Quantifying stranded assets of the coal-fired power in China under the Paris Agreement target

Weirong Zhang [a] , Yiou Zhou [b] , Zhen Gong [c] , Junjie Kang [d] , Changhong Zhao [a] , Zhixu Meng [a] , Jian Zhang [a] , Tao Zhang [e] and Jiahai Yuan [a,f]

a School of Economics and Management, North China Electric Power University, Beijing, People’s Republic of China;

b School of Foreign Languages, North China Electric Power University, Beijing, People’s Republic of China;

c State Power Investment Corporation Research Institute, Co. Ltd., Beijing, People’s Republic of China;

d Institute of Energy, Peking University, Beijing, People’s Republic of China;

e Software Development Center, China Merchants Bank, Shenzhen, People’s Republic of China;

f Beijing Key Laboratory of New Energy and Low-Carbon Development (North China Electric Power University), Beijing, People’s Republic of China

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ABSTRACT

Coal-fired power plays a critical role in China’s compliance with the Paris Agreement. This research quantifies China’s stranded coal assets under different coal capacity expansion scenarios with an integrated approach and high-precision coal-fired power database. From a top-down perspective, firstly, the pathway of China’s coal-fired power capacity consistent with the global 2°C scenario is outlined and then those stranded coal-fired power plants are identified with a bottom-up perspective. Stranded value is estimated based upon a cash flow algorithm. Results show that if coal capacity stabilizes during 2020–2030, China will only incur a sizeable yet manageable stranded asset loss (USD 55 billion, 2020–2045). However, a continued increase of coal-fired capacity, of another 200∼400 GW, would significantly enlarge the loss by 2.7∼7.2 times. Further, once commissioned coal-fired power would form a resource lock-in effect. Thus, it will miss a short-term opportunity to develop new energy sources and induce a long-term need to invest in coal-fired power negative emission technology. Therefore, halting the construction of new coal-fired plants is a low-cost and no-regret option for China.

KEYWORDS: Coal-fired power, stranded assets, China, Paris Agreement

1. Introduction

Soaring energy consumption has led to a rapid increase in CO2 emissions in China, making its climate policy efforts to keep within 2°C under the Paris Agreement challenging. In 2018, China’s total energy-related CO2 emissions exceeded 10,000 Mt (Global Carbon Atlas, 2020). Coal-fired power plays a critical role in China’s compliance with the Paris Agreement. In 2018, coal-fired power contributed to 64% of China’s total power generation (CEC, 2019a). And power sector CO_2 emissions account for 40% of China's total emissions (Meng et al., 2017; Shan et al., 2018; Xinhua Finance, 2019).

China's actions on coal-fired power are vital to limit global CO_2 emissions. At the end of 2019, there were 5529 coal-fired power units in China: among which 4631 are operating with 1058 GW and 898 units are planned with 428 GW. In response to the impact of the COVID-19 pandemic, local governments have announced investments in a large number of key projects to boost the economy. As of June 2020, more than 90 GW of new and renewed coal power projects have been started (Sohu, 2020). Simultaneously, about 20 GW of coal power projects has been approved within three months, from March to May in 2020 (China Dialogue, 2020). President Xi Jinping addressed the UN General Assembly in September 2020, stating that China would reach peak CO_2 emissions before 2030 and reach carbon neutrality before 2060 (BBC, 2020). The role of China's coal power in its future energy mix remains controversial and uncertain. The conflict between ambitious carbon neutral targets endorsed by the Chinese government from the national level and the construction of coal power stations approved by local governments is due to the short-sighted pursuit of short-term economic benefits. It shows a lack of consideration of the national climate strategy at the local government level. The future of coal power development in China must align local and central government policy. Meanwhile, interested parties, such as CEC[1] (2019b) and think tanks such as SGERI[2] (2019a) and EPPEI[3] (2019), have openly lobbied for national coal power capacity to grow by 1250∼1400 GW by 2030; these actors advance energy security as a key argument for such capacity increases, even with the risk of severe financial losses within the coal-fired power sector. Therefore, it is critical to provide China's decision-makers with a reliable analysis of the coal-fired power pathway and the potentially enormous negative impacts of stranded assets due to unrestrained coal power capacity additions in the face of China's climate goals.

There are many definitions of stranded assets depending on different sectors (Buhr, 2017; Caldecott et al., 2013; CTI, 2011; Roper et al., 2006). A general definition of stranded carbon assets is not available, but most definitions centre on carbon-intensive assets that lose value or turn into liabilities before the end of expected economic life (Paun et al., 2015; Ploeg & Rezai, 2020). A variety of factors could lead to assets becoming stranded. These include the following: new government regulations that limit the use of fossil fuels (such as the carbon market), a change in demand (for example, a shift towards renewable energy), environmental and climate risks, or even legal action (Sini, 2018). For this research, we define stranded assets as high-carbon assets in the power sector that are still within design service life and have prematurely lost financial value or are devalued before the end of design service life because of carbon allowances limits. However, due to environmental challenges and the newly proposed carbon neutral commitment for China (BBC, 2020), if all these planned coal power units are built and commissioned, it will cause some of the coal power units to be stranded earlier than their design service-lifetime, imposing an economic burden on society and finance.

Considering stranded assets in the global power sector, IEA (International Energy Agency) and Pfeiffer et al. (2018) pointed out that to meet the Paris Agreement climate goals, even if all the projects currently planned are immediately terminated, a large number of the globalized fossil energy power assets will be stranded (Carbon Brief, 2017). USD 927 billion in the global power sector will be stranded by 2050, among which around three-quarters would be coal (Saygin et al., 2019). Simultaneously, the issue of stranded assets in China's coal-fired power sector should not be underestimated. Various research studies point out the problem of stranded assets. Carbon Tracker (2016) warns that if China continues to build new coal-fired power plants, it will cause a loss of an additional USD 490 billion. Caldecott et al. (2017) predict that the annual value of stranded assets in China's coal-fired power sector would reach USD 449∼1047 billion with a 'sudden death' assumption. Saygin et al. (2019) conclude that by 2050, to reach the 2°C climate target, USD 420 billion will be stranded in China's power sector based on a simplified bottom-up analysis that considers the capital stock turnover of fossil fuel-fired power plants. Cui et al. (2019) predict that China's cumulative value of stranded assets for currently operating coal-fired power plants is about USD 9.3∼35 billion under well-below-2°C with the guaranteed minimum of 30 years operating lifetime. A summary of the studies regarding stranded assets in China's coal-fired power sector is provided in Appendix 1.

Most previous studies on the value of stranded coal assets in China have been conducted from an international perspective, rather than focusing specifically on China (Saygin et al., 2019). These studies were conducted either based on operating coal power units or coal power units under construction and planned, which solely identified stranded coal assets by simple criteria (operating time/unit capacity/all shutdowns), neglecting the fact that when new coal power is built, old units will be squeezed out of the market. This study considers the stranded coal power assets that would result from different coal capacity expansion scenarios based on actual China coal power unit information, regarding the size of active units, and 2°C climate target constraints. Also, we identify coal power assets that will be stranded and evaluate their stranded value based on the composite performance score obtained from the units' performance, following the elimination of inefficient units by more efficient units over time (NRDC, 2019).

2. Data and methods

This research combines the 'top-down' and 'bottom-up' approaches to assess CO_2 emissions of China's coal-fired power sector in cost-optimal 2°C scenario pathways, as shown in Figure 1. Based on the 'top-down' method, we estimated the carbon budget for China's coal-fired power sector. Then we have the potential CO_2 emissions from currently operating and planned coal plants based on the 'bottom-up' method. China's power market and carbon market are gradually maturing, and the carbon price fluctuation would reflect on the electricity price, eventually changing the unit dispatching order. High carbon units will have to withdraw from the market under the cost pressure of reducing carbon allowances (Zhao et al., 2019). Outdated coal-fired power plants with the potential for their CO_2 emissions to exceed the carbon budget will withdraw from the market ahead of schedule. This part of coal-fired power plants will become stranded assets.

2.1. Potential CO_2 emissions in China's power sector based on the 'top-down' principal

From IPCC AR5, to limit temperature rise well below the 2°C target by a cost-optimal path, China needs to limit cumulative carbon allowances by 280~400 $GtCO_2$ during 2011–2050 (Commit, 2018a). China's energy-related sector accounted for 75% (average) of total national CO_2 emissions during 1990–2018, and referring to China's CO_2 emissions from 2011 to 2018 in the energy sector (Climate Action Tracker, 2019; Global Carbon Atlas, 2020), we derive the energy cumulative carbon allowances from 2019 to 2050 for 132~222 $GtCO_2$ (mean: 177 $GtCO_2$). According to the proportion of CO_2 emissions from the coal-fired power sector under accelerated electrification

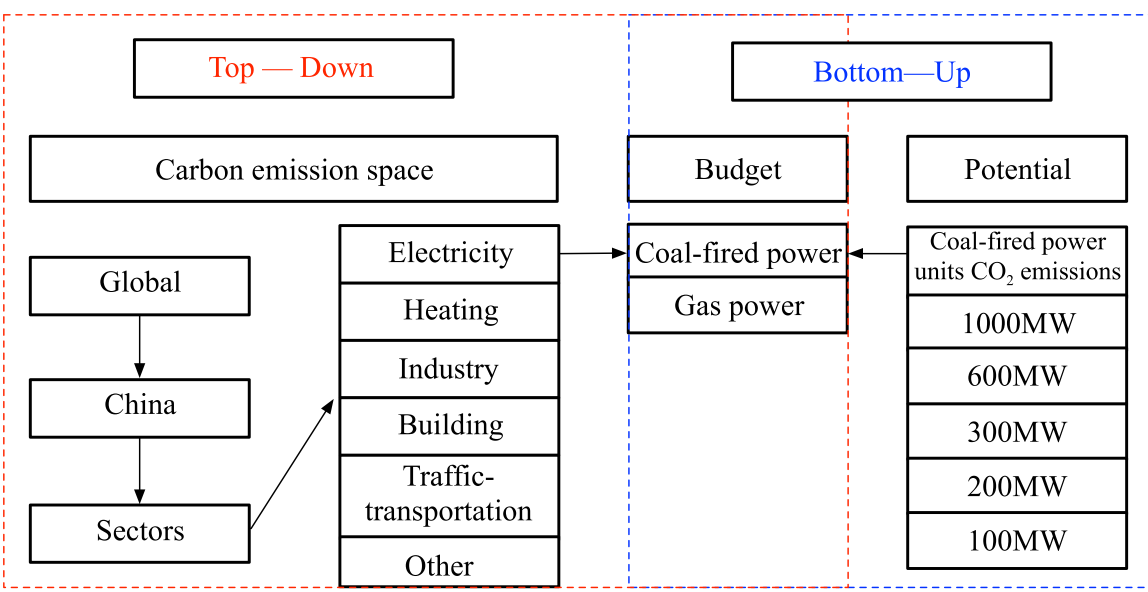


Figure 1. The 'top-down' and 'bottom-up' methods to assess CO_2 emissions of China's coal-fired power sector.

(SGERI, 2019b), we derived the coal-fired power sector's carbon allowances. Under the Paris Agreement 2°C target, the cumulative carbon allowances for the power sector over 2019 and 2050 would be 60~93 $GtCO_2$, among which the ones from the coal-fired power sector would account for 53~86 $GtCO_2$, as shown in Figure 2.

The power system needs to be carbon-zero ahead of the energy system. As the most technically feasible and easiest to decarbonize, the power sector needs to set an ambitious target on the low-carbon transition. Under the constraint of the carbon neutrality goal by 2060, China's energy system needs to achieve zero emissions around 2050, where fossil energy consumption would fall to zero. It is strongly suggested that China's power sector achieve zero carbon in the power system between 2040 and 2045 (Zhou, 2020). Based on research on China's cumulative carbon allowances, the peak year, plateau period, downward trend, and the change of CO_2 emissions from the coal power sector in the share of the energy-related sector (see Appendix 2 for details), we develop three scenarios – namely, high, moderate, low – of annual carbon allowances for the coal-fired power sector under the 2°C climate target; these are designed to achieve zero carbon power system goals by 2050, 2045 and 2040, respectively, as shown in Figure 3. We set the moderate scenario as the baseline scenario at which the coal power sector's carbon allowances will be 70 $GtCO_2$, with CO_2 emissions peaking at 4.46 $GtCO_2$ in 2025, reaching a plateau period during 2025–2030, declining rapidly after 2030, and achieving net-zero by 2045. We carried out a sensitivity analysis on high carbon allowance and low carbon allowance scenarios (see Section 3.2). Under the low carbon allowance scenario, the 1.5°C climate goal would very likely be achieved.

It is necessary to define the allowable coal power development scale if the 2°C climate target were to be achieved. The allowable scale is calculated based on baseline carbon allowances, including carbon emission intensity declining, as shown in Appendix 3. To achieve the 2°C climate target under the baseline scenario, China must maintain its coal-fired capacity at around 1180 GW by 2025, below 1000 GW by 2030, and reduce to 195 GW by 2040. Due to high uncertainty in policy support, options such as strategic reserve plant requirements and CCS deployment were not considered when calculating the allowable coal-fired power plants scale (Brunekreeft et al., 2016; Sgouridis et al., 2019).

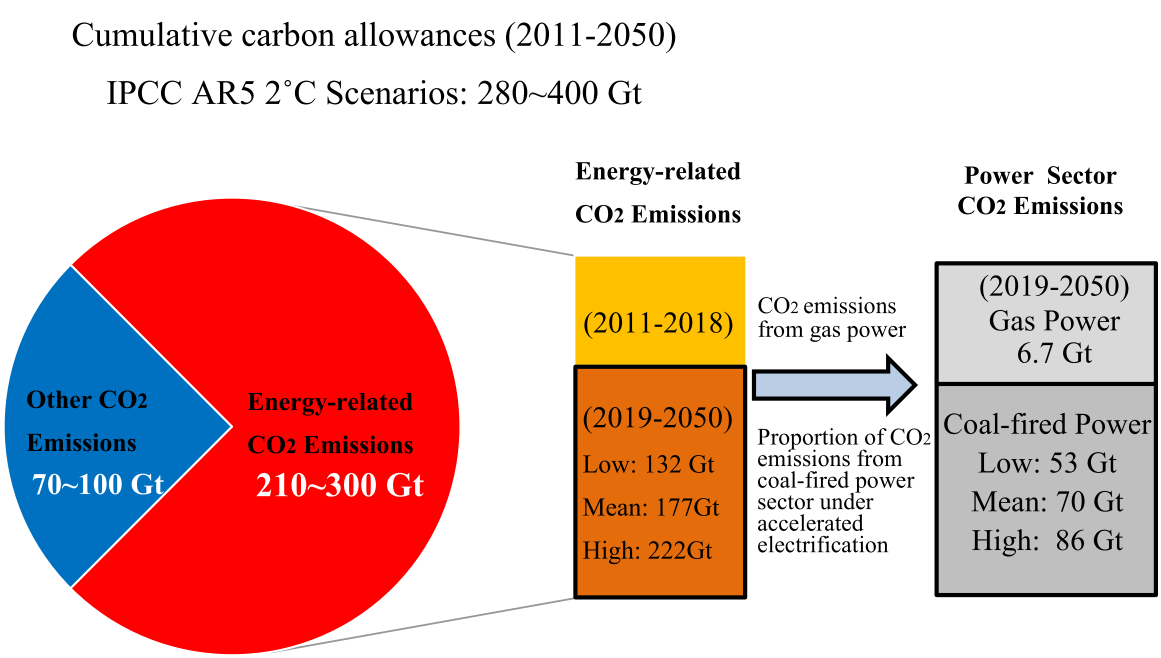


Figure 2. Potential cumulative carbon allowances for China under 2°C climate goal.

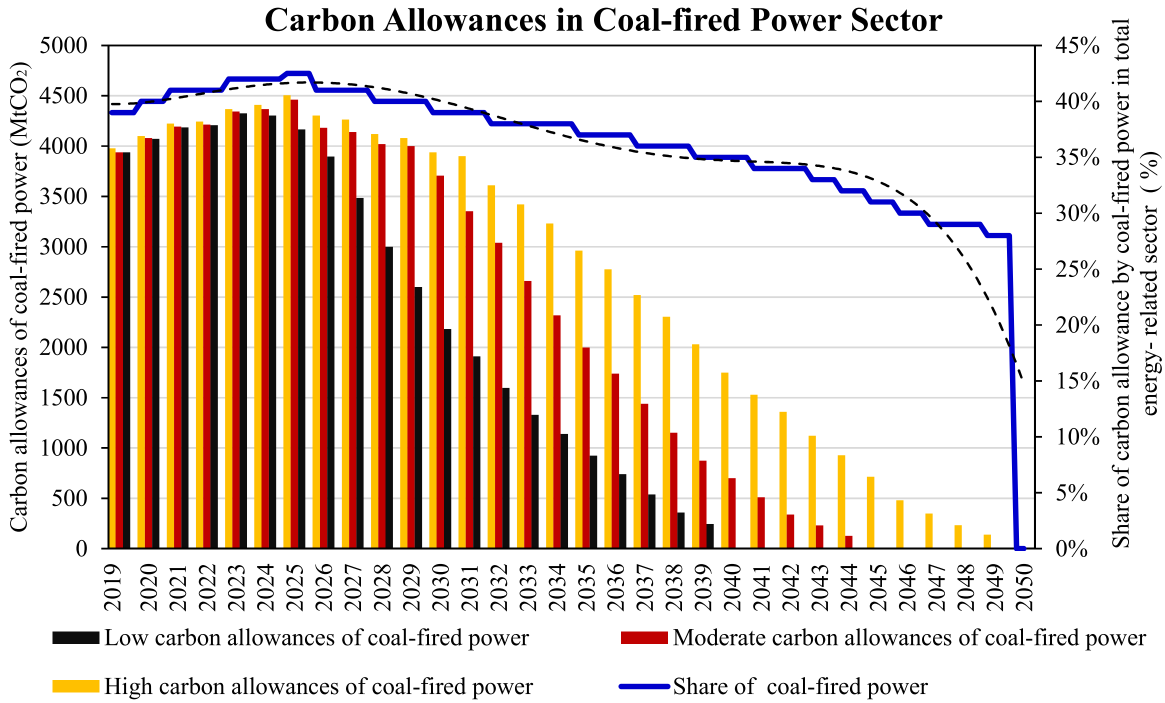


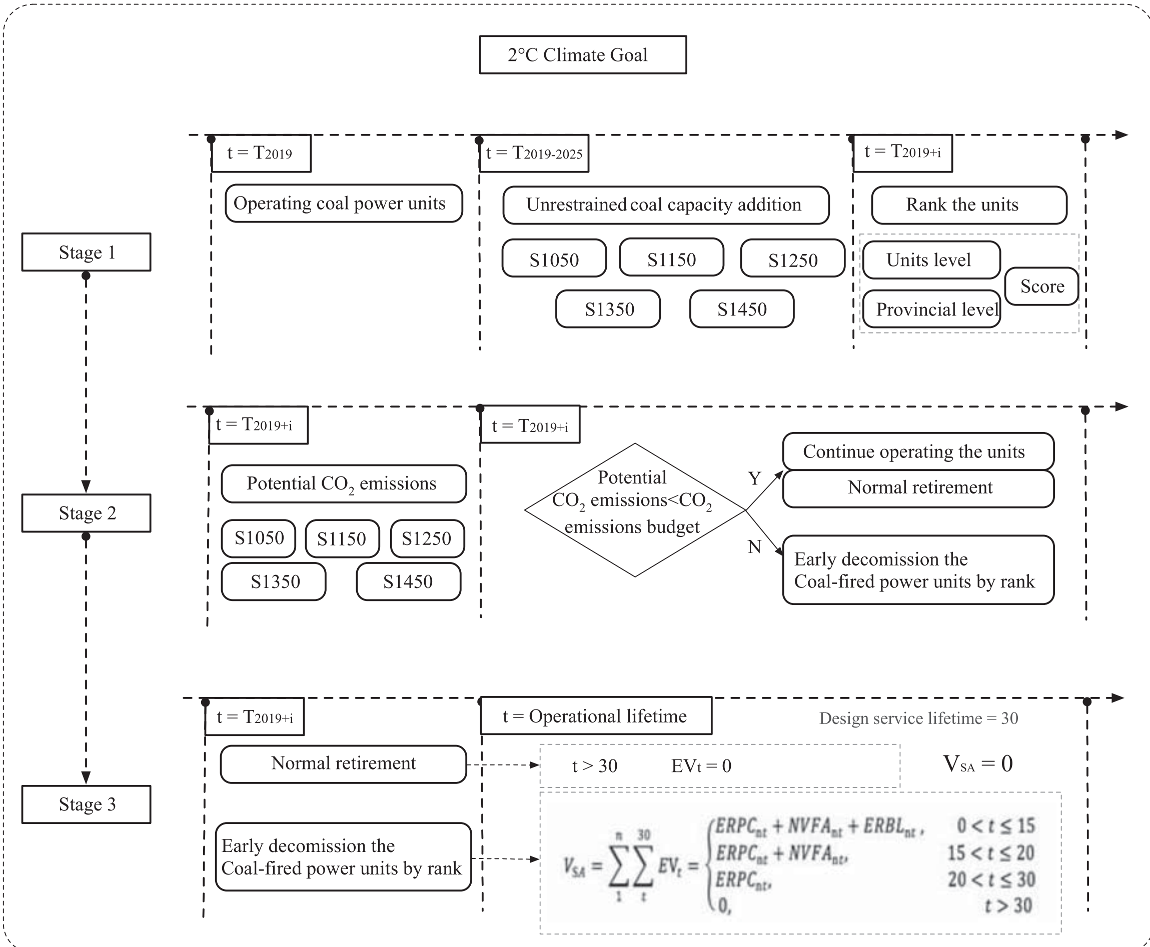
Figure 3. The annual carbon allowances for the coal-fired power sector during 2019–2050 under 2°C climate target. The left-hand vertical axis represents the emissions of coal-fired power (the bars in $MtCO_2$). The right-hand vertical axis shows the share of carbon allowance from the coal-fired power sector in total energy-related sector (the blue line in %). The ratio is at the same level in the three scenarios.

2.2. Bottom-up approach to determine stranded coal-fired power units based on unrestrained coal capacity addition

According to the bottom-up plan, we derive currently operating and planned coal-fired power unit data in China from the most recent versions of six databases, as shown in Appendix 4. Based on the bottom-up approach, we got potential CO_2 emissions from currently operating and planned coal-fired power units during 2019–2050. Comparing this with the carbon budget of the baseline 2°C climate goal, we find that China's CO_2 emissions will far exceed the Paris Agreement's 2°C climate goal once the planned units are commissioned, as shown in Appendix 5. Firstly, we compute the remaining budget for CO_2 emissions in the baseline scenario. Then we use an integrated approach model, as shown in Figure 4. In this way, we estimate the impacts on stranded assets of unrestrained coal capacity addition under the 2°C climate goal.

In stage 1, we mark the scenario as S1050, in which there are only 1058 GW operating units in the system, and planned units would no longer be commissioned. Then we continue to set the unrestrained coal capacity addition based on operating units. For the scenarios where planned units were still commissioned, we mark for every additional 100 GW as S1150, S1250, and S1350. Moreover, S1450 indicates that all currently planned units are completed and put into production. According to the unit level information in the coal-fired power database and the units' geographic information on the provincial level, we derived all the coal-fired power units' composite scoring. Eventually, we sorted them all to determine the sequence of being stranded (see Appendix 6 for details).

In stage 2, we computed the CO_2 emissions of coal-fired power units under S1050, S1150, S1250, S1350, and S1450 scenarios. We compared them with the carbon allowances for the baseline scenario under the 2°C climate goal year by year. When the CO_2 emissions of coal-fired power exceed the carbon allowance, outdated coal-fired power units (i.e. units with lower scores) that exceed the carbon allowance would be decommissioned early and become stranded assets. We mark the year when the carbon allowance was



$$V_{SA}=\sum_{1}^{n}\sum_{t}^{30}EV_t=\begin{cases}ERPC_{nt}+NVFA_{nt}+ERBL_{nt}, & 0<t\le 15\\ ERPC_{nt}+NVFA_{nt}, & 15<t\le 20\\ ERPC_{nt}, & 20<t\le 30\\ 0, & t>30\end{cases}$$

Figure 4. The model of stranded assets caused by unrestrained coal-fired power units capacity addition under 2°C climate goal.

exceeded as the time when the coal-fired power unit was stranded (this part is implemented using Python codes).

In stage 3, based on the stranded year of the coal-fired power units, we derived the operating life of coal-fired units. We computed the coal-fired power assets devalued before the end of the design service lifetime. Then we obtained the value of stranded assets caused by an early exit from the market (see Section 2.3 Algorithm for estimating the value of stranded assets).

2.3. Algorithm for estimating the value of stranded assets

In this research, the value of stranded assets mainly refers to the value of coal-fired power units within the design service life that exit early from the market to achieve the well below 2°C goals as outlined above. The different commissioned and stranded years of the units cause the difference in the value of stranded assets. We obtained the units' capital expenditure based on the units' commissioning year, capacity, and affiliated region (NEA[4]; EPPEI & CREEI[5] [2006, 2011, 2016]). Then we use the capital expenditure to derive the net value of fixed assets and expected return of funds to calculate the value of stranded coal-fired power assets (see Appendix 7 for specific calculation parameters). With every new unit entering the market, we assume an early decommissioning of a unit with a lower score would occur. The stranded asset value of the coal-fired power plant comprises the unrecovered net value of fixed assets in the period from the stranded year to the 30th year of its design service lifetime, the expected return on investment of equity funds, and the interest of the bank loan. We assume that after the unit has been in operation for 30 years, it will be decommissioned normally, and from then on, they will not contribute to the stranded asset value. The following Formula 1 shows the value of stranded assets due to the early withdrawal of all stranded units generated from the stranded year to the 30th year of its design service life:

$$V_{SA} = \sum_{1}^{n} \sum_{t}^{30} EV_t = \begin{cases} EREF_{nt} + NVFA_{nt} + ERBL_{nt}, & 0 < t \leq 15 \\ EREF_{nt} + NVFA_{nt}, & 15 < t \leq 20 \\ EREF_{nt}, & 20 < t \leq 30 \\ 0, & t > 30 \end{cases} \quad (1)$$

where V_{SA} stands for the value of stranded coal-fired power assets, EV_t stands for annualized expected return value of coal-fired power assets, 'EREF' stands for the expected return on equity funds, 'NVFA' stands for the net value of fixed assets, 'ERBL' stands for the expected return of bank loan, '*n*' stands for code of the stranded units, and '*t*' stands for operating period.

3. Results

Unrestrained development of coal-fired power will cause a large scale of stranded assets. We estimated the specific value of stranded assets in various scenarios and conducted the sensitivity analysis. In addition, we assessed the benefits and challenges of restraining new additions of coal-fired power plants.

3.1. The economic value of stranded coal-fired power assets

3.1.1. The economic value of national stranded coal-fired power assets under different scenarios.

The scenarios represent different pathways for coal-fired power capacity additions. Accordingly, we sort out coal-fired power capacity additions from 2019 to 2025 – identifying eight different possible options depending upon the plants' operating status, vintage, and performance (Figure 5). We find that the value of national total stranded assets is growing significantly with increasing coal-fired power capacity additions, as shown in Figure 5. Judging from the final situation of commissioning the planned coal-fired power units, the plan of no more new units would cause the least loss due to stranded asset value. The more the planned units were built and commissioned, the higher the losses due to stranded asset value. Under Scenario S1050 (no more new units), the stranded asset losses would be USD 55 billion (CNY 382 billion, USD 1 to CNY = 7). With the construction of additional 100, 200, 300 GW, and all planned coal-fired power units were commissioned (marked corresponding as Scenarios S1150, S1250, S1350, and S1450), the stranded asset losses would be USD 113, 203, 299, and 451 billion, respectively (CNY 793, 1419, 2095 and 3160 billion, USD 1 to CNY = 7). Once the planned units were commissioned, many current operating units would be squeezed out of the market, forming higher levels of stranded assets. Comparing the scenario of stopping new build immediately with scenarios of expanding coal-fired power to 1250∼1400 GW shows large differences in the value of stranded assets.

3.1.2. The economic value of regional and provincial stranded coal-fired power assets under different scenarios

The results show that the more planned units were commissioned at the regional level, the higher the value of stranded assets, which is consistent with the national level (Figure 6). Among them, North China Grid and Northwest China Grid assets are at higher risk of stranding. North China Grid's stranded value accounts for 43∼54% of the national total, the highest among six regions because North China accounts for 30% of the nation's operating units and 32% of the planned units. Moreover, among all operating units in the region, 300 MW capacity or less accounts for more than 20%. The region's units score relatively low on performance and therefore face a high risk of stranding. Northwest China Grid's risk of stranding is placed right after North China. The value of stranded assets accounts for 17∼22% of the national total. Besides, considering

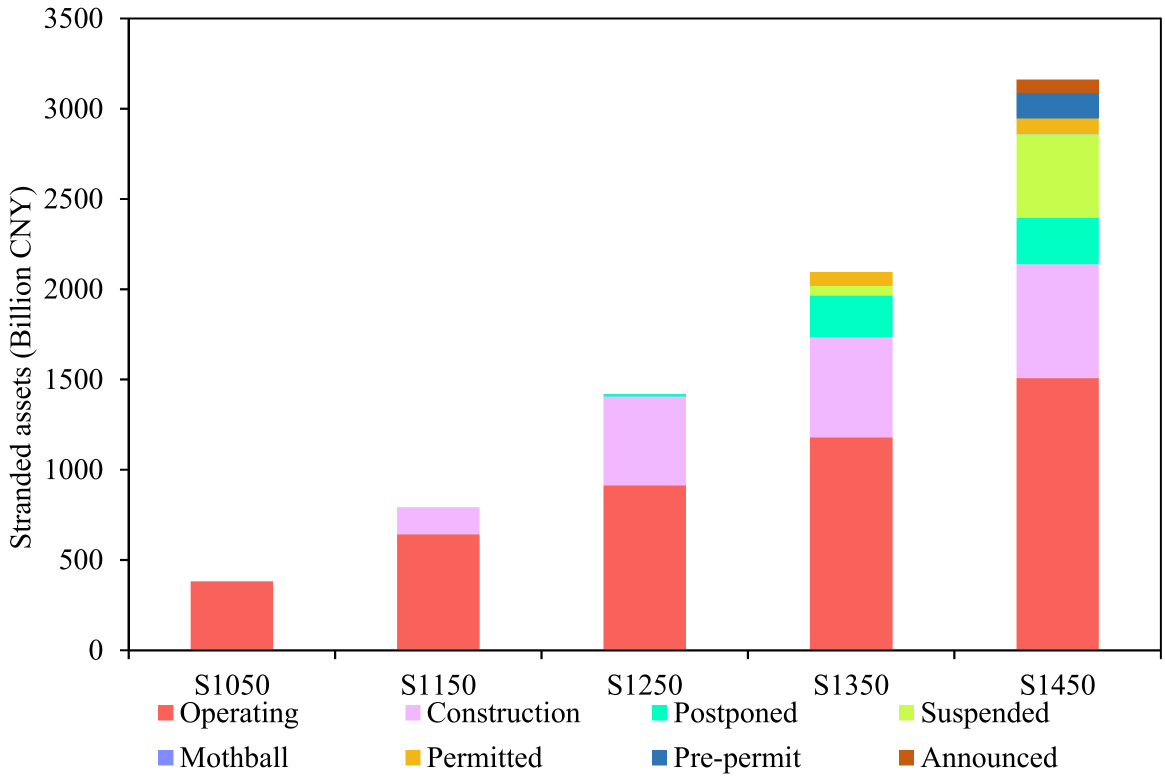


Figure 5. The value of stranded assets in China under unrestrained development of capacity addition in coal-fired power unit scenarios.

that 70~80% of investment in China's coal-fired power plants comes from bank loans, stranded coal-fired power assets will also pose significant risks to the financial sector (NEA, 2020).

According to the distribution of stranded assets in provinces within the power grid, the stranded assets are concentrated in the Xinjiang and Shaanxi Provinces in the Northwest Power Grid (Appendix 8). These trends are driven by the changes in coal-fired power capacity addition and the coal-fired power unit efficiency. The upward pressure on CO_2 emissions will cause many low-efficiency units with low-performance scores in these provinces to withdraw from the market, i.e. in Shandong, Inner Mongolia, and Shanxi, the number of the operating coal-fired power units below 300 MW in these three provinces are 818 units (total 34,089 MW), 251 units (total 18,346 MW), and 165 units (total 8345 MW). Once additional coal-fired power units were commissioned, the risk of stranding spreads out to four provinces – Shaanxi, Anhui, Xinjiang, and Guizhou – as the number of planned coal-fired power units in those provinces are 74 units (total 45,740 MW), 74 units (total 37,667 MW), 78 units (total 36,900 MW), and 54 units (total 22,140 MW).

3.1.3. The economic value of stranded coal-fired power assets based on the attributes of the company under different scenarios

We quantify the scale of stranded assets based on ownership attributes for each company to which the power plant belongs. The results are shown in Figure 7. In terms of stranded value, state-owned power plants accounted for 56~67% of the total value, which is significantly higher than in private power plants. This situation is consistent with the national power sector landscape, where most coal-fired power companies are state-owned. With planned units being commissioned, the stranding risk in state-owned plants would increase correspondingly. As shown in scenario S1050, the stranded assets of private and state-owned plants are CNY 167 billion and CNY 215 billion (1:1.29). In scenario S1350, with 300 GW planned units being implemented, stranded assets of private and state-owned plants would rise to CNY 693 billion and CNY 1400 billion (1:2.02), respectively.

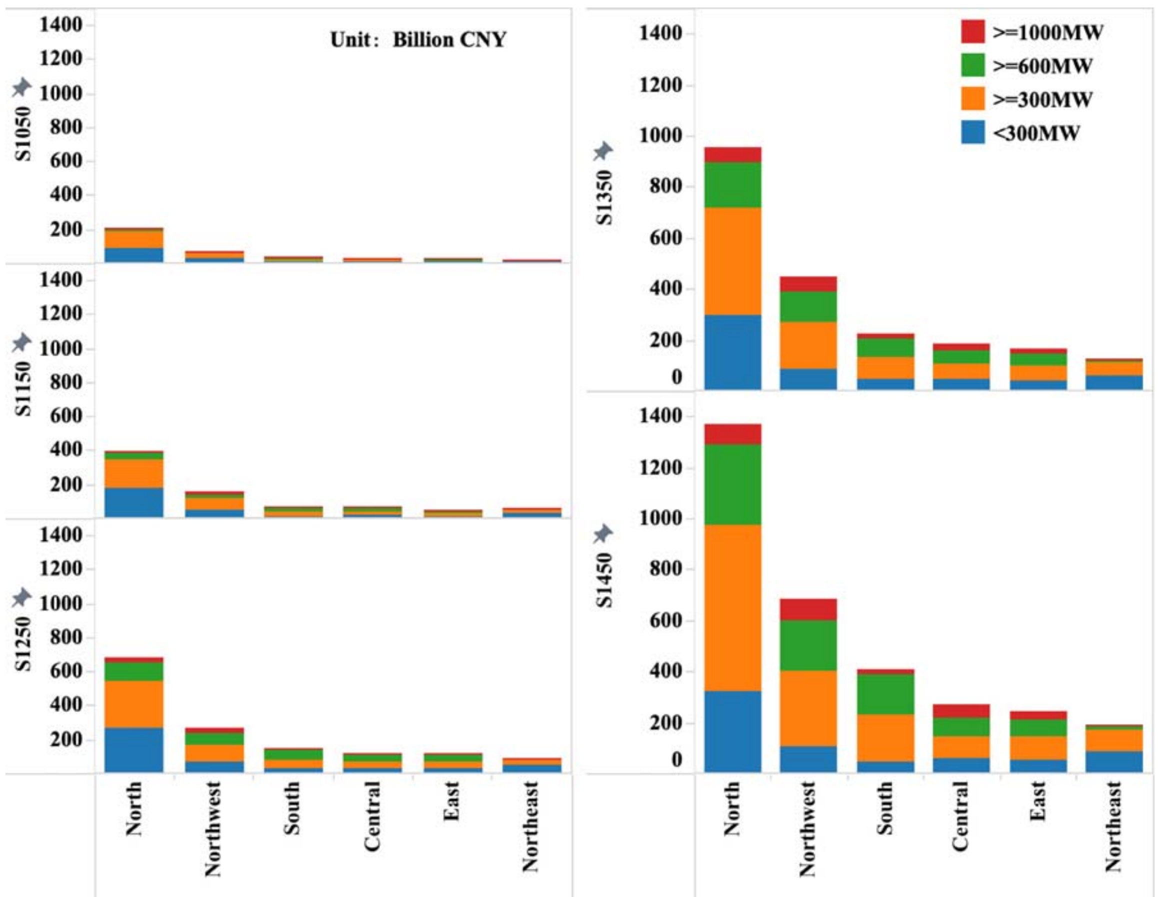


Figure 6. The value of stranded assets in each region under unrestrained development of coal-fired power units capacity addition scenarios.

Captive power plants[6] account for about 10% of the country's total installed capacity, and most of them have a smaller capacity, larger coal consumption, and higher levels of pollution. They would be the first to be squeezed out of the market, ranging from 13% to 20% of the total value of stranded coal-fired power assets under all scenarios.

3.2. Sensitivity analysis

Parameter selection in the stranded assets model faces many uncertainties. In this section, a sensitivity analysis is performed to estimate the impact of model parameter selection on the economic value of national coal-fired power stranded assets. We assess how changes in key parameters affect trends positively or negatively. Results

Table 1. The sensitivity analysis of change in value of national stranded coal-fired power assets.

	Positive change		Negative change	
Key parameters	Changes of parameter	Changes of value	Changes of parameter	Changes of value
Carbon allowance	23%, high carbon	−47%	−32%, low carbon	77%
Carbon intensity	−10%	−32%	10%	35%
Depreciation period	−33%, 15yr	−36%	33%, 25yr	77%
Expected return rate on the market	−10%	−10%	10%	10%
Bank loan interest rate	−10%	−7%	10%	7%

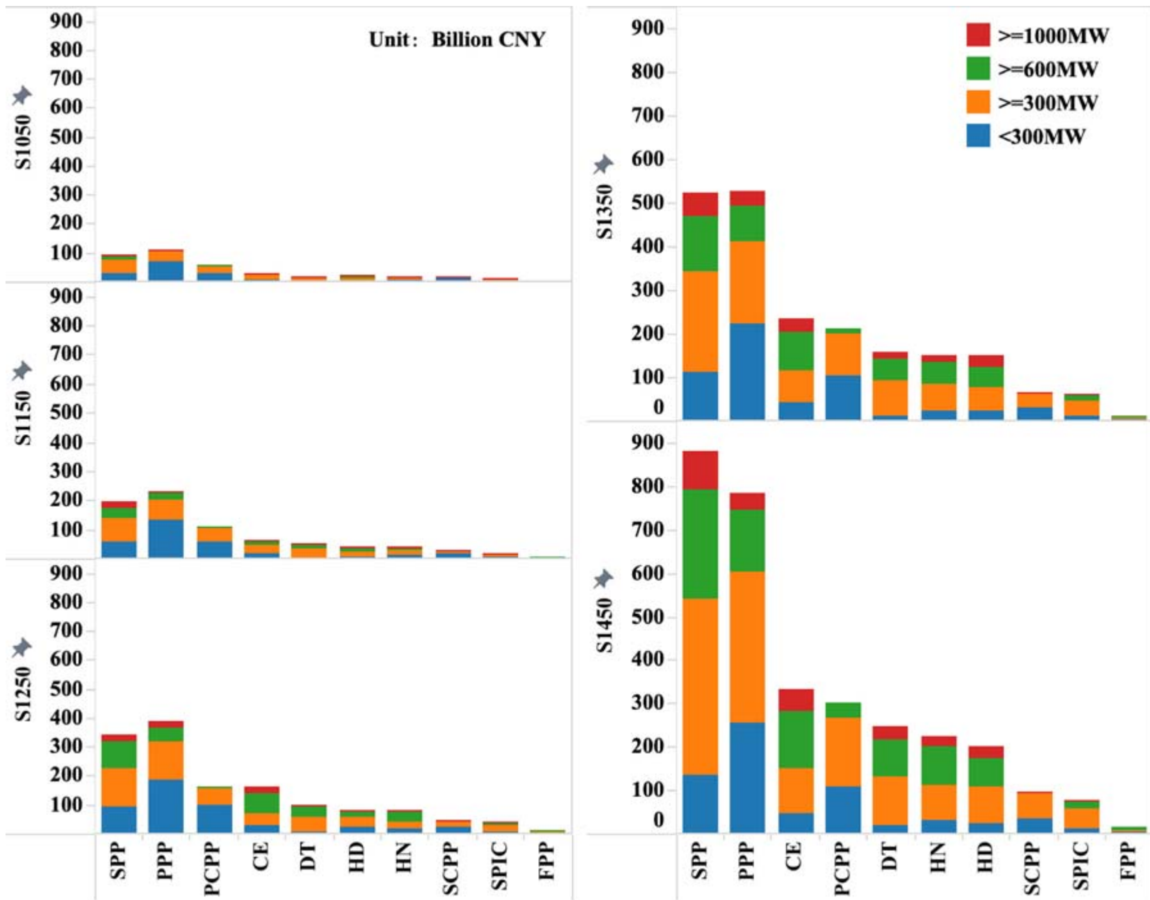


Figure 7. The value of stranded assets in power groups under unrestrained development of coal-fired power units capacity addition scenarios. PPP, SPP, and FPP stand for private power plants, state-owned power plants, and foreign-funded power plants, respectively. PCPP and SCPP stand for privately/state-owned captive power plants. CE (China Energy Investment Corporation), HN (China Huaneng Corporation), HD (China Huadian Corporation), SPIC (China State Power Investment Corporation), and DT (China Datang Corporation) are the five largest power generation groups in China. The power units are thus divided into different private attributes (PPP and PCPP), state-owned attributes (SPP, SCPP, CE, HN, HD, SPIC, DT), and foreign attributes (FPP) based on the information about the power plant's ownership.

of the sensitivity analysis are shown in Table 1. For every 10% reduction in carbon emission intensity, the value of total stranded assets will be reduced by more than 30%, which shows that a units' high energy efficiency can reduce CO_2 emissions. Carbon allowances also have a significant impact on the value of total stranded assets. Under low-carbon allowance constraints, the value of total stranded assets will increase by about 80%, illustrating the great uncertainty inherent in the climate change issue, the carbon allowances is depend on the risk of temperature rise. If the units' depreciation period was shortened by five years, the value of total stranded assets will also drop by 36%, which indicates that accelerating depreciation could reduce stranded assets.

3.3. Benefits and challenges of limiting new additions in coal-fired power units

The strict control of coal-fired power development can reduce investment in new coal-fired power plants. If the planned units are not to be put into production, more than CNY 1500 billion capital expenditure can be saved. Even if all current under-construction units are completed (about 200 GW), there would still be more than CNY 700 billion capital expenditure saved. Meanwhile, if the construction funds of planned units was to be invested in renewable energy, 217 GW of wind and solar capacity could be added (assuming an installation cost of

7000 CNY/kW) (Polaris Power Net, 2020). Besides, limiting new additions in coal-fired power units can significantly reduce CO_2 emissions. If no planned coal-fired power units were built, CO_2 emissions would be reduced by approximately 1.59 Gt annually. If all current under-construction units were completed, annual CO_2 emissions would still be reduced by about 0.87 Gt. Many other countries have already proposed a coal phase-out deadline and required no more investment in the coal-fired power sector. Moreover, stranded coal power generation assets can also affect the coal-related upstream assets.

Pro-active transition measures in the coal sector can promote renewable energy development, reduce coal-related early deaths, and reduce unemployment due to capacity closures while conserving water and protecting the ecosystem (He et al., 2020). Cai et al. (2018) pointed out that, under the Paris Agreement, in 2050, the scale of health co-benefits brought by CO_2 emissions reduction would increase to USD 53.79 ~ 171.93 billion, three to nine times the implementation costs for realizing NDC targets (USD 19.57 billion). Reducing the use of coal power would directly improve air quality (Thibaud, 2018). Some worry that halting the construction of new coal power may impact the provision of a stable electricity supply in recent years. However, Greenpeace (2020) has shown that new coal power units are not essential, while demand response, pumped storage, and even cross-provincial transmission for optimal dispatching are far more economical for the short-term peak power supply. These are all wake-up calls for China's coal-fired power development, and the current time window is undoubtedly the best choice for the cost of power transition.

Limiting new additions of coal-fired power units can reduce CO_2 emissions and save investment costs. However, achieving well below 2°C temperature rise will also require new technology support, including a long-term need for breakthroughs in carbon capture and storage (CCS) and even bioenergy with carbon capture and storage (BECCS) negative emission technologies. However, these are still at the early stages of development. Recent studies show that approximately 175 GW existing coal-fired power plants could be retrofitted with CCS, and the minimum abatement cost is USD 1212 billion for the national-level CCS layout (Huang et al., 2019; Wang et al., 2020). Coal-fired power would form a resource lock-in effect once it is built. The hint is that it will miss the opportunity to develop renewable energy investment and require very high-cost investment in coal-fired power negative emission technology in the long term.

4. Conclusion and policy implications

China's coal power development in the coming 14th Five-Year Plan is crucial to China's proposed carbon neutrality target and achievement of a global 2°C climate goal. This research combines a 'top-down' coal-fired power development path under cumulative carbon allowances and a 'bottom-up' phase-out plan for coal-fired power fleets supported by a high-precision database to conduct a multi-scenario study and quantify stranded assets in the coal-fired power sector consistent with the 2°C climate goal. The main conclusions and policy implications are as follows:

(1) Different policy trends and investment choices would make a big difference in economic costs regarding achieving the 2°C climate goal over the next five years. The scale of stranded coal-fired power assets in China will remain acceptable and manageable (USD 55 billion, 2020–2045), only if no new units are built. However, once an additional 100, 200, 300 GW, or 400 GW are commissioned, additional stranded assets will be 2.08, 3.71, 5.48 times, or even 8.2 times higher, respectively. Our conclusion is very straightforward: halt the construction of new coal-fired power plants is a no regrets, low-cost option for China to meet its carbon neutrality target.

During the 14th Five-Year Plan period, for realizing decarbonization goals, it is necessary to strictly control coal power's additional capacity, not only at the national level, but also the sub-national level. The use of carbon allowances for achieving the 2°C climate target is a means to place a strong constraint on coal power development and allows dynamic assessment of the remaining carbon allowances for the coal power sector. Developing an orderly exit pathway for coal power in the long term with well-defined phase-out criteria could guide decisions. Estimating the cost of a coal power technology transition (life extension, flexibility retrofits, carbon capture and storage, etc.) and of energy replacement programmes (renewable energy, nuclear energy, etc.), and providing social services to support could guide a just transition of coal power (Grubert, 2020; Jiangsu NEA, 2020; NRDC, 2020), to avoid large economic and social impacts caused by stranded coal assets.

(2) Due to the impacts of the distribution of stranded units, North China Grid and Northwest China Grid assets are at higher risk of stranding. If additional coal-fired power units were to be built, the stranded asset risk in major coal-fired power provinces like Shandong, Shanxi, Shaanxi, Xinjiang, Anhui, and Guizhou would increase rapidly. Coal-fired power assets are mainly state-owned, which account for 56~67% of the total stranded assets value. The risk of them being stranded will increase significantly, with large numbers of planned units being commissioned.

Considering that 70~80% of investment in China's coal-fired power plants comes from bank loans, stranded coal-fired power assets will also pose significant risks to the local financial sector. Therefore, the local financial sector needs to work with the energy sector to innovate through green financial mechanisms and guide finance to gradually withdraw from the coal sector and turn to support clean and renewable energy. In the long run, the cost of the switch from coal to renewable energy will be compensated by avoiding substantial stranded risks. Eventually, renewable energy will bring forth new growth.

Notes

1. China Electricity Council (CEC).
2. State Grid Energy Research Institute (SGERI).
3. China Electric Power Planning & Engineering Institute (EPPEI).
4. National Energy Administration (NEA).
5. China Renewable Energy Engineering Institute (CREEI).
6. Due to the frequent increase in electricity tariffs charged by the electric utility, poor reliability of electric supply, forced outages, long power cuts, etc., a large number of industries have switched over to their own generating station (plant) within their own campus. This method of generation is called Captive Power Generation and such plants are known as 'Captive Power Plants'. (https://electricalvoice.com/captive-power-plants/).

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ORCID

Weirong Zhang http://orcid.org/0000-0002-5371-1418
Jiahai Yuan http://orcid.org/0000-0002-1150-7750

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