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Coal transitions in China's power sector: A plant-level assessment of stranded assets and retirement pathways

Thomas Spencer, Nicolas Berghmans, Oliver Sartor (IDDRI)

OVERINVESTMENT IN NEW COAL PLANT

This paper estimates the potential scale of stranded assets in the coal power sector in China under different policy scenarios. A number of factors are putting significant pressure on the coal-power sector: a recent investment bubble in new capacity, structural slowing in electricity demand growth, upcoming moves to liberalize electricity markets and introduce a carbon market, and continued support for renewable and low-carbon sources of electricity. Stranded assets in the Chinese coal-fired power sector are estimated at 90 billion USD_{2015} under the current policy trajectory (NDC-Style Scenario). This situation threatens to increase the political economy challenges of China's electricity sector transition to a low-carbon system. This situation is not unique to China: other countries will also face coal-sector stress due to the competitiveness of renewables, and therefore managing existing coal power capacities needs to move to the forefront of climate and energy policy efforts.

INVESTORS AND THE ENVIRONMENT WILL BENEFIT FROM A COAL-PHASE DOWN PLAN

To turn this situation around, Chinese authorities should have a strategy for a managed phase-down of coal power assets. All new construction of coal power plants should cease: recent project cancelations have been a step in the right direction. A planned retirement schedule for old coal plants that have already made a return on investment should be developed to 2030. Existing, newer coal plants should be prepared to play a role and receive revenues for balancing a high renewables system. A managed 2°C-compatible climate mitigation scenario, in which old plant are retired after 30 years, both puts China's electricity sector on an accelerated pathway to decarbonization, as well as lowering the risks of stranded assets compared to the NDC-Style Scenario, by a total of 12 billion USD_{2015}.

INCENTIVES FOR STATE-OWNED ENTREPRISES IS KEY TO COAL TRANSITIONS

Banking sector exposure to stranded assets in the Managed 2°C Scenario are estimated at less than 10% of the banking sector's loan loss provisions: risks of financial disruption are manageable. State-owned enterprises' (SOE) lower cost of capital and lower profitability expectations could allow a faster transition out of coal. The key is to create incentives for them to halt investment, and phase out existing plant. A 'coal sector bad bank' could achieve this.

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EXECUTIVE SUMMARY

This study examines the financial health of the Chinese coal power sector, which is going through several significant transitions. Overinvestment and structural slowing of demand growth has led to a situation of severe overcapacity and declining load factors. Rapid growth of low-carbon electricity sources to meet energy transition and environmental objectives will put continued pressure on the coal power sector. Necessary reforms to electricity markets, and the introduction of a carbon market, will impact on the dispatch and margins of the coal fleet. Thus, the financial health of the coal power sector is an important concern for policymakers and industry today.

The financial health of the Chinese coal power sector is an important issue for climate policy. From a pure political economy perspective, it may be difficult to continue to expand low-carbon electricity at the rate required without parallel policies to manage the transition out of high-carbon forms of electricity generation. In this context, the issue of stranded assets is crucial. Furthermore, excessive capital impairment both on the utility and financial sector side may reduce the capital available to be invested in low-carbon sources.

It is also worth noting that the issue of avoiding stranded assets in the coal power sector is of relevance not only to China. While each country is different, the challenge of managing the transition from a significant share of coal-fired assets in the power sector to a lower share, particularly in a context of falling load factors and competitiveness of coal is of international relevance. This paper therefore explores this issue through the particular lens of the Chinese coal transition, but China is but one example of a broader phenomenon that is of relevance to climate mitigation and the transition away from coal in the power sector.

To shed light on these questions, this study created a model which simulated historical and future revenues, rates of return and net present value on a plant-by-plant basis for a representative sample of 421 GW of coal-fired plants in China. Results are then scaled to the size of the entire coal fleet constructed since 2005. The analysis is based on four scenarios:

- a counterfactual ***Reference Scenario***, assuming an implausible continuation of current conditions;
- a ***2°C Scenario***, assuming load factors and margins in line with a transition to a 2°C consistent power sector;
- a ***Managed 2°C Scenario***, as in the 2°C Scenario but additional efforts are made to halt new coal investment, accelerate the retirement of the coal fleet, and ensure the coal fleet is able to receive adequate remuneration for its contribution to balancing;
- an ***NDC-Style Scenario***, assuming load factors and margins in line with achieving China's NDC. This should be taken as the current policy scenario.

The assessment of the financial health and stranded asset risk of the Chinese coal-fired power fleet is complicated by its ownership and financing structure. 61% of installed capacity is entirely state-owned. Another 33% is mostly state-owned, through for example listed subsidiaries in which parent State-Owned Enterprises (SOEs) retain a controlling stake. The sector is highly leveraged with a debt share in the range of 60-80%, provided

Table E1. Numerical results of the scenario analysis, in billion USD2015

	Discount Rate								
	5%			6.5%			8%		
	NPV	Stranded asset value	Banking sector exposure	NPV	Stranded asset value	Banking sector exposure	NPV	Stranded asset value	Banking sector exposure
2°C	11.7	-155.6	-65.4	-46.2	-122.5	-51.4	-92.7	-98.0	-41.2
Managed 2°C	69.5	-97.8	-41.1	-2.3	-78.6	-33.0	-58.9	-64.2	-27.0
NDC-Style	54.3	-113.0	-47.5	-14.2	-90.4	-38.0	-68.3	-73.6	-30.9

largely by state-owned commercial and policy banks, lending at subsidized rates. It is estimated that the SOE interest rate was around 4.5-5% over the past 5 years.

On the other hand, the private sector weighted average cost of capital is in the order of 8% in the power sector. Ending distortions to capital allocation is a crucial policy lever for strictly limiting new additions and phasing out old, inefficient and unprofitable coal capacity. Evaluating coal-fired power investment on market-based criteria makes sense for assessing economic efficiency relative to alternative, higher yield investments.

For these reasons, we conduct the modelling of the coal-fired power sector with discount rates of 5%, 6.5%, and 8%. 6.5% is the central discount rate, i.e. roughly the cost of capital to the sector weighted by state versus private ownership and their respective costs of capital.

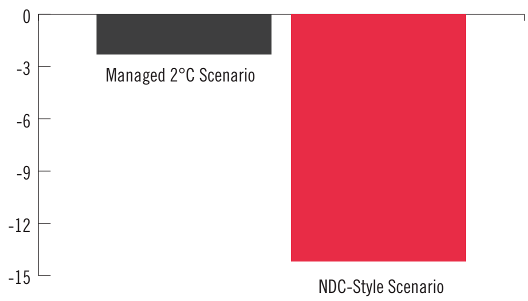
Table E1 presents the central results. The table presents, firstly, the cumulative Net Present Value (NPV) at the respective discount rates of the entire coal-fired power fleet since 2005 (a cumulative investment cost of some 500 billion USD_{2015}). Secondly, the table presents the stranded asset value of the respective scenarios, defined as the net present value asset write down between the scenario in question and the counterfactual Reference Scenario. Finally, the table present the banking sector exposure to this stranded asset value, defined according to known debt-equity ratios and assuming a 40% recovery rate for impaired assets.

Overall, one can draw four conclusions from the study's analysis.

First, the Chinese investment in coal-fired power has been tremendously wasteful, particularly when measured against market-based capital costs and the opportunity costs of other higher-yield investments. Using the central discount rate of 6.5%, the Chinese coal fleet is estimated to have a cumulative negative net present value (NPV) of -2.3 billion USD_{2015} in the Managed 2°C Scenario and -14.2 billion USD_{2015} in the NDC-Style Scenario. The sector is therefore already at high risk of generating stranded assets, independently of future climate policy.

Second, the presence of huge, new capacity of coal-fired power has undoubtedly increased the political economy challenges of transition towards a low-carbon power sector. However, the current policy trajectory (NDC-Style Scenario) is already itself negative for the coal-fired power sector, while the Managed 2°C Scenario *improves* on this outcome (see Figure E1). **There is therefore a clear financial rationale for strengthening the ambition of Chinese power sector transition to low-carbon sources, combined with a policy to manage the existing coal-fired fleet (see below).**

Figure E1. Cumulative net present value of the coal fleet, 6.5% discount rate, Managed 2°C Scenario versus NDC-Style Scenario, in billion USD_{2015}



Third, the stranded asset exposure of the banking sector to the coal-fired power sector is not itself a systemic risk. Current loan-loss provisions of the Chinese banking sector are estimated at 370 billion USD, which is sufficient to cover the estimated losses of the Managed 2°C Scenario (-33.0 billion USD_{2015}) or the NDC-Style Scenario (-38.0 billion USD_{2015}). The challenge is that the power sector is but one of the sectors having significant non-performing loans. But provided that generalized financial sector turbulence can be avoided, energy transition driven disruption would not pose a systemic risk to the financial sector. This provides a further argument for the feasibility of moving to an accelerated power sector transition.

Fourth, the ownership structure of the sector gives certain tools to the Chinese government to mitigate the stranded asset risk, rein in investment, and phase down coal power. China's SOEs can accept lower returns on investment than purely commercial players, due to their lower funding costs and lower profitability expectations. The challenge is to use this advantage to engineer an earlier transition out of existing coal, while at the same time exposing the SOEs to market incentives for new investment. Recent policy has essentially treated SOEs as providers of the public good of macroeconomic stability, privileging the provision of continued investment support to the Chinese economy over economic efficiency (hence the poor financial performance of coal investments shown in Table E1). But coal-fired power represents just 1% of total annual gross investment, and hence halting it would not have macroeconomic effects. On the other hand, clean air and climate mitigation are important public goods; delivering on them in China requires an accelerated transition out of coal.

The paper suggests four policy ideas to move forward.

First, further binding incentives are required to rein in the investment boom in coal-fired power. Coal-fired power investment continues unabated despite the manifest issue of overcapacity. Since 2013, net additions have averaged 60 GW, including 50GW as recently as 2016, while load factors have fallen by 8.5 percentage points. Recent 2017 announcements of freezes on coal-fired plant investments are a step in the right direction.

Second, in addition to halting new investment, the paper suggests that there is a strong financial case for a strengthening of tools to retire old plant. Policy makers could, for instance, consider setting longer-term targets towards 2030 for the retirement of old plant and for total installed coal capacity (which should decline by 2030 from the current level of 1027 GW). Coal-fired power should be brought within the purview of 'supply-side reform' in order to phase out excess capacity. We estimate that by 2030, around 22% of capacity built since 2005 would be amortized and could be considered for retirement, after a reasonable return on investment (figures from the Managed 2°C Scenario at 6.5% discount rate). Chinese policy-makers should conduct further microeconomic analysis to determine an acceptable "retirement schedule" for the coal-power fleet, without which expansion of low-carbon electricity in line with a 2°C pathway, or even the NDC pathway, appears difficult.

Third, investments need to be made to enable the coal-fired power sector to play a role, and be adequately remunerated for it, in balancing the grid in a high renewables system. Fiscal and/or financial support may be required to support the flexibilization of the coal-fired power fleet.

Fourth, active intervention may be required to restructure the balance sheets and governance of coal-sector SOEs. One such option would be for the Chinese government to consider the creation of a 'coal sector bad bank'. Legacy assets would be 'escrowed' within SOEs, and subject to lower expectations of rates of return (e.g. through lower dividend payments, loan forbearance etc.). New entities for new investments would be operationally separate, and subject to market-oriented discipline (market oriented lending rates, high dividend policies, etc.). By putting legacy assets into a 'coal asset bad bank' subject to more lenient rates of return, the Chinese government could benefit from the past privileges accorded to SOEs such as subsidized cost of capital, in order to hasten the transition away from coal. It would also improve the political economy, by separating out interests in coal-fired assets and new, low-carbon investments.

Finally, the results of this study are relevant for other jurisdictions as well. Coal-fired power is under pressure from several factors. Renewables are increasingly competitive with new and potentially in the future existing coal. Air pollution is a pressing problem in many jurisdictions. Climate change mitigation requires the accelerated phase down of coal. Thus, situations similar to that found in China may occur elsewhere in the coming years. It is crucial that policy-makers recognize early on the risks of stranded assets. It no longer enough today to have policies to support the entry of renewables: controlling investment in coal and even more managing existing capacities needs to move to the forefront of climate and energy policy efforts.

1. INTRODUCTION AND RATIONALE

In 2016, coal-fired electricity contributed 66.8% of China's total electricity production and 79.7% of total CO_2 emissions from fossil fuel combustion (Enerdata, 2017). At the same time, the coal-dominated electricity sector contributed significant shares to national emissions of local air pollutants, such as particulate matter (23%), SO_2 (45%), and NO_x (64%) (Yuan *et al.*, 2016). Transitioning away from coal towards low-carbon electricity sources is thus a crucial pillar of China's strategy to mitigate greenhouse gas (GHG) emissions and reduce local air pollution.

Hitherto, the focus of such strategies has typically been on policies to promote an increasing share of low-carbon sources in new generation capacity. **However, for several reasons the focus of China's electricity sector transition strategy must now shift towards including policies to manage retirement and operation of the existing installed coal capacity.**

1.1. Slower demand growth and concerns of oversupply

Between 2000 and 2010, China's final electricity demand grew at 13%/year, several percentage points above GDP growth. Between 2011 to 2016, that growth slowed significantly to 5.2%/year, and even more significantly in the period 2014 to 2016 to 2.8%/year. This is evidence of the macroeconomic transition known as the "new normal", characterized by slower headline GDP growth rates and a restructuring of the economy towards less energy-intensive sectors. Thus, from a situation in which adding new capacity to meet rapid demand growth was the primary concern, China is entering a prolonged period of slower energy and electricity demand growth (Spencer, Colombier, Wang, Sartor, & Waisman, 2016). At the same time, capacity additions have continued at a fast pace, including in the recent period 2014 to 2016. This in turn has led to a situation of oversupply in the Chinese electricity sector, evidenced by dramatically declining plant load factors for coal notably, although wind and solar capacity factors are below international benchmarks as well.[1] **Declining plant load factors may create financial concerns for generators (Zhao *et al.*, 2017), and hence potentially for the financial sector more broadly. Perhaps more significantly, a situation of overcapacity creates a more difficult political economy within the sector, as firms lobby for a share of generation and resist new entrants (Rüdinger *et al.*, 2014).**

1.2. Ambitious plans for the deployment of low-carbon electricity

Within this context, the Chinese government has ambitious plans for the deployment of low-carbon electricity sources to meet climate and clean air goals. By 2020, 350 GW of hydro capacity, 58 GW of nuclear, 230 GW of wind and 110 GW of solar PV are to be installed, according to government targets (Yuan *et al.*, 2016). By 2030, the share of non-fossil fuels should be at least 20% in the primary energy mix, which would necessitate a much higher share of non-fossil fuel sources in the electricity sector, in the order of 40-50% (Spencer *et al.*, 2015). **Unless the necessary massive entry of new low-carbon generation is combined with management of the existing thermal fleet, load factor and profitability risks could be exacerbated.**

1.3. Reforms to electricity markets and carbon pricing

Part of the reason for the recent investment boom in coal-fired power in China, despite overcapacity, is the structure of the Chinese electricity market. Electricity tariffs received by generators are regulated, and based on an operating cost plus return on investment model. As coal is a key input cost, generator tariffs are linked to the price of coal, which is deregulated. This adjustment is made with a lag, and thus in recent years the decline in coal price has not been passed through immediately into electricity tariffs. Thus, the price received by generators is not linked directly either to the generators' principle input cost, coal; nor to the demand-supply balance in the wholesale market. Furthermore, the Chinese dispatch model is not based on marginal generation costs, but rather the principle of "equal share dispatch". Under this model, regulators allocate equal generation hours to generators. The resulting dispatch is neither economically nor environmentally efficient, as costlier, emissions intensive plants run just as much as more efficient ones. **This lack of market-based investment and operational incentives contributed to the bubble in coal investment in recent years.**

In 2015, the Chinese government announced plans to move progressively towards a more market-based organisation of the electricity sector. This includes the creation of wholesale electricity markets to replace regulated pricing and "equal

1. Some of this may be due to grid connection and evacuation constraints, some due to the political economy of generators fighting for a share of demand.

share dispatch". Their introduction should be progressive, with pilot provinces required to go faster and further. Nonetheless, the expectation is that the share of competitively procured and dispatched generation will increase significantly. In a context of overcapacity, this shift towards competitive procurement and dispatch will lower the tariffs received by generators, as evidenced by significant tariff declines already seen in pilot provinces (Zhao *et al.*, 2017). Indeed, one of the objectives of the reforms is to lower electricity costs for industrial consumers, but the flipside of that will be more pressure on coal generators' margins. Moreover, the move to more economic dispatch will redistribute revenues among more efficient and less efficient generators (RAP, 2016).

At the same time as these electricity market reforms, the Chinese government is implementing a national carbon market from 2017. This will likewise have an impact on the merit order of dispatch, reducing the running hours and hence profitability of less efficient versus more efficient coal power plants, and of low-emissions plants versus coal plants. Assuming auctioning of permits, carbon pricing would raise input costs to generators, which may be more difficult to pass on to consumers in a context of overcapacity.

The sum trend of these policy changes is likely to exacerbate the squeeze on coal generators' margins, which may further impact on the profitability of coal-fired power plants in the context of low load factors (Zhao *et al.*, 2017).

1.4. Objectives of this paper

Within this context, there has been increasing interest in the microeconomics of Chinese coal-fired power plants (Zhao *et al.*, 2017), the risk of stranded assets in the Chinese coal power sector (Caldecott, Dericks, *et al.*, 2017), and policy approaches to manage the closure of coal-fired power plants in China (Robinson & Xin, 2017). However, there are gaps in the existing literature. Zhao *et al.* (2017) examined the micro-economics of a coal power plants, but their approach does not allow a feedback loop between scenarios on overall demand and generation capacity, retirements schedules of existing plants, and the margins on coal generation in the light of above-mentioned policies on electricity markets and carbon markets. Caldecott *et al.* (2017) provide a very comprehensive analysis of environment and market risks factors faced by Chinese coal-fired power generators. However, their scenario analysis of the magnitude of the stranded asset risk for Chinese coal-fired power plants is highly stylized, assuming that all existing and planned coal-fired power plants are completely stranded over an arbitrary 5-year, 10-year, 15-year or 20-year period. Nor do they examine the impact of the above identified factors, such as the overall demand/supply balance and resulting load factor, or impact of electricity market or carbon market reforms on generation margins.

The objective of this paper is to take forward this literature. It addresses the following questions:

- Under plausible scenarios for the development of the demand/supply balance, load factors, and generation margins, what is the profitability of Chinese coal-fired power plants and the scale of potential asset stranding?
- What policies could be deployed to limit the political economy frictions of power sector transition in China, in particular to avoid either: i) a situation in which the political economy of a system under overcapacity slows down the deployment of low-carbon sources; or ii) unmanaged transition leads to large-scale, disruptive asset stranding?
- What would be the potential economic retirement schedule of Chinese coal-fired power plants, given the modelled investment costs, load factors, and margins? Put more simply, how quickly could China get out of coal power?

The paper is structured as follows. Section 2 presents the methodology, including its rationale and limitations. Section 3 presents the numerical scenario results. Section 4 provides conclusions and a discussion of the implications of the results for policy.

Box 1. This paper within the context of the Coal Transitions Project

- The *Coal Transitions Project* is a large-scale, multi-country project examining pathways and policies to transition away from coal in the interests of mitigating climate change and achieving sustainable development. Initial outputs have examined policies to reduce impacts of coal transition on affected social groups, in particular workers and mining communities (Caldecott, Sartor, *et al.*, 2017). The present study is a preliminary assessment of the issue being addressed in the project with respect to China, namely stranded assets and transition pathways in the coal-fired power sector. A companion paper to be published by the end of 2017 by Tsinghua University will provide an even more detailed assessment, including a more comprehensive methodology overcoming the shortcomings of the present approach explained in Section 2.
- For more information on the project, see www.coaltransitions.org

2. METHODOLOGY

The starting point of the methodology is a plant-by-plant assessment of historical and future profits received by coal-fired power plants in China, under different scenarios. This allows in turn an assessment of coal plants' return on investment, amortization schedule, and potential stranded assets. The following sections detail the data sources taken for the plant-level information, information on investment costs, load-factors and generation margins, scenario architecture and central assumptions, the model's structure and calculation methods, and limitations and weaknesses of the approach.

2.1. Plant-level data

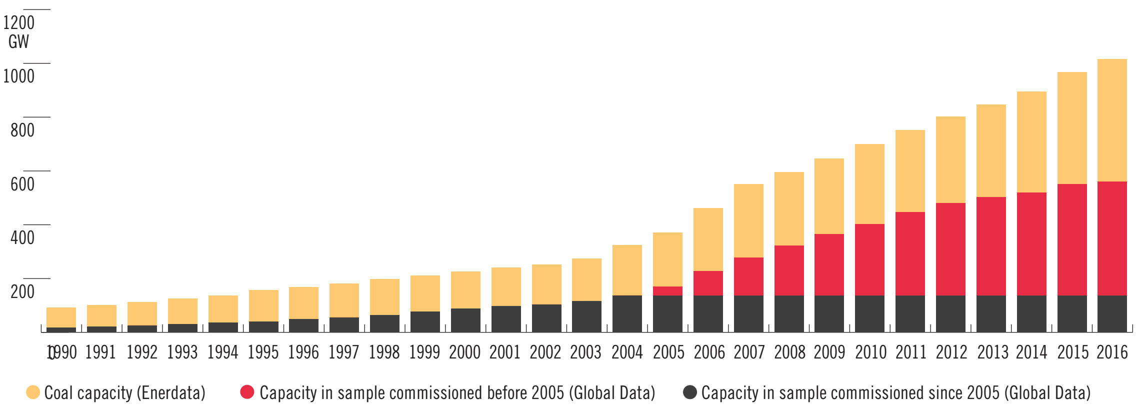
Plant-level data was derived from the GlobalData database of coal-fired power plants (GlobalData, 2017). This provided information regarding the year of commissioning and capacity installed for each plant. It should be noted that the database is constructed from secondary sources (press releases, company reports, etc), and contains only a subset of Chinese coal-fired power plants. Primary data sources such as the China Electricity Council (CEC), supplied in Enerdata (2017), provide total installed capacity for Chinese coal-fired power plants, and this was used to compare the extent to which the GlobalData plant level database covered net capacity additions to the Chinese coal fleet (Figure 1).

The sample includes 61% of net capacity additions to the Chinese coal fleet since 2005. The missing capacity may be due to three reasons: i) the capacity is not captured at all in the GlobalData base; ii) we exclude from our sample smaller CHP plants and captive power plants, as their economics will be different from electricity only plants; iii) the plants are included in the GlobalData database but without a known commissioning date, and are therefore excluded from our database. We are thus left with a sample of 421 GW of coal-fired capacity installed since 2005 with known installation dates and capacity sizes. We focus in this analysis on plants commissioned since 2005 since i) older plants are likely to be amortized already; ii) information on commissioning date and operating conditions such as margins on generation becomes less complete and robust before 2005; iii) plants installed since 2005 represent some 70% of total cumulative capacity to-date. **This sample is representative of the larger fleet installed since 2005 and conclusions drawn based on this sample are therefore scaled to the entire fleet constructed since 2005**.

2.2. Investment costs

The GlobalData database contains investment costs for 39 plants installed since 2005, gleaned from secondary sources such a press releases and company reports. This data contains no marked temporal trend, indeed there is a slight deflationary trend in real terms since 2005. There is a clear difference between large and smaller plants, however. This allows us to make assumptions regarding the investment cost of each plant in the sample described in Section 2.1 above. We assume overnight costs of USD2015 710 per kW for plants above 500 MW and USD2015 850 per kW for plants below 500 MW. Overnight costs assume a 6.5% interest rate across a ca. 2-year construction period. These results compare favourably with the IEA/NEA Projected Costs of Generating Electricity Study, which give a figure of 813 USD per kW, albeit derived from a sample of one plant (IEA and NEA, 2015).

Figure 1. Cumulative capacity and sample

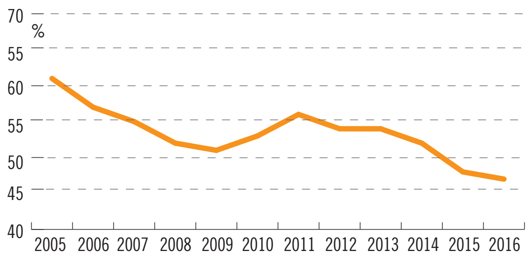


Source: authors based on (GlobalData, 2017) and (Enerdata, 2017)

2.3. Load factors

An important limitation of the approach in this paper relates to the information regarding load-factors. Ideally, given that the plant-by-plant data is geographically specific, one would use a provincial load factor. However, this comes against two limitations. Firstly, to our knowledge historical provincial load factors are not available in the public domain. Secondly, as we are projecting forward market conditions at least 30 years from now, making provincial projections of load factors would require taking numerous assumption regarding provincial growth rates, demand and supply balance, as well as regional interconnections and electricity trade. In order to simplify the analysis, we use a single fleet-wide load factor for the historical period from 2005 derived from coal capacity and generation data taken from Enerdata (2017). For load factors used in the simulation of future periods see Section 2.5 below.

Figure 2. Fleet-wide load factor for coal power



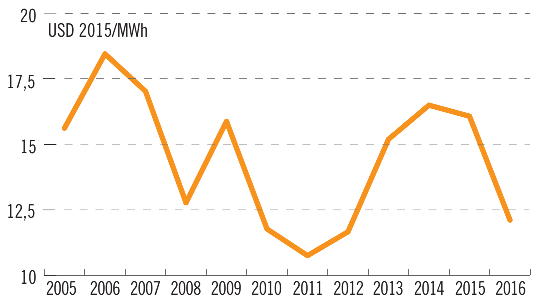
Source: authors based on (Enerdata, 2017)

2.4. Margins on generation

We use company reports from listed Chinese utility to calculate margins on electricity generated for the historical period, by subtracting the reported input costs (coal procurement, wages, depreciation, etc) from the reported tariff received on electricity generated. Both input costs and tariffs received on electricity generated are defined in terms of weighted utility fleet-wide averages, and therefore we can extrapolate from this to the country-wide fleet.

For projected margins on electricity over the future projection period, it was not possible to calculate them endogenously in the model. On the one hand, neither plant level thermal efficiency data nor sufficiently disaggregated demand data is available in the public domain to construct supply and demand curves. In addition, such modelling would require making strong assumptions about the consequences for coal generators' margins arising from future regulatory changes introduced by the electricity market reform agenda and carbon pricing. For example, it is still uncertain the extent to which economic-based dispatch (so-called merit-order dispatch) will replace or not in the future the current dispatch model based on the allocation of a guaranteed quota of annual running hours for each power plant.

Figure 3. Fleet-wide margin on electricity generated



Source: authors based on company reports

However, both regulatory evolutions go in the same direction and will pressure coal producer's margins. Carbon pricing reduces more coal-fired margins compared to less emitting technologies in a competitive environment. Regarding electricity market reforms recent political pronouncements opened the door for pilot regions to experiment market-based dispatch, create institutions to prioritize the dispatch of fast-growing clean energy, and encourage energy companies to dispatch more efficient plants first (Kahrl, Dupuy, & Wang, 2016). We therefore consider likely that coal power producers' margin will diminish in the future compared to historical data and use the minimum historical annual margin observed as a good estimate of future margins on coal power produced, namely 10.75 USD_{2015}/MWh in 2011 (see Section 2.5). A sensitivity analysis is conducted around this assumption, see Box 2.

2.5. Scenario architecture

This section presents the scenario architecture for the simulations of the future period. This comprises of two key elements:

- Assumptions about the demand/supply balance in the Chinese coal fleet and resultant load factors.
- Assumptions about the margins received on generation.

In the absence of an electricity simulation model (see Section 2.7 for a discussion of the limitations of the approach), these assumptions must be made exogenously, but in such a way as to ensure the internal consistency of each scenario. The starting point for assumptions about the demand/supply balance and load factors is the IEA 450 ppm (2°C Scenario) and New Policies Scenario (NDC-Style Scenario from the 2016 *World Energy Outlook*). We make exogenous assumptions about the margins received on generation based on the load factor in each scenario (assuming that lower load factors would lead to lower margins in the presence of reforms to increase the competitiveness of Chinese electricity markets – see above), and the degree of progress on the market reforms described above. Such assumptions are informed by the literature on the impacts of these reforms described in Section 1.3 above.

Three scenarios are assessed in the paper, and one counterfactual Reference Scenario:

- *Reference Scenario*: this scenario is a counterfactual in that it is neither plausible nor internally consistent. It is not presented in detail in the paper, but is used as a reference against which to compare the results of the other scenarios. In the Reference Scenario, conditions are frozen as of 2016 in terms of the coal plant load factors and margins. As noted above, this is unlikely, as many factors including policy and further investment will change the demand and supply balance in the Chinese electricity system and margins on generation.
- 2°C *Scenario*: this scenario assumes that electricity demand and generation capacities develop as per the IEA 450 scenario, leading to a sharp decline in coal plant load factors to 35% in 2030. Concurrently, lower load factors and electricity and carbon market reforms squeeze margins down to 10.75 USD_{2015}/MWh.
- *Managed 2°C Scenario*: in this scenario, assumptions are as per the 2°C Scenario, but with additional policies to manage the transition in the existing coal fleet. No new coal plants are assumed after 2017, and all plants are retired after 30 years. This leads to a moderate rise in plant load factors to 38% by 2030, and rising further thereafter. At the same time, it is assumed that margins on electricity generated decline due to lower load factors (as in the 2°C Scenario) but are complemented by revenues for the provision of balancing services. In this scenario, margins average 12.95 USD_{2015}/MWh across the projection period.
- *NDC-style Scenario*: demand and capacities develop as in the IEA New Policies Scenario, leading to a load factor of 45% in 2030 (compared to 46% in 2016). Concurrently, low load factors and market reforms push margins down to 10.75 USD_{2015}/MWh.

2.6. Structure and calculation of the model

The model represents each plant individually since the year of commissioning, and calculates its profits annually based on its running hours and the margin received on generation, as calculated based on the methodology described above. Profits are discounted based a discount rate of 5%, 6.5% and 8% from the year of commissioning. 6.5% is considered as the central discount rate to be applied to the scenarios, with the other values being sensitivity analyses. Further discussion around this important parameter in the context of the ownership and financing structure of the Chinese coal-fired power fleet is provided in Section 4.

2.7. Limitations of the methodology

There are clearly several limitations of the methodology:

- The model does not spatially disaggregate load factors and margins based on geographical location of the plants. For the historical period, this does not matter so much as regulated pricing meant that generators received comparable margins in different geographies, even if input costs diverged. It matters for the historical calculation of load factors, as significant regional disparities already existed. However, as mentioned above, the lack of historical data and the challenge of projecting provincial load factors several decades hence necessitate this simplifying assumption.
- The model does not endogenously calculate margins (see above). Ideally, one would have calculated margins based on a supply curve built from the plant-by-plant database and an annual demand curve. However, in the absence of plant-level efficiency data it is not possible to construct a supply curve. In addition, endogenously calculating margins requires far-reaching assumptions about the degree of electricity market and carbon market reforms. Thus, one cannot escape from the need to make assumptions, and therefore the transparent scenario architecture described above provides a good basis to analyse different broad directions of policy.
- The model does not calculate dispatch for each plant based on their cost of supply determined by input costs and thermal efficiencies. As mentioned above, thermal efficiency data is absent from the GlobalData database.

Nonetheless, the methodology is useful. It allows a macro-level analysis of the profitability of the Chinese coal fleet under different transparent assumptions. The results generated can be thought of as an 'fleet-wide average' under the different scenarios, abstracting away from the differences between provinces or more or less efficient plants. **Given the future uncertainty around electricity demand growth, capacity additions, and the extent of electricity and carbon market reform, a more complex model set-up may not necessarily increase robustness. There is value in having a set of simple, transparent, contrasting scenarios aiming at framing the broad contours of the problem and solutions for policy-makers.**

3. SCENARIO RESULTS

3.1. 2 °C Scenario

This scenario examines the consequences for Chinese coal-fired power plants of the internationally agreed 2°C scenario, assuming no other mitigating policies are put in place to manage the transition in the coal sector. The two main drivers of this scenario are as follows: firstly, the necessary massive scale up of low-carbon electricity supply significantly depresses the load factor for coal-fired power plants; secondly, the combination of low-load factors, electricity market reform and carbon pricing is assumed to squeeze margins on generation downwards.

Figure 4 represents the internal rate of return (IRR) for coal-fired power plants in the sample under this scenario. The x-axis represents the year of commissioning for the plants in question. A benchmark rate of return for the sector of 6.5% is also shown (cf. Zhao *et al.*, 2017). Two other benchmark rates of return are shown as well, namely the interest rate estimated for SOEs of 5% and the private sector weighted average cost of capital (WACC) for the power sector. These assumptions are discussed further in Section 4.

A significant majority of plants within the sample fall under the sector specific benchmark rate of return of 6.5% across their 30-year lifetime. Only larger plants, constructed early in the period 2005-2016 fall above this benchmark rate of return, since they have been running since 2005 during a period of higher load factors and margins. Plants above 500 MW have an average IRR of 5.29%, while plants below 500 MW have an average IRR of 3.68%. Plants constructed recently are projected to have very low IRRs. On the other hand, if the SOE benchmark rate of interest is taken then the IRR of most of the coal plants looks somewhat better, although larger plants of >500 MW constructed in the second half of the period 2005-2016 still fall under this benchmark. On the other hand, the entire fleet fall under the private sector benchmark rate of return of 8%.

Figure 5 shows the cumulative amortized capacity across the projection period under different discount rates of 5%, 6.5%, and 8%. It should be born in mind that the sample size of plants in the model is 421 GW. Thus, Figure 5 shows that under a discount rate of 6.5%, less than 15% of the sample's capacity would be amortized by 2030, rising to just over 23% by 2040. This gives a sense of by when, from a social planner's perspective, plants could be retired from the system after amortization and then some return on capital.

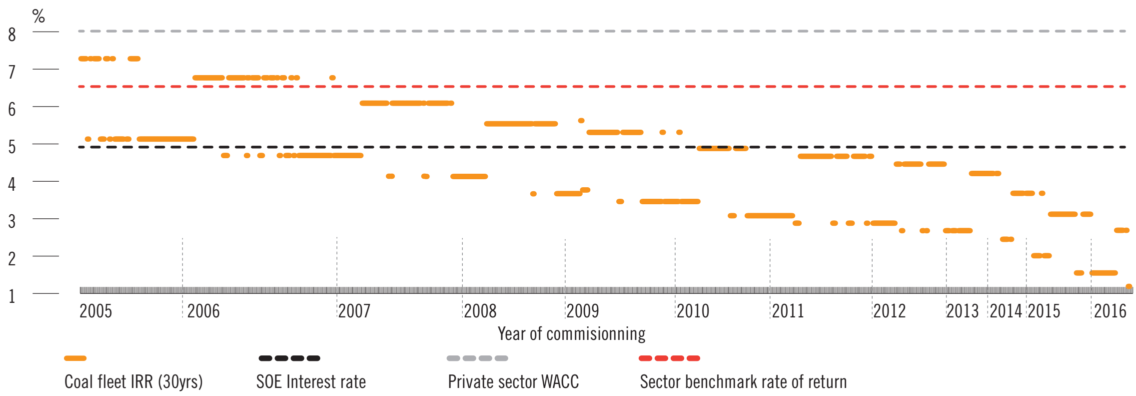
We define stranded assets as assets that are unable to recover their investment costs as intended over the technical lifetime of the asset and consequently lose economic value over time. Based on the investment costs given in Section 2.2, we estimate that the total investment in Chinese coal-fired power capacity since 2005 has been 504.5 billion USD_{2015}. It should be noted that this figure and subsequent figures here are for the entire net capacity constructed since 2005, which was obtained by multiplying the results for the sample in the model by the ratio of total capacity additions over capacity additions in the model. Figure 6 shows the estimated net present value (NPV) of the Chinese coal power fleet constructed since 2005 at their year of commissioning under the 2°C Scenario across a 30-year plant lifetime, at the different discount rates used in this study.

3.2. Managed 2 °C Scenario

In this scenario aggressive measures are assumed to be taken to halt the building of new coal-fired power plants and to retire plants after a 30-years lifetime. Likewise, it is assumed that complementary revenues are received by coal-fired power plants for the provision of balancing services in the context of an increased renewable share of the power mix. Balancing services refer to the service provided by reserves to ensure the necessary equilibrium between supply and demand in the power grid on a short time scale (seconds to hours). Wind and solar energy are different from conventional power as they only produce when the wind blows and the sun shines. In a high renewables system, reserves are required to offset forecasting errors, which increase the need to withhold capacity and activate it. This in turn increases balancing costs, composed usually of a capacity payment to reserve the capacity and an activation fee.

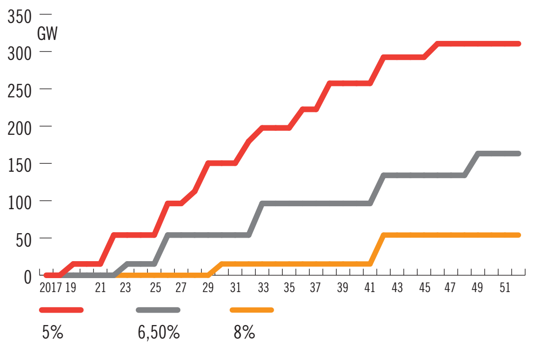
Estimating the cost of balancing services is difficult, as it requires several assumptions about how power plant dispatch and balancing are organized (market-based or administrative); the level

Figure 4. IRR for coal-fired power plants, 2°C Scenario



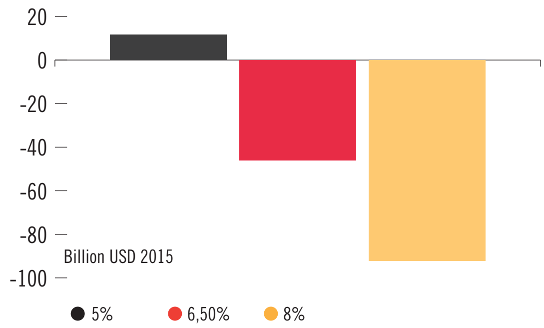
Source: authors' calculations

Figure 5. Cumulative amortized capacity under different discount rates, 2°C Scenario



Source: authors' calculations. N.B sample size is 421 GW

Figure 6. Net present value of coal-fired power fleet since 2005 at different discount rates, 2°C scenario, billion USD2015



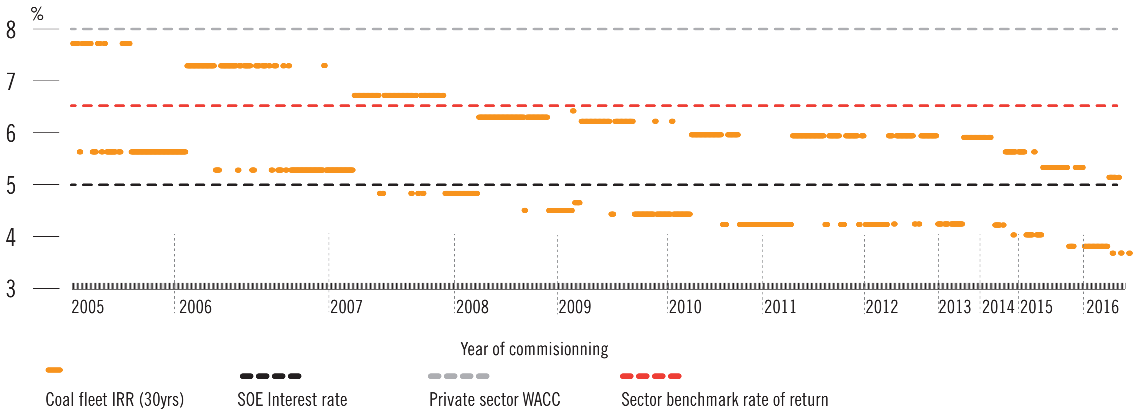
Source: authors' calculations

Table 1. Illustrative calculation of balancing services value of the coal-fired power fleet.

Item	Unit	Source		2020	2025	2030	2035	2040
Total generation	TWh	IEA 450 scenario	A	6601	7235	7869	8360	8851
Coal generation	TWh	IEA 450 scenario	B	3950	3278	2606	1993.5	1381
Variable RES	TWh	IEA 450 scenario	C	675	1197	1719	2155.5	2592
% share variable RES	%	IEA 450 scenario	D	10%	17%	22%	26%	29%
Balancing costs	USD/MWh	Estimation based on i)	E	4	6	8	8	8
Balancing costs, total	Million USD	C*E	F	2700	7182	13752	17244	20736
% share of coal in dispatchable generation	%	B/(A-C)	G	67%	54%	42%	32%	22%
Balancing value of coal	USD/MWh	G*D/B	H	0.46	1.19	2.24	2.78	3.31

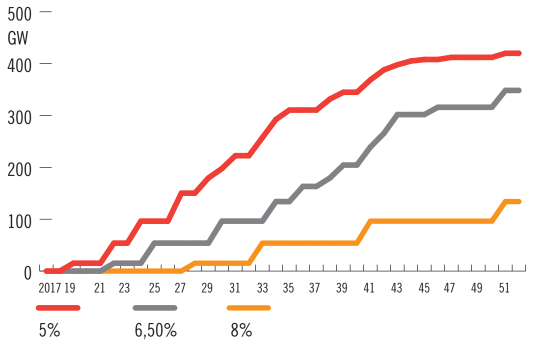
Source: authors' calculations, i) (Agora Energiewende, 2015)

Figure 7. IRR for coal-fired power plants, Managed 2°C Scenario



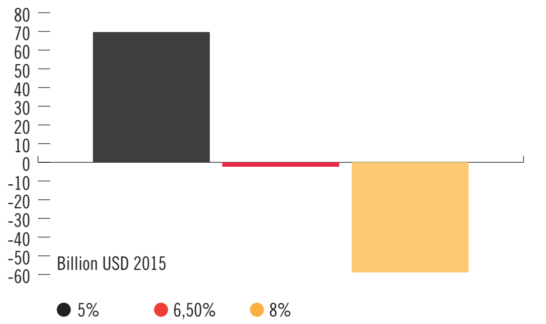
Source: authors' calculations

Figure 8. Cumulative amortized capacity under different discount rates, Managed 2°C Scenario



Source: authors' calculations. N.B. sample size is 421 GW

Figure 9. Net present value of coal-fired power fleet since 2005 at different discount rates, Managed 2°C scenario, billion USD2015



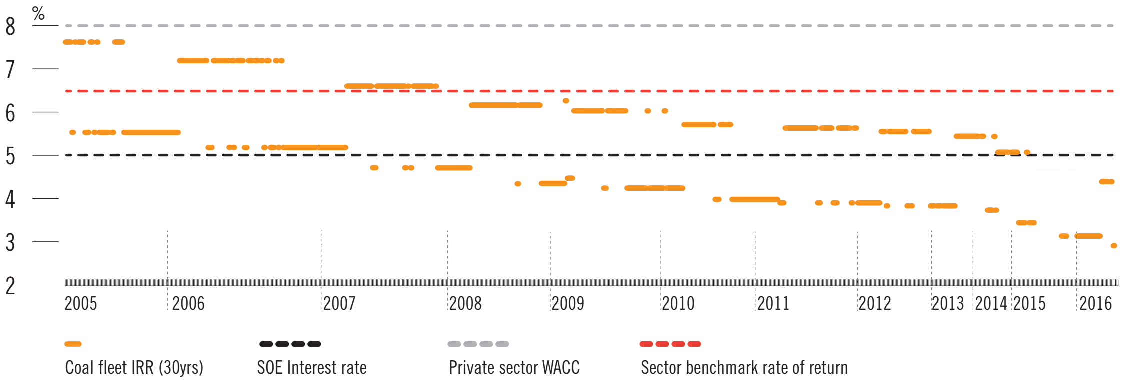
Source: authors' calculations

of forecasting error and the potential to reduce it through the aggregation effect; and other flexibility solutions in the system on the supply and demand side. All this will determine the efficiency of balancing and the value that power plants can extract from being flexible. So far, the literature suggests that balancing costs can be relatively low, even with high penetrations of variable renewable energy. A meta-study conducted by Agora Energiewende (2015) estimates that "…in power systems with mostly thermal plants, balancing costs are estimated to between zero and 6 EUR/MWh [7 USD/MWh], even at wind penetration rates of up to 40 percent". On this basis, we can conduct a thought experiment to assess the complementary balancing revenues that coal-fired power plants might receive.

Given that China is still at an early stage of the move to a market-based approach for its electricity system, we use conservative assumptions regarding the cost of balancing. We assume that balancing costs reach 8 USD/MWh by 2030, for a variable renewables penetration of 22%. Less conservative assumptions would suppose that the Chinese power market and coal-fired plants can quickly be optimized to ensure the depth, liquidity and efficiency of balancing markets, resulting in lower balancing costs than assumed here. Table 1 presents this illustrative calculation. The calculation assumes that the coal fleet receives a share of balancing costs estimated for the penetration of renewables seen in the 2°C Scenario, proportional to its share in total dispatchable generation. The estimated value of balancing services for coal-fired generation is ca. 2.24 USD/MWh by 2030. This compares with the delta of 4 USD/MWh between the assumed margin on generation in the 2°C Scenario (10.75 USD/MWh) and the margin on generation prevalent today (14.75 USD/MWh).

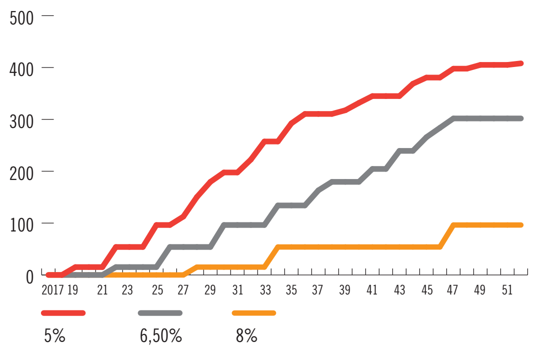
Let us now assume that the coal-fired power fleet receives the generation margin of the 2°C Scenario (10.75 USD/MWh), plus the value of balancing services provided by coal power (estimated

Figure 10. IRR for coal-fired power plants, NDC-Style Scenario



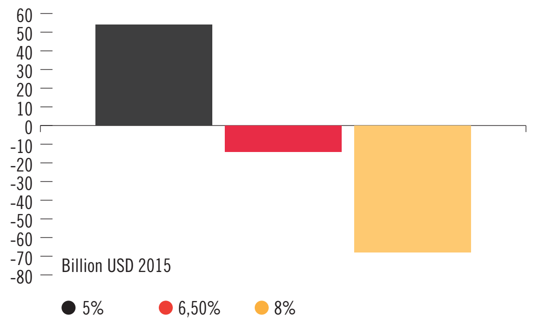
Source: authors' calculations

Figure 11. Cumulative amortized capacity under different discount rates, NDC-Style Scenario



Source: authors' calculations. N.B sample size is 421 GW

Figure 12. Net present value of coal-fired power fleet since 2005 at different discount rates, NDC-Style Scenario, billion USD_{2015}



Source: authors' calculations

at 2.24 USD/MWh in 2030). Figure 7 and Figure 8 present the results of this scenario. The scenario improves the situation somewhat for the coal-fired power fleet. The average IRR for plants above 500 MW is 6.35%, compared to the sector specific hurdle rate of 6.5%; for plants below 500 MW it is 4.71%. Figure 8 shows that by around 2030, only around 23% of the existing plant capacity is amortized, assuming a 6.5% discount rate. This rises to about 49% by 2040.

Figure 9 shows the results in terms of the NPV of the coal-fired power fleet under different discount rates in the Managed 2°C Scenario. NPV at 6.5% discount rate is still negative, at -2.3 billion USD_{2015}, albeit improved compared to the 2°C Scenario. The stranded asset value compared to the counterfactual Reference Scenario is -78.6 billion USD_{2015} at a 6.5% discount rate.

Box 2. Sensitivity of results to assumptions about margins

- As noted above, a weakness of the model is that assumptions on generation margins are exogenous, due in part to the complexity of projecting forward uncertain market conditions in the longer-term and the unavailability of data. In this text box, we conduct a sensitivity test regarding assumptions about margins generated. To do so, we take the Managed 2°C Scenario and a discount rate of 6.5% as the central case. We assume that margins across the projection period are sustained at i) their historical high of 18.46 USD_{2015} ii) levels seen frequently in European markets suffering from overcapacity, namely 8 USD_{2015}. Unsurprisingly, the sensitivity analyses have a significant impact on the cumulative NPV of the coal-fired fleet:
  - Managed 2°C Scenario, 6.5%, sensitivity i): 96 billion USD_{2015}
  - Managed 2°C Scenario, 6.5%, sensitivity ii): -69.8 billion USD_{2015}
- The sensitivity analyses reveal to what extent electricity market reform would have a significant distributional impact on the Chinese economy. In a competitive market, the marginal

price should be the cost of generation of the most expensive supplier required to meet demand. In a situation of overcapacity, a large share of plant would operate at or close to the margin, receiving therefore low margins on generation or not running at all. The corollary of this is that wholesale electricity prices for consumers would be low. On the other hand, in the kind of scenario represented by sensitivity analysis i), investors in coal-fired power plant are probably being remunerated above the marginal cost of supply. This would raise costs for consumers, but protect investors. The sensitivity analyses highlight that there is 'no free lunch': in a situation of overcapacity, either investors lose revenues or rate-payers (or tax-payers) pay for electricity above the marginal cost of supply. How the Chinese government handles this distributional issue will be crucial for the issue of stranded assets. The fact that the vast majority of capacity is state-owned and given the mandate of SOEs to provide social goods like macro-economic stability (including industrial competitiveness), it is reasonable to expect that power producers may bear much of the burden of cleaning up the overcapacity issue. Hence, our core assumptions of declining margins across the projection period appear reasonable.

3.3. NDC-Style Scenario

Limiting warming to well-below 2°C is the globally agreed objective under the Paris Agreement. However, countries' aggregate commitments do not yet add up to a pathway to 2°C. It is useful, moreover, to examine a 'current policy' trajectory, as this itself might comprise risks and challenges. **An unstable *status quo* can be one further motivation for strengthening well-designed policy towards the 2°C objective.** Comparing the 2°C Scenario and the NDC-Style Scenario can give an indication of the impact of moving to a 2°C pathway, compared to the current trajectory.

In this section, we present the results of the NDC-Style Scenario. This takes as its central assumption the demand-supply balance in the electricity sector seen in the IEA New Policies Scenario (NPS). Under this scenario, the share of zero-carbon generation rises to 42% in 2030, and the share of coal generation falls to 51% in the same period. The load factor for the coal fleet reaches 45% in 2030 (compared to 46% seen in 2016), as total coal generation grows by 9% between 2016 and 2030 and installed coal capacity by 11%. In the face of prolonged low capacity factors for coal, as well as electricity and carbon market reforms discussed in Section 1.3, the margin on generation is assumed to fall to 10.75 USD_{2015}.

Figure 10 shows the IRR for coal-fired power plants on a 30-year horizon. The average IRR for plants above 500 MW is 6.09%, for plants below 500 MW capacity it is 4.47%. Figure 11 shows the cumulative amortized capacity under this scenario, at different discount rates. Interestingly, the trajectory of amortization does not differ radically from that in the 2°C pathway in the shorter-term, because the capacity factors between the two scenarios diverge less in the short-term than in the longer-term. Under the 6.5% discount rate, 23% of capacity is amortized by 2030, rising to 43% by 2040.

Figure 12 shows the cumulative NPV of the Chinese coal fleet under the NDC-Style scenario. At a 6.5% discount rate the NPV of the fleet is estimated to be negative, at - 14.2 billion USD_{2015}. The stranded asset value for the NDC-Style scenario is estimated to be -90.4 billion USD_{2015} at the 6.5% discount rate, which is higher, interestingly, than the estimated stranded asset value of the fleet in the Managed 2°C Scenario. **This shows that the *status quo* itself is distinctly negative for the coal fleet, and that a deliberate and careful policy to manage the transition towards a scenario with higher climate ambition need not lead to worse outcomes for the coal fleet.**

4. DISCUSSION

4.1. "Chinese characteristics" in the power sector and implications for the results

4.1.1. Ownership and financing structure of the Chinese coal-fired power sector

The Chinese coal-fired power sector is dominated by the state-owned sector. According to the study by Hervé-Mignucci, Wang, Nelson, & Varadarajan (2015), some 61% of installed capacity is entirely state-owned. Another 33% is mostly state-owned, through for example listed subsidiaries in which parent State-Owned Enterprises (SOEs) retain a controlling stake (so-called ListCos). SOEs experience different incentives to private corporations, both in terms of input costs (in particular for our analysis, the weighted average cost of capital, as well as subsidized costs for other factors of production) as well as expectations regarding profitability (e.g. lower dividend payments to the government than private sector players, capital recycling of dividend payments back to SOEs, loan forbearance from the state-owned banking sector). It is therefore important also to understand the financing structure of the Chinese coal-fired power sector. Firstly, the sector is highly leveraged with a debt-equity ratio in the range of 60-80% debt. Secondly, SOEs tended to provide the bulk of equity capital. Thirdly, on the debt side the bulk of debt has been provided from the big 5 state-owned commercial banks, with state-owned policy banks also playing an important role. The state-owned banks lend to SOEs at subsidized rates relative to benchmark rates, and indulge in significant forbearance regarding non-performing loans.

All of this is consistent with the state-owned sector essentially playing the role of 'automatic stabilizer' of the economy since the global financial crisis (Batson, 2016), holding up rates of investment and hence economic growth. The problem is when this leads to a build-up of overinvestment and potential financial risk, as seen in the coal-fired power sector. This section aims to analyse some of these issues and how they relate to the results presented in preceding sections.

Data suggest that SOE costs of capital could be in the order of one percentage point lower than comparable peers, while enjoying credit ratings 2-3 notches higher thanks to implicit state guarantees and other privileges (Maliszewski *et al.*, 2016). This is important for our purposes: the hurdle rate used in the analysis above should approximate the sector's cost of capital to form an appropriate benchmark for investment decisions. In turn, the results above are significantly influenced by the hurdle rate/discount rate that is applied to the modelled future cash-flows.

Maliszewski *et al.* (2016) estimate the SOE interest rate to be around 4.5-5% over the past 5 years. China has a high savings rate, which contributes to a low domestic cost of credit. Since 2003, nominal yields on ten years maturity government bonds have always navigated between 2.8% and 4.5%, translating in real yields below 2.5 % in most of the period except for the year 2009. For this reason, we conducted a sensitivity analysis using a discount rate of 5% in the preceding Section 3.

4.1.2. Money for nothing and your coal for free: Why it may make sense to evaluate the coal-fired power sector on market-based terms

There is a lively debate within the macroeconomic literature as to whether China's high rate of investment and credit growth is a macroeconomic and financial risk (see notably the discussion between Chinese authorities and the IMF in the 2017 Article IV review of China – [IMF, 2017]). Maliszewski *et al.* (2016) summarize this debate well:

> *"Some 'China watchers' regard the fast credit growth as benign, arguing that this is a reflection of high and stable domestic savings channeled to investment. Others are sceptical, pointing to cross-country evidence of severe fallouts from similar credit booms, evidence of overcapacity in several industries, and deteriorating profitability in the corporate sector. This suggests that capital has been misallocated, the current growth model is not sustainable, and China will have to deal with the debt overhang problem."*

For our purposes regarding investment in the coal sector, three arguments are relevant to this broader macroeconomic debate:

- *Climate policy*: Hervé-Mignucci, Wang, Nelson, & Varadarajan (2015) argue that the availability of cheap financing was a significant driver of the boom in coal-fired power plants. Although steps are being made to rein in investment in coal-fired power plants, significant net additions were still being made as recently as 2016 (50 GW). From the perspective of strictly limiting new additions and phasing out old, inefficient and unprofitable capacity, ending distortions to capital allocation is an important policy lever.
- *Opportunity cost*: while a lower cost of capital may increase the attractiveness of a given portfolio of investments, persistent distortions in capital allocation will lead to wasteful investment and lower returns from that investment. This is certainly occurring in China. Thus, evaluating coal-fired power investment on market-based criteria makes sense from the point of

evaluating its economic efficiency relative to alternative, and likely higher yield investments. Indeed, the Government of China has introduced attempts at market oriented incentive structures within SOEs, for example performance evaluation based on the concept of Economic Value Added (the return on capital invested should exceed the cost of capital).

- *Performance problems*: even compared to a lower hurdle rate of 5%, there is still a significant share of coal-fired power plants having a lower IRR, particularly for plants built more recently and in the worse-performing scenarios (e.g. 2°C Scenario or NDC-Style Scenario). Thus, while the cumulative NPV in the scenarios may still be positive, this nonetheless hides significant under-performing investments.

For these reasons, the preceding analysis of Section 3 used a sensitivity analysis of an 8% discount rate, which approximates the private sector power utility cost of capital (see Table 3 below). In addition, the following section undertakes an analysis of Chinese coal-fired power, focusing on the market-based criteria and information generated by corporate disclosure by the majority state-owned listed utilities (ListCos).

4.1.3. Comparing scenario results to market-based financial performance metrics in the Chinese power sector

In this section, we analyse current profitability of listed Chinese power sector companies. Table 2 presents a commonly used profitability ratio for leading Chinese power sector companies from 2012 to 2016. This ratio is Return on Capital Employed (ROCE), which measures earnings before tax and interest divided by capital employed. Capital employed is defined as the sum of shareholder equity and outstanding debt liabilities. ROCE is a useful indicator: it should be higher than the company's weighted cost of capital (WACC) if the company's capital is to be considered as productively employed. Annex 1 in Section 6 contains the full list of companies aggregated in Table 2 below.

Several conclusions can be drawn from the data presented in Table 2. Firstly, the ROCE of Chinese private sector power utilities has averaged 7.63% over the last five years since 2012, and has been on a declining trend. In 2016, it averaged 5.02%. This value can be compared to the modelled internal rate of return of the Chinese coal powered fleet in the above scenarios in Section 3: in the the NDC-Style Scenario, the average IRR of the coal power fleet is 5.34%. Thus, the results of the NDC-Style Scenario suggest a continuation of the current situation of power sector stress, with a low ROCE. Secondly, Table 2 clearly shows a decline in the performance of Chinese power sector utilities as load factors have fallen since 2013. This supports the analysis in the above sections that the current situation of overcapacity and declining margins, projected to continue and indeed worsen in the future under the NDC-Style Scenario, is already having a negative impact on the financial health of Chinese utilities. Thirdly, Chinese utilities outperform the average ROCE of an international peer group, except for in 2016. This is not so surprising as the international peer group includes utilities from mature markets where GDP, inflation and sectoral growth is much slower. What really matters for the analysis is the return on capital employed versus the cost of obtaining that capital.

Table 2. ROCE for a subset of Chinese power sector companies, compared to international peers (%)

	2012	2013	2014	2015	2016	Average 2012-16
China, selected power sector firms	8.83%	9.36%	7.75%	7.18%	5.02%	7.63%
International selected peer group firms	4.97%	4.37%	4.15%	3.20%	6.03%	4.54%

Source: authors' analysis based on data from (GlobalData, 2017)

Any investment will be weighed against the cost of obtaining the resources to invest, namely the cost of capital. Even a low ROCE may be acceptable, if the cost of capital is even lower. We use a public corporate valuation database of listed firms to ascertain the weighted average cost of capital (WACC) for the Chinese power sector, and compare this with the return on capital employed (ROCE). Table 3 shows the WACC for power sector firms for China, the USA and Europe for 2016. It also shows the Economic Value Added (EVA) of the power sector, which is used to estimate the value a company generates from the funds invested in it. EVA is defined as ROCE minus WACC. A positive number indicates that a firm is creating economic value net of its cost of capital, a negative value indicates that capital is not being deployed to create economic value. It should be noted that the ROCE given in Table 2 above is different from that given in Table 3 below, because the samples for the two values are different (15 firms versus 77 firms respectively). While Table 3 below is more comprehensive in terms of sample-size, data is only given for a single year, whereas the data in Table 2 enables us to see a time-series for recent years.

The results in terms of the negative financial performance of Chinese listed power sector firms supports the modelling in Section 3 regarding the negative NPV of the Chinese coal-fired power fleet under current conditions and relative to a market-oriented discount rate. This provides further arguments that the current status quo is unstable, and that a managed transition scenario towards 2°C-consistent transformation could be an improvement on the situation.

Table 3. Power sector WACC and EVA for China and international peers

	China	USA	Europe
Power sector WACC	8.12%	3.81%	6.42%
Power sector ROCE	6.56%	7.32%	7.79%
Power sector EVA [ROCE – WACC]	-1.56%	3.50%	1.37%

Source: Stern School of Business, New York University (Damodaran, 2017). Based on a sample of 77 firms for China; 68 for USA; and 73 for Europe.

4.1.4. Conclusion

The preceding discussion highlighted the difficulty of evaluating the issue of 'stranded assets' in the Chinese coal-fired power sector, due to its ownership structure and the peculiar distortions to capital allocation still prevailing in China. The above discussion may pull the conclusions in two opposing directions. On the one hand, one might argue that the state-dominated structure of the sector and the availability of low-cost financing mitigates the risks of 'stranded assets' by lowering the hurdle rate for project evaluation. Indeed, this is the tendency of some of the macroeconomic literature on 'overinvestment' in China, which concludes that China's current level of investment may not be excessive when judged against the low cost of financing. In this view, the numerical evaluation of 'stranded assets' produces much less negative results. On the other hand, one might argue that China's current level of investment in coal-fired capacity is wasteful when judged against opportunity costs; worsens the political economy of the transition to a low carbon power sector; and should be evaluated against market-based criteria. In this view, the numerical evaluation of stranded assets results in significant negative values, potentially presenting a serious challenge to the political economy of transition to a low-carbon power sector

One could attempt to reconcile this in two ways. Firstly, one can try and derive a weighted cost of capital to the Chinese power, based on its ownership structure between private firms and SOEs. This would derive a cost of capital to the sector of about 6.5%, assuming a 60-40 break-up of ownership and private WACC of 8% (as per Table 3) and an SOE cost of capital of 5.5% (as per the most recent year figure given in (Maliszewski *et al.*, 2016). This is very close to the central discount rate used in the scenario analysis in Section 3. This thus validates the results showing negative NPV in each of the three scenarios. Secondly, the ownership structure of the fleet and the low cost of capital apparently enjoyed by SOEs means that the benchmark rate of return for the existing Chinese coal fleet should be lowered. This would reduce stranded asset risks. But more importantly, it would also allow the definition of an earlier pathway to phase down of the coal fleet, based on a lower target rate of return.[2]

Overall, we can make two strong conclusions, and one weak conclusion. Firstly, the Chinese investment in coal-fired power has been tremendously wasteful, particularly when measured against market-based capital costs and the opportunity costs of other higher-yield investments. A medium discount rate of 6.5% results in a significantly negative NPV for the coal-fired power fleet. Secondly, the presence of huge, new capacity of coal-fired power has increased the political economy challenges of transition towards a low-carbon power sector. It is urgent that investment incentives are adjusted for the SOEs, including the assessment of investment projects based on a market-oriented cost of capital and hurdle rate. Finally, the weak conclusion of the analysis is that the ownership structure of the sector gives certain tools to the Chinese government to mitigate the stranded asset risk, rein in investment, and phase down coal power. China's SOEs can accept lower returns on investment than purely commercial players, due to their lower funding costs. The challenge is to use this advantage to manage the transition out of coal, while at the same time exposing the SOEs to market incentives regarding the negative value of new coal power investment in the context of overcapacity and energy transition.

4.2. Are stranded assets in the Chinese power sector a macro-financial risk?

Since the 2008-9 financial crisis, China's economic growth has been significantly driven by credit expansion to the non-financial sector. The debt-to-GDP ratio has grown rapidly, with total domestic non-financial sector debt having risen to 236.4% of GDP in 2016 (IMF, 2017). This represents historically extremely rapid growth, and a high absolute level particularly for a country of China's income per capita. Accompanying this, the situation of overinvestment, over-capacity, and poor credit allocation has meant that loan quality is often low.

2. In a fully market-based sector, plants should retire when their short-term operating costs exceed their short-term revenues. However, given the structure of the sector in China, it may be more appropriate to target a phase-out plan on a lifetime benchmark rate of return.

McKinsey Global Institute (MGI) estimates that about 7% of all bank assets were non-performing loans in 2015 (MGI, 2016). This is significantly higher than the reported 1.7% officially estimated, and highlights the problem of an "extend and pretend" approach to insolvent companies on the part of the largely state-owned banking sector.

The problem lies in the decline in corporate profitability in multiple sectors associated with the 'old growth model' of manufacturing and infrastructure investment. Table 4 shows the EVA of selected industries in China. These also display negative value creation, i.e. the return on capital employed is greater than the weighted average cost of capital. Thus, the power sector is by no means unique in facing a situation of potential economic losses and stranded assets. MGI estimates that 100% default rate for non-performing loans and a 40% recovery rate would entail 369 USD_{2015} of losses for the banking sector, which is roughly equal to the loan loss provisions of the Chinese banking sector (estimated at ca. 2.3 trillion RMB, or ca. 370 billion USD). Thus MGI conclude "this base-case stress test illustrates that commercial banks have sufficient capital buffers today to absorb potential loan losses without extreme capital impairment" (MGI, 2016).

These figures put the above analysis of the stranded assets in the Chinese coal power sector in perspective. The following section conducts a more detailed analysis of financial sector risks.

Table 4. Economic value added of selected Chinese industries

Industry Name	EVA (ROCE - WACC)	Book Value of Capital (bn USD)
Chemical (Basic)	-4.46%	80.68
Coal & Related Energy	-5.68%	164.29
Construction Supplies	-5.84%	209.49
Metals & Mining	-7.87%	117.89
Oil/Gas (Integrated)	-10.28%	470.23
Power	-1.56%	412.37
Real Estate (Development)	-1.81%	728.52
Steel	-9.51%	177.55

Source: authors based on (Damodaran, 2017)

The debt-equity ratio of the Chinese coal-fired power sector is 60-80% according to Hervé-Mignucci, Wang, Nelson, & Varadarajan (2015). Let us assume therefore that the exposure of the banking sector is equal to 70% of the stranded asset value of the coal fleet, which is -78.6 billion USD_{2015} in the Managed 2°C Scenario at a 6.5% discount rate. Thus, the banking sector's exposure to this stranded asset would be representing an expected NPV of 54.88 billion USD_{2015}. Assuming a 40% recovery rate on loans-in-default as per (MGI, 2016), the write down on this expected NPV is equal to -33.0 billion USD_{2015}. This methodology has been used to quantify the banking sector exposure for the other scenarios and at different discount rates.

Table 5. Banking sector exposure to stranded asset risks in different scenarios and at different discount rates

	5%	6.50%	8%
2°C Scenario	-65.4	-51.4	-41.2
Managed 2°C Scenario	-41.1	-33.0	-27.0
NDC-Style Scenario	-47.5	-38.0	-30.9

Source: authors' calculations

Given the scale of loan-loss provisions, we can conclude that the issue of stranded assets in the Chinese coal-fired power fleet is unlikely to pose a significant risk, in isolation, to the banking sector. The problem could arise if there is a larger breakdown of financial conditions in China, in which case loan defaults from the power sector would be but one source of stress, but here climate policy and the energy transition would not be to blame.

4.3. The political economy of transition

The above analysis has suggested two broad conclusions. Firstly, the transition towards a 2°C compatible pathway need not necessarily exacerbate stress on the Chinese coal power sector, provided that sufficient policy provisions are made to manage the transition for the coal fleet. In this regard, the financial outcome of the Managed 2°C is estimated to be marginally superior to the current trajectory of the NDC-Style Scenario. Secondly, it has been shown that the financial risk to the banking sector and financial sector more broadly of a transition in the coal power sector is manageable. Certainly, cumulative risks to the financial sector from high corporate indebtedness and poor performance are significant. However, in a situation of macroeconomic slow-down and financial crisis, the power sector would be just one of the sectors contributing to financial sector stress, *with or without the energy transition*. Thus, we can conclude that the macro-financial risks of stranded assets of the energy transition per se are manageable and should not be a reason to delay the energy transition towards a 2°C-compatible pathway.

This raises the question of what are the true political economy barriers emanating from the coal sector regarding ambitious climate and energy transition policies? We could identify three. Firstly, from a policy-maker's perspective there is the question of the cost and technical feasibility of a transition to a higher share of renewables.

Table 6. Generation portfolio of key utilities in China (MW)

	Datang International Power Generation Co Ltd (Subsidiary of China Datang Corp)	GD Power Development Co., Ltd. (Subsidiary of China Guodian Corporation)	Huadian Power International Corporation Ltd	Huaneng Power International, Inc.
Coal capacity	32330	14600	34978	82340
Wind	682	543	951.9	1172
Solar	117	0.9	1.2	20
Hydro	2683	4308	2231	322.5

Source: authors' analysis based on data from (GlobalData, 2017)

Secondly, the concentration of losses within the coal-power industrial complex appears as a major blockage to power sector transition. The dominant state-owned utilities are predominantly focused to-date on the coal sector; we can illustrate this by examining the power capacity portfolios of the listed subsidiaries of the big four SOEs. Some of these companies are also engaged in the upstream coal production sector, and as well as transportation and marketing. In this sense the proposed consolidation of the coal-sector SOEs raises concerns. The third issue relates to the geographical concentration of coal-mining employment, and the challenge of shifting employment from the coal sector into other sectors, given the concentration of skills and regional economic activity within the coal sector (Caldecott, Sartor, & Spencer, 2017).

5. CONCLUSIONS & POLICY IMPLICATIONS

Overall, one can draw four conclusions from the study's analysis. First, the Chinese investment in coal-fired power has been tremendously wasteful, particularly when measured against market-based capital costs and the opportunity costs of other higher-yield investments. Second, the presence of huge, new capacity of coal-fired power has undoubtedly increased the political economy challenges of transition towards a low-carbon power sector. Third, the ownership structure of the sector gives certain tools to the Chinese government to mitigate the stranded asset risk, rein in investment, and phase down coal power. China's SOEs can accept lower returns on investment than purely commercial players, due to their lower funding costs and lower profitability expectations. The challenge is to use this advantage to engineer an earlier transition out of existing coal, while at the same time exposing the SOEs to market incentives for new investment. Fourth, the risks of financial sector contagion of coal transition in China are limited and manageable, provided that generalized financial turbulence outside the coal sector can be avoided.

The paper makes four policy recommendations. First, it is urgent that Chinese policy makers make real incentives to rein in the investment boom in coal-fired power, which continues unabated despite the manifest issue of overcapacity. Since 2013, net additions have averaged 60 GW, including 50GW as recently as 2016, while load factors have fallen by 8.5 percentage points. Second, SOE governance reform is crucial to halting investment and managing transition out of coal. The government could consider an approach that creates a firewall between legacy assets and new investments, e.g. the creation of a coal-sector 'bad bank'. Legacy assets would be subject to lower expectations of rates of return (e.g. through lower dividend payments, loan forbearance etc.), while any new investment would be subject to market-oriented discipline (market oriented lending rates, high dividend policies, etc). By putting legacy assets into a 'coal asset bad bank' subject to more lenient rates of return, the Chinese government could benefit from the privileges accorded to SOEs to hasten the transition away from coal. Third, investments need to be made to enable the coal-fired power sector to play a role, and be adequately remunerated for it, in terms of balancing the grid in a high renewables system. Fourth, in addition to halting new investment, it is important that efforts be strengthened to retire old plant.

ANNEX

Table 7. Return on capital invested for selected Chinese coal-fired power companies

		2012	2013	2014	2015	2016	Average 2012-16
China Shenhua Energy Company Limited	ROCE	18.82	18.65	13.81	7.09	8.56	13.39
Huaneng Power International, Inc.	ROCE	5.51	11.25	11.20	12.84	6.32	9.42
Shanghai Electric Group Co Ltd	ROCE	11.82	10.04	10.35	9.19	6.86	9.65
China Coal Energy Company Limited	ROCE	8.45	3.98	1.28	0.02	3.39	3.42
Huadian Power International Corporation Ltd	ROCE	6.42	11.23	12.54	12.61	7.01	9.96
GD Power Development Co., Ltd.	ROCE	5.23	7.04	7.13	5.71	4.76	5.97
Datang International Power Generation Company Limited	ROCE	7.04	6.56	5.56	6.73	7.25	6.63
Dongfang Electric Corporation Limited	ROCE	13.58	13.49	5.81	1.44	-7.77	5.31
China General Nuclear Power Corp	ROCE	10.92	8.48	5.38	5.09	5.56	7.09
Guangdong Electric Power Development Co., Ltd.	ROCE	8.54	11.98	10.75	10.28	3.79	9.07
Harbin Electric Company Limited	ROCE	8.50	3.92	2.23	1.52	3.68	3.97
China Yangtze Power Co Ltd	ROCE	8.46	10.85	8.69	10.74	5.33	8.81
Guangzhou Development Group Co., Ltd.	ROCE	5.52	6.61	7.58	8.48	6.21	6.88
China Longyuan Power Group Corporation Ltd	ROCE	8.42	8.09	8.47	9.16	9.11	8.65
Shanghai Electric Power Co Ltd	ROCE	5.29	8.27	5.42	6.77	5.27	6.20
All company average, China	ROCE	8.83	9.36	7.75	7.18	5.02	7.63
Centrica plc	ROCE	17.08	12.17	-8.69	-7.75	17.74	6.11
Consolidated Edison, Inc.	ROCE	6.28	6.25	5.37	5.93	5.8	5.93
Duke Energy Corporation	ROCE	2.79	4.59	4.42	4.6	4.38	4.14
Electricite de France S.A.	ROCE	4.25	4.28	3.8	1.96	3.41	3.54
Engie S.A.	ROCE	5.02	-5.49	5.98	-2.88	2.5	1.03
Iberdrola, S.A.	ROCE	5.47	2.82	4.92	4.25	4.92	4.48
Korea Electric Power Corporation	ROCE	-2.1	1.13	4.06	7.48	7.77	3.67
PG&E Corporation	ROCE	3.67	3.66	4.52	2.65	3.57	3.61
Public Service Electric and Gas Company	ROCE	8.09	7.76	8.17	8.57	4.21	7.36
Southern Company	ROCE	7.95	5.51	5.88	6.19	4.78	6.06
SSE plc	ROCE	6.28	6.44	6.77	5.31	11.18	7.20
Tokyo Electric Power Company Holdings, Incorporated	ROCE	-5.2	3.32	4.65	2.15	2.1	1.40
International peer group	ROCE	4.96	4.37	4.15	3.20	6.03	4.54

Source: authors based on (GlobalData, 2017)

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