle of this century. Among them, the proportion that fossil fuels account for markedly decreases, especially for coal to fall sharply from 68.8% in 2010 to 45.1% in 2050. Meanwhile, electricity consumption presents similar slowing growth trend, starting from 3982TWh in 2010 up to 9236TWh in 2030 and then slowly rising to 13520TWh in 2050. Regarding the generation mix, the share of coal is declining stepwise while renewables will reach 32.7% in 2030 and 38.3% in 2050. The increasing importance of renewables will be led by wind and solar power, accounting for approximately 14% of total power generation in 2050. The total installed capacity will increase to 2562GW in 2030 and reach 3664GW in 2050, of which coal-power remains its dominant position, while wind and solar power are catching up with a capacity of 597GW in 2030 and 737GW in 2050 respectively, as shown in Fig.1(a).

Considering the intermittency of renewables in situation without electricity storage technologies referred as ‘w/o STG’ in Fig.1(a), results indicate that the overall power generation remain consistent with the reference scenario. However, slight changes exist in the amount of total installed generation capacity, with 2594GW in 2030 and 3706GW in 2050, which are 32GW and 42GW higher compared to the reference case. Possible reason for this increase can be that more capacity should be installed to tackle with the imbalance between power supply and demand, caused by the intermittent character of renewables and the volatile power load curve across various time-slices.

After the introduction of electricity storage technologies, referred as ‘STG’ in Fig.1(a), the total amount of power generation and its mix are almost same with the reference scenario. However, an obvious decline in installed generation capacity relative to the situation considering intermittent character of renewables and the volatile power load curve but no storage solution, decreasing by 145GW down to 2417 GW in 2030 and a decline of 148GW down to 3516GW. By introducing storage technologies, the energy system is improved. The lower installed generation capacity to some extent implies that the scope of wind and solar power previously abandoned starts decreasing. In 2030, power generation driven by wind and solar will reach 1161TWh, and sharply increase by over 60% to over 1885TWh, accounting for more than 14% of the overall power generation. Meanwhile, the electricity stored and released across time-slices will increase along with the strong growth of renewables, 320.5TWh and 413.1TWh in 2030 and 2050 respectively. These figures indicates that electricity storage technologies can play an active role in smoothing the intermittency of renewable resources and contribute to making the high renewable energy penetration future available in China.

Moreover, the installed capacity of electricity storage continues increasing during the overall modelling period, the major incremental of which takes place during 2010 to 2030. The installed storage capacity will reach 88GW in 2030 and 123GW in 2050, as shown in Fig.1(b). The pumped hydro option will maintain at base year level and gradually withdraw, while CAES and battery technologies will be considerably cost-effective since 2020 and present rapid growth. In contrast, constrained by the high cost and resource limitations, thermal storage and hydrogen conversion are not used.

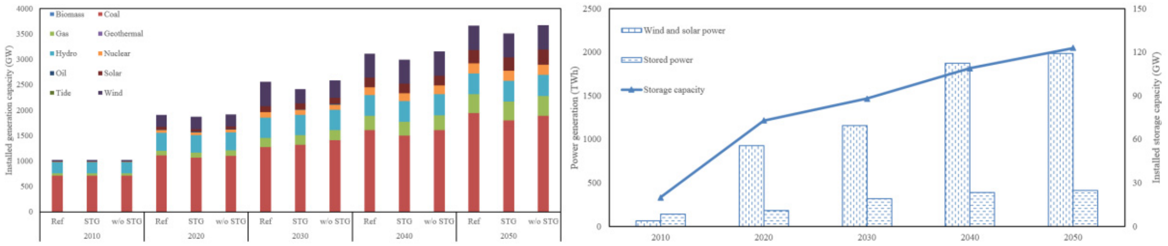

Fig. 1. (a) installed generation capacity; (b) installed storage capacity

In addition, the rising overall system costs are mainly driven by the construction of storage infrastructure. During 2010-2020, the annual investment on storage is 18.3 billion RMB. While due to the lacklustre in the incremental and decrease in cost, the annual investment cost will decline to 2.7 billion RMB during 2040-2050. Furthermore, a series of enhanced renewables scenarios where wind and solar power is assumed to increase year by year are designed. Till 2050, wind and solar power will occupy a share of 20%, 25%, 30% and 40% respectively in overall power generation. A striking feature of the results is that the amount of electricity stored will decline after an initial increase trend. The main reason is that the proportion renewables account for in power generation is set by directly increasing their installed capacity, which offsets the contribution of storage technologies in stabilizing the power system.

4. Conclusions

The main obstacle to the development of electricity storage technologies in China is still the cost issue, to which the solution is substantial technological breakthrough. In our research, a new quantitative assessment of the role that electricity storage plays in achieving the high renewable penetration future is conducted. From perspective modelling work, it can be identified that the introduction of volatility in power demand, intermittent character of renewable energy in power supply side and electricity storage technologies doesn't incur significant changes in the overall power generation structure. Furthermore, in absence of electricity storage technologies, the overall installed generation capacity slightly increases to tackle with the imbalance between power supply and demand, caused by the intermittent character of renewables and the volatile power load curve among various time-slices. While, the inclusion of electricity storage will cut down the installed capacity relative to the reference scenario.

To support a high penetration scenario of renewable energy, electricity storage technologies should develop rapidly since 2020. The installed storage capacity will reach 88GW in 2030 and 123GW in 2050. It indicates that electricity storage will help stabilize the power system and can play an active role in smoothing the intermittency of renewable resources and contribute to making the high renewable energy penetration future available in China. Furthermore, it is of significance that more modelling efforts should be conducted at more disaggregated time-slices level rather than only annual level to reveal more details about the potential effects electricity storage might have on the overall energy system.

5. Copyright

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References

[1] UNFCCC. Conference of the Parties (COP), 2015. Adoption of the Paris Agreement. Proposal by the President. Paris Clim. Chang. Conf. - Novemb. 2015, COP 21 21932, 32.

[2] BP, 2016. BP Statistical Review of World Energy. Available at: https://www.bp.com/content/dam/bp/pdf/energy-economics/statistical-review-2016/bp-statistical-review-of-world-energy-2016-full-report.pdf.

[3] Energy Research Institute of National Development and Reform Commission, 2015. China 2050 High Renewable Energy Penetration Scenario and Roadmap Study. doi:10.1002/ejoc.201200111.

[4] Stram, B.N., 2016. Key challenges to expanding renewable energy. Energy Policy 1–7. doi:10.1016/j.enpol.2016.05.034.

[5] Luo, X., Wang, J., Dooner, M., Clarke, J., 2015. Overview of current development in electrical energy storage technologies and the application potential in power system operation. Appl. Energy 137, 511–536.

[6] de Sisternes, F.J., Jenkins, J.D., Botterud, A., 2016. The value of energy storage in decarbonizing the electricity sector. Appl. Energy 175, 368–379.

[7] Braff, W.A., Mueller, J.M., Trancik, J.E., 2016. Value of storage technologies for wind and solar energy (In review). Rev. doi:10.1038/nclimate3045.

[8] Loulou, R., Remme, U., Kanudia, A., Lehtila, A., Goldstein, G., 2005. Documentation for the TIMES Model Part I. IEA Energy Technol. Syst. Anal. Program. 1–78.

[9] Nijs, W., Simoes, S., Ruiz, P., Sgobbi, A., Thiel, C., 2014. Assessing the role of electricity storage in EU28 until 2050. Int. Conf. Eur. Energy Mark. EEM.

[10] Denholm, P., Fernandez, S.J., Hall, D.G., Mai, T., Tegen, S., 2012. "Energy Storage Technologies," Chapter 12. National Renewable Energy Laboratory. Renewable Electricity Futures Study, Vol. 2, Golden, CO: National Renewable Energy Laboratory; pp. 12-1 – 12-42.

[11] Simoes, S., Nijs, W., Ruiz, P., Sgobbi, A., Radu, D., Bolat, P., Thiel, C., Peteves, S., 2013. The JRC-EU-TIMES model. Assessing the long-term role of the SET Plan Energy technologies, EUR – Scientific and Technical Research series.

[12] Capasso, C., Veneri, O., 2015. Experimental study of a DC charging station for full electric and plug in hybrid vehicles. Appl. Energy 152, 131–142.

[13] Capasso, C., Iannuzzi, D., Veneri, O., 2014. DC charging station for electric and plug-in vehicles. Energy Procedia 61, 1126–1129.

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